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Ongoing advanced Developments for future Infrared Sounding Applications

Template reference : 100181670S-EN

2nd IASI Conference 25-29 January 2010

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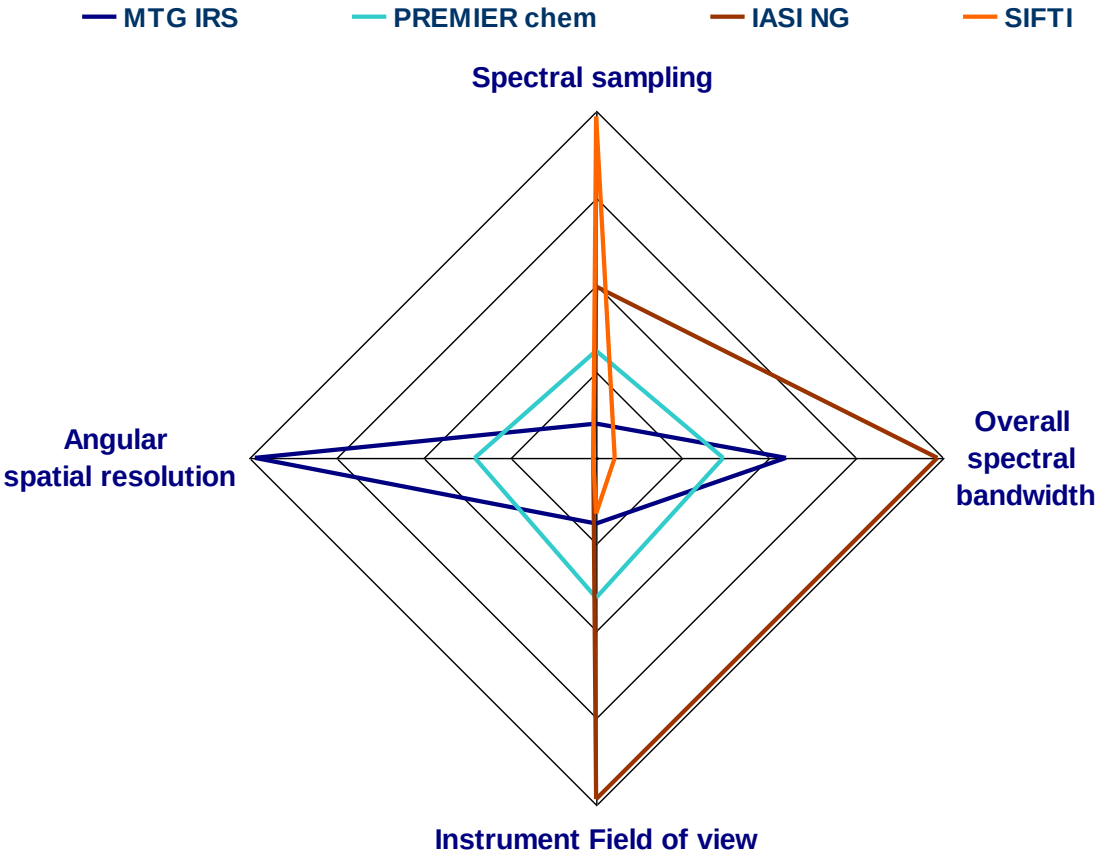
Presentation overview

- Comparison of basic requirements of IR sounding mission opportunities IASI-NG, IRS MTG, PREMIER, SIFTI
  - Instrument design trends
  - Requested fields of development
- Ongoing projects and technological developments
  - Static interferometer: SIFTI phase A results
  - Imaging Fourier Transform Spectrometer
    - An instrument test bench to validate Imaging FTS technologies
    - An upgrade of the IASI LASER source
    - An active cooling cryostat test bench
  - From IASI to IASI-NG :
    - IASI performance a valuable basis for IASI-NG
    - IASI flight survey
    - how to improve performance by a factor two !

Comparison of basic requirements of IR FTS mission opportunities

	MTG IRS	PREMIER (chemical. mode)	IASI New Generation	SIFTI
Mission objectives	Atmospheric motion vectors measurements	Imaging limb emission spectroscopy	Multi purpose instrument: meteorological (main), chemical and climatology	Air quality Measurement of CO and O_3 down to low troposphere
Spectral sampling	1 / 1,6 cm	1 / 5 cm	1/ 8 cm	1 / 16 cm
Spatial resolution	Square pixels 4 / 36000 km	Rectangular pixels 80 / 6400 km (hor) 2 / 6400 km (vert)	Circular pixel 12 km / 840 km	Circular pixel 11 km / 740 km
Instrument Instantaneous Field of view	Square 22 mrd	Rectangular 38 x 14 mrd²	Square 89 mrd	Circular 15 mrd (mono pixel)
Spectral bands	680- 1210 cm^{-1} 1600 - 2250 cm^{-1}	770-980 cm^{-1} 1070-1650 cm^{-1}	645-1150 cm^{-1} 1150-1550 cm^{-1} 1550-2100 cm^{-1} 2100-2760 cm^{-1}	1021-1080 cm^{-1} 2132-2190 cm^{-1}
Instrument specificity	IFTS on GEO orbit	IFTS on LEO orbit 3 spatial and spectral resolutions : chemical, dynamic, imager	A new design to achieve IASI performance x 2 !	A new compact and static FTS on LEO orbit

Spectral and spatial requirements

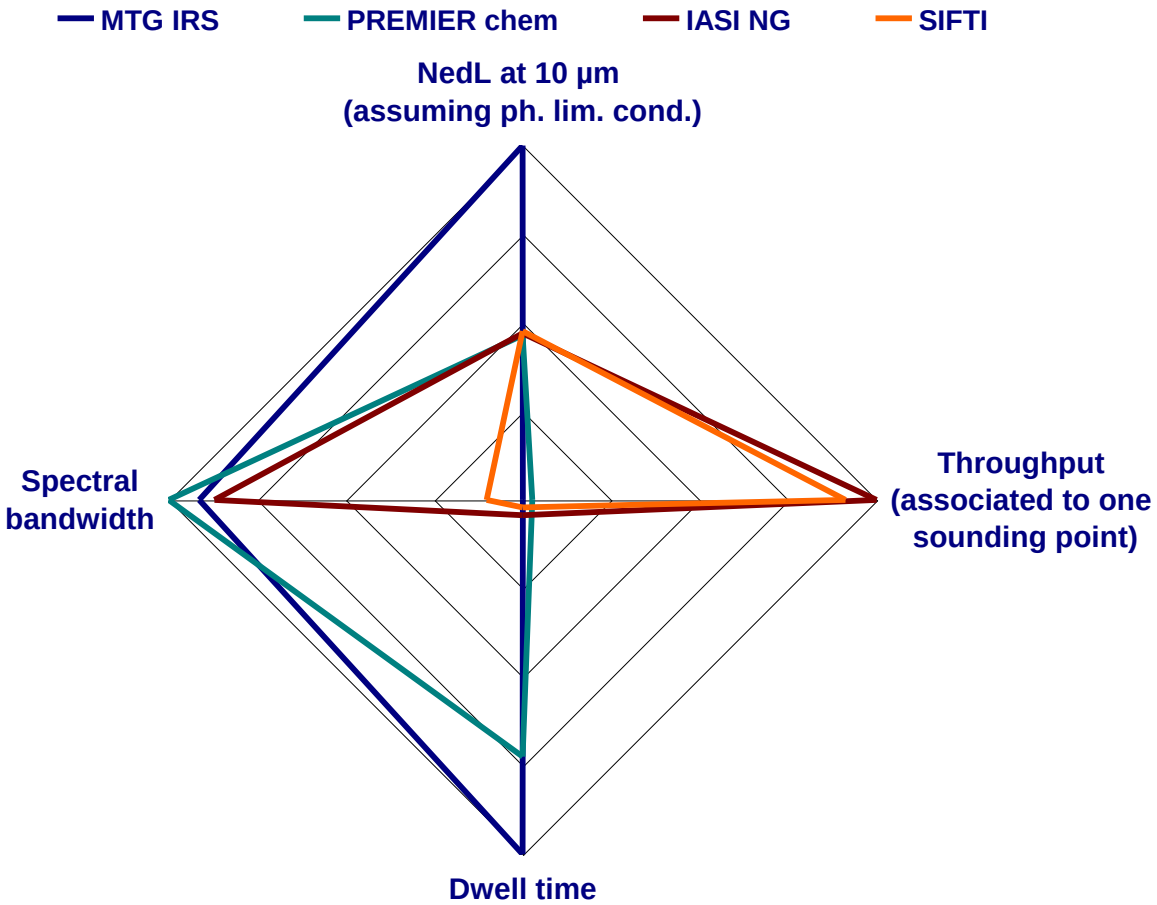


- SIFTI is provided with a very high spectral sampling of narrow spectral bands
- IASI-NG requires a very large instantaneous field of view and 4 focal planes to achieve high radiometric resolution within a large spectral bandwidth
- MTG IRS is an IMAGING FTS with a very sharp angular spatial resolution

- PREMIER is an IMAGING FTS with an high spatial resolution (along vertical axis only) and a sounding FTS with a significant spectral sampling (in chemical mode).

Radiometric requirement

- The global trend of the new generation of instruments is to improve the radiometric resolution from two FTS well known advantages: THROUGHPUT and MULTIPLEX



- IASI-NG, PREMIER, SIFTI are sized with a better radiometric potential than IRS-MTG which is penalized by its angular spatial resolution
- Radiometric optimisation is done from:
  - Large throughputs per sounding point for SIFTI and IASI-NG
  - Large dwell times for IRS-MTG and PREMIER
  - Narrow spectral bands for SIFTI

Others design trends

- Improvement of radiometric resolution
  - → to strengthen ILS knowledge requirements
    - → a constant OPD acquisition with an accuracy down to the nanometre
    - High performance interferometer mechanism
    - High accuracy metrology based on stabilised LASER source
    - Low noise sampling technologies

- Introducing high dissipative detector (MTG, PREMIER) or spectral bands multiplication (IASI-NG)
  - → generalizes the use of active cooling technologies.

New requirements lead to new FTS concepts

- SIFTI main characteristics synthesis
  - Very high spectral resolution
  - Radiometric resolution optimized from:
    - Narrow spectral bands
    - Large throughput per sounding point
      - ✓ At the limit of the throughput advantage (contrast down to 10% at OPD max) with one on-axis pixel
    - Short dwell time
- Theses characteristics have led to the development of a new FTS concept : the STATIC INTERFEROMETER CONCEPT.

New requirements lead to new FTS concepts

- MTG and PREMIER main characteristics synthesis
  - High angular spatial resolution
  - Moderate spectral resolution
  - Radiometric resolution optimized from:
    - Large input pupil dimension for MTG (also required to achieve the angular resolution)
    - Large dwell time and then low signal modulation frequency
      - ✓ Detector R/O frequency constraint
      - ✓ Sensitivity wrt micro vibration
- MTG and PREMIER are IMAGING FTS associating imaging and sounding capacities

New requirements lead to new FTS concepts

- IASI-NG main characteristics
  - Spectral resolution improved by a factor 2 wrt IASI
    - T/O between Interferometer design evolution or development of single side acquisition principle
  - Radiometric resolution improved by a factor 2 wrt IASI
    - Larger throughput per sounding point
    - Larger dwell time (larger instrument field of view)
    - Detection optimization
      - ✓ Four spectral bands
      - ✓ LW detection improvement
  - The short dwell time combined to the high spectral resolution led to high frequency signal modulation

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Current advanced projects and technological developments

Static interferometer: SIFTI phase A results

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SIFTI mission objectives

- SIFTI target mission
  - Improve vertical infrared sounding of O_3 and CO down to low troposphere

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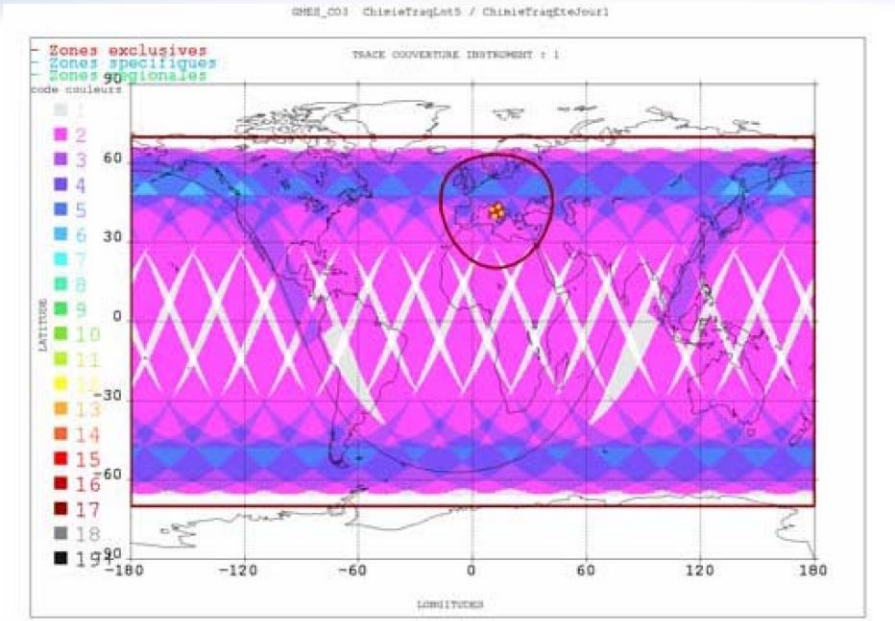
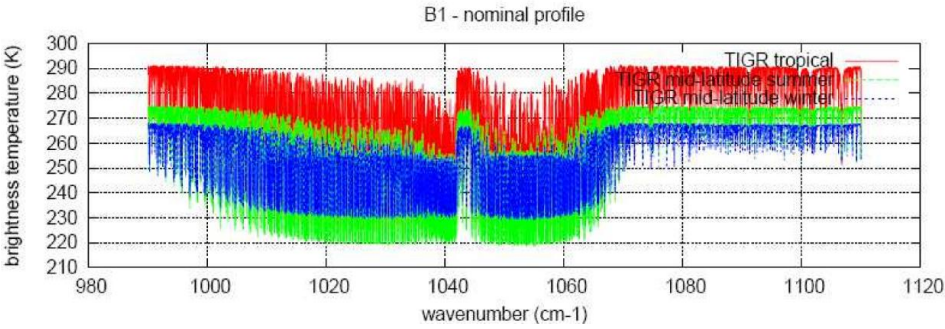
  - Improve vertical infrared sounding of O_3 and CO down to low troposphere
- Air quality, troposphere composition
  - Pollution transportation and daily pollution
    - Maximisation of Earth global coverage between [-55° and 55°]
    - 5 passes during day time at solstices

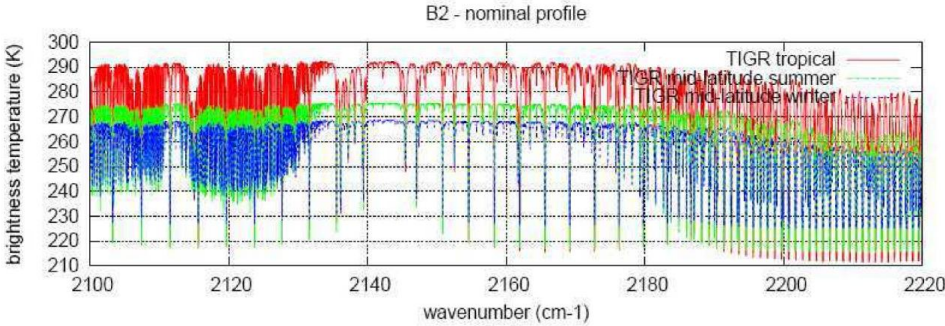


SIFTI daily coverage

SIFTI mission objectives

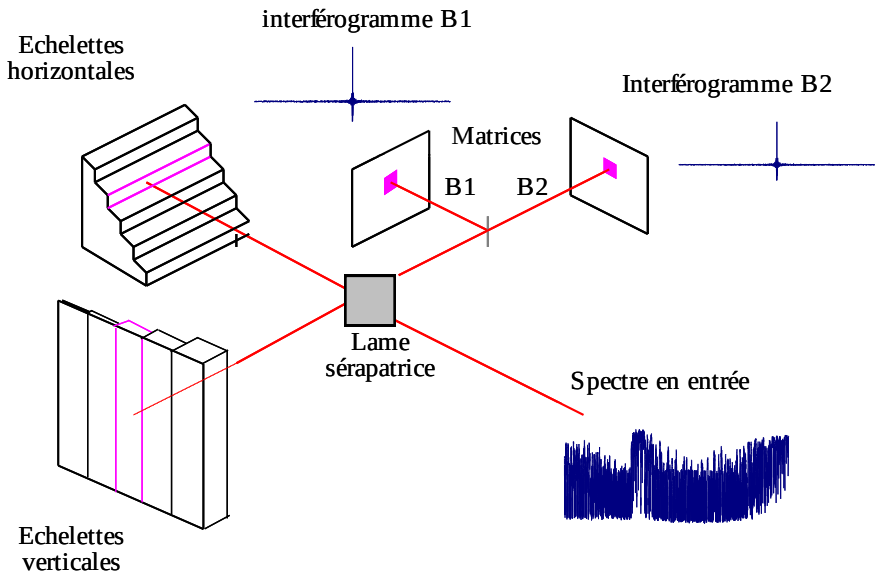
- SIFTI target mission
  - Improve vertical infrared sounding of O_3 and CO down to PBL
- Air quality, troposphere composition
  - Pollution transport and daily pollution
    - Maximisation of Earth global coverage between [-55° and 55°]
    - 5 passes during day time at solstices
  - High spectral and radiometric resolutions in narrow spectral bands
    - [1030 – 1070 cm^{-1}] Band 1 for CO
    - [2140 – 2180 cm^{-1}] Band 2 for O_3
    - [4270 – 4300 cm^{-1}] Band 3 for CO





Static interferometer principle

- OPD creation principle in static interferometer
  - OPD spatial sampling created by static mirrors split into facets
    - One mirror with « regular » small steps
    - One mirror with « regular » large steps
  - Pupil decomposition in facets, each facet is an interferogram sample



- Intrinsic advantage of static interferometer
  - Access to large OPD range : 8 cm (0.0625 cm^{-1} spectral sampling)
  - Direct access to decimated interferogram (general Shannon theory)
    - Limited number of OPD samples (50 x 50)

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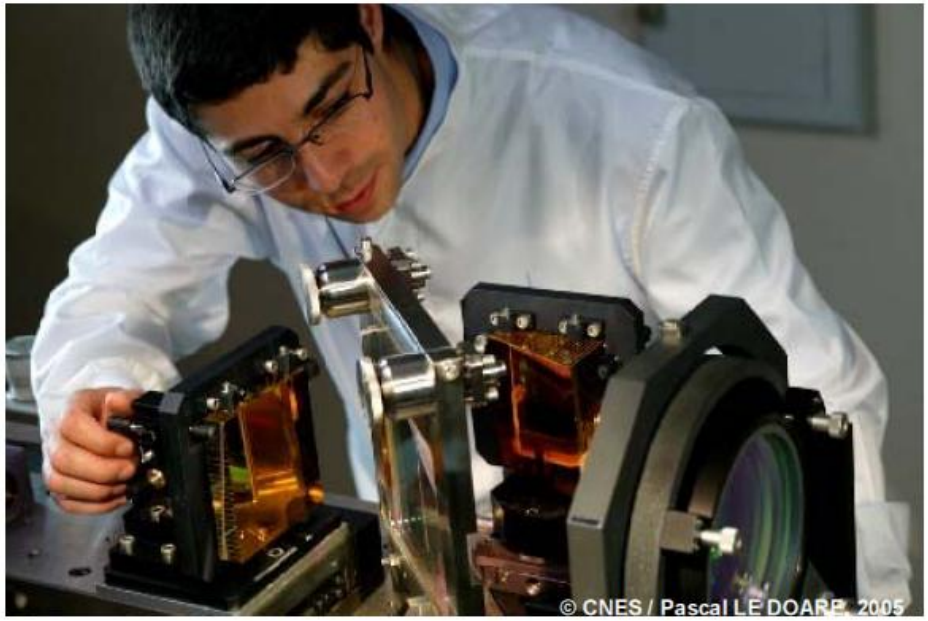

CNES R&T: CO_2 breadboard

- Intrinsic advantage of static interferometer
  - Access to large OPD range : 8 cm (0.0625 cm^{-1} spectral sampling)
  - Direct access to decimated interferogram (general Shannon theory)
    - Limited number of OPD samples (50 x 50)
- CNES advanced development from 1998 (patent deposit of the facet mirror interferometer principle)

Interferograms requirements

- Static means spatial dispersion of interferograms upon 2D detectors

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$$I(OPD) = G(OPD).\int_{\Delta\sigma_{total}} B(\sigma).R(OPD,\sigma).\left[1+T(OPD).\cos(2.\pi.\sigma.OPD)\right]d\sigma + I_{par}$$

Gain & transmission non uniformities	Spectral response non uniformities	Contrast	OPD	Parasitic interfero

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Gain & transmission non uniformities	Spectral response non uniformities	Contrast	OPD	Parasitic Interfero.

  - SIFTI challenge : to characterize interferogram terms with an accuracy consistent with the *I(OPD)* 10^{-4} rms knowledge need

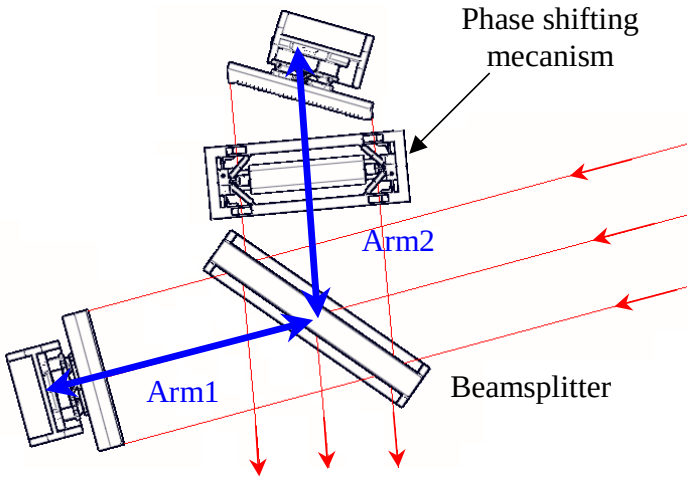
Fully static / no signal modulation

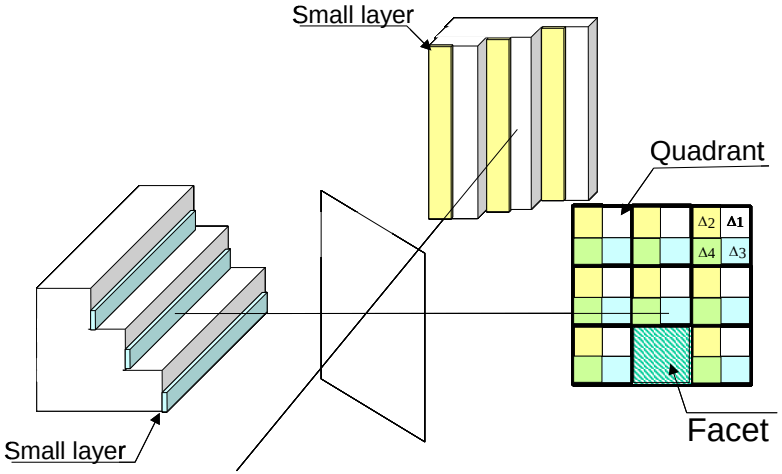
- A key Static Interferometer performance driver is the suppression of the interferogram baseline in order to relax requirements on spatial non uniformities

2 analysed concepts

Dynamic modulation
with phase shifter mechanism

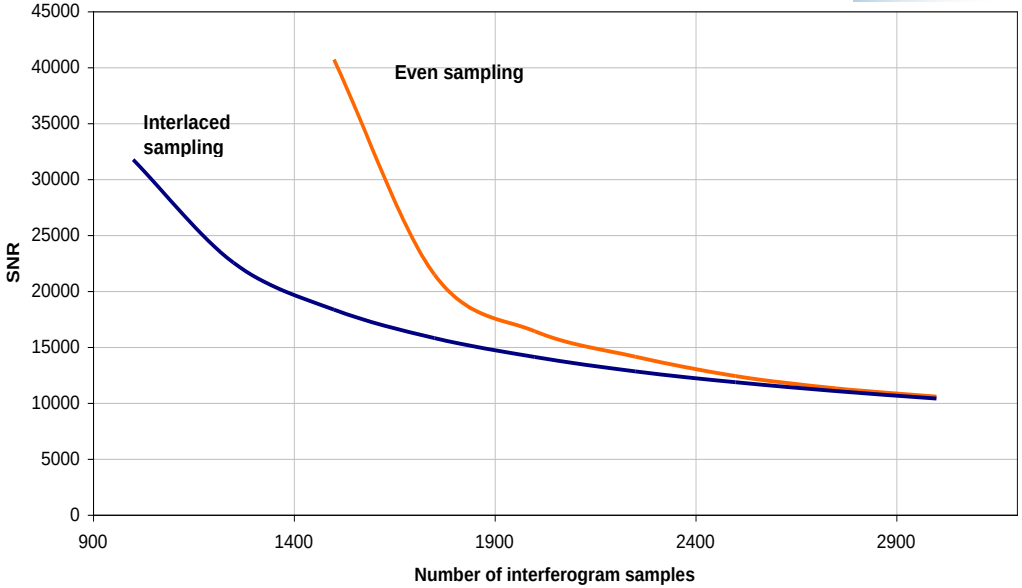
Static modulation
with quadrants subtraction





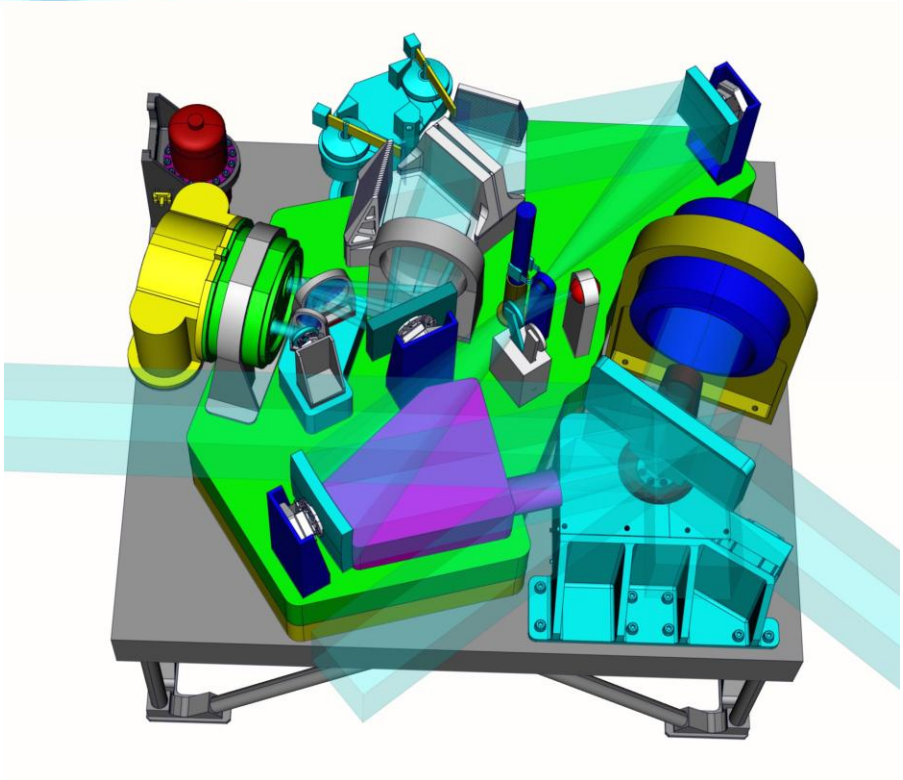
- Full static concept preferred : complexity reduction, compactness & cost saving

Radiometric performance



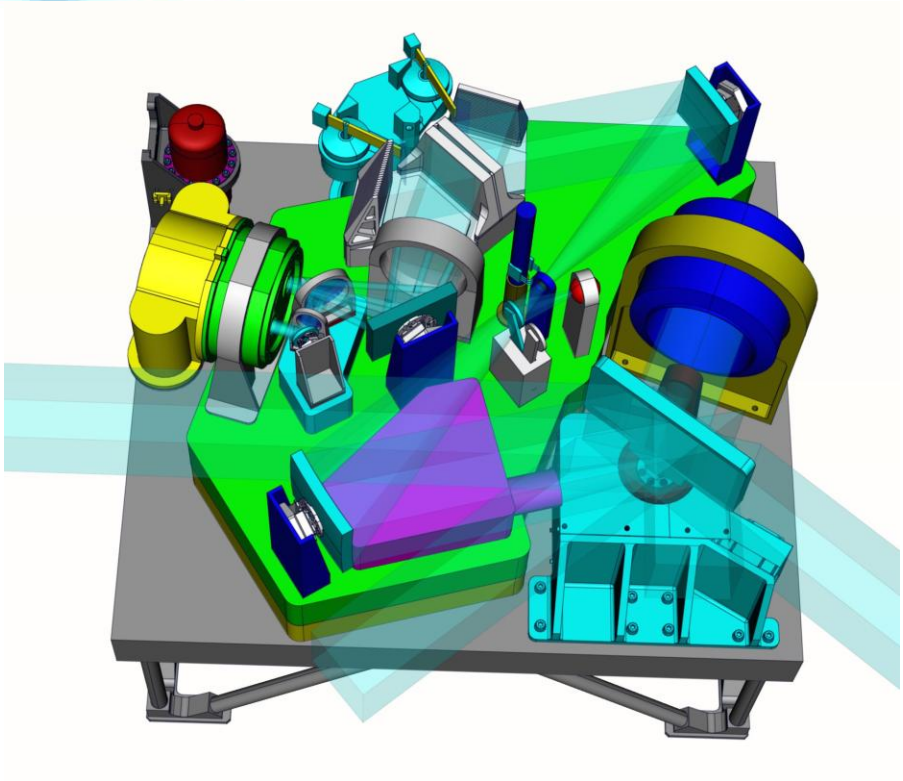
- SNR requirement depends on:
  - number of OPD samples
  - sampling arrangement
- The two sampling frames separated by a multiple of $\lambda/4$ optimizes the mission performance
- Chosen set-up allows acquisition of opposite and quadrature signals per facet
  - Combination provides two sampling frames shifted by $\lambda/4$
  - Only 2 x 625 interferogram samples acquired
  - Generate Layer thickness optimised for B2 band
    - Slight loss of contrast in B1
- Performance objectives achieved with :
  - Input pupil : 100 x 100 mm²
  - Dwell time : 216 ms
  - Video chain based on standard MCT and electronic video components

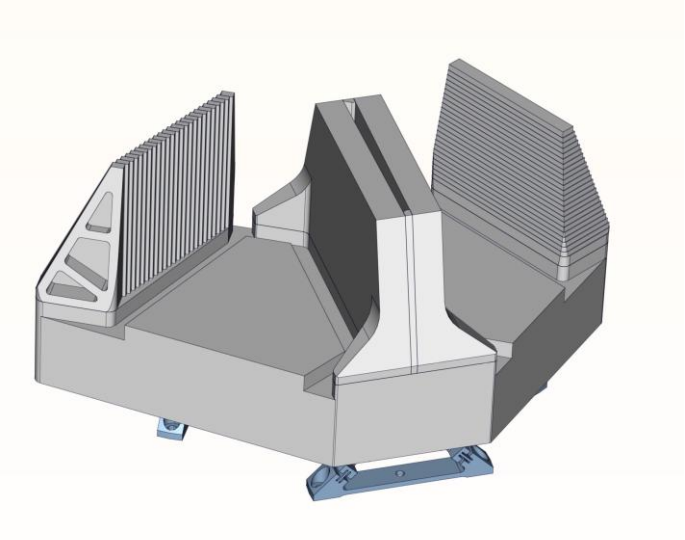
A first feasibility study : SIFTI for CO and O3 measurements



- Instrument provided with high performance calibration sources to access to IASI class performance
  - High performance calibration source
  - LASER source (flight perf. securisation)
  - Gain calibration device

A first feasibility study : SIFTI for CO and O3 measurements





ISE design by WINLIGHT-SYSTEM

- The interferometer mirrors and plates are assembled by molecular adhesion
  - Static interferometer
  - Very compact and light weighted design
  - Ultra stable OPD

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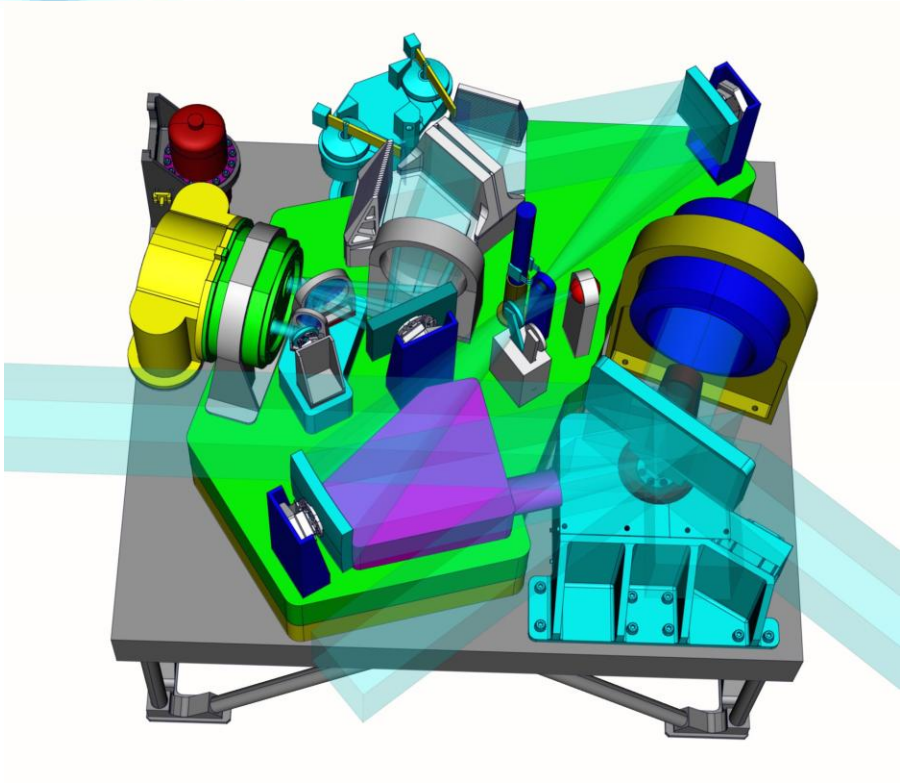
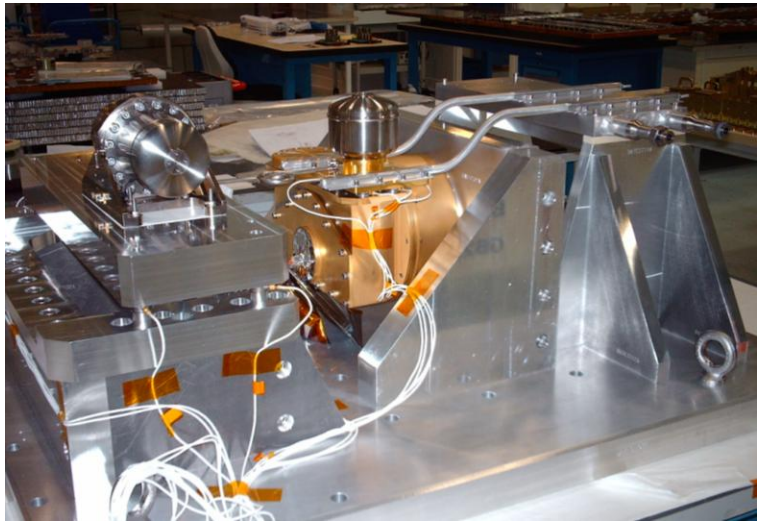
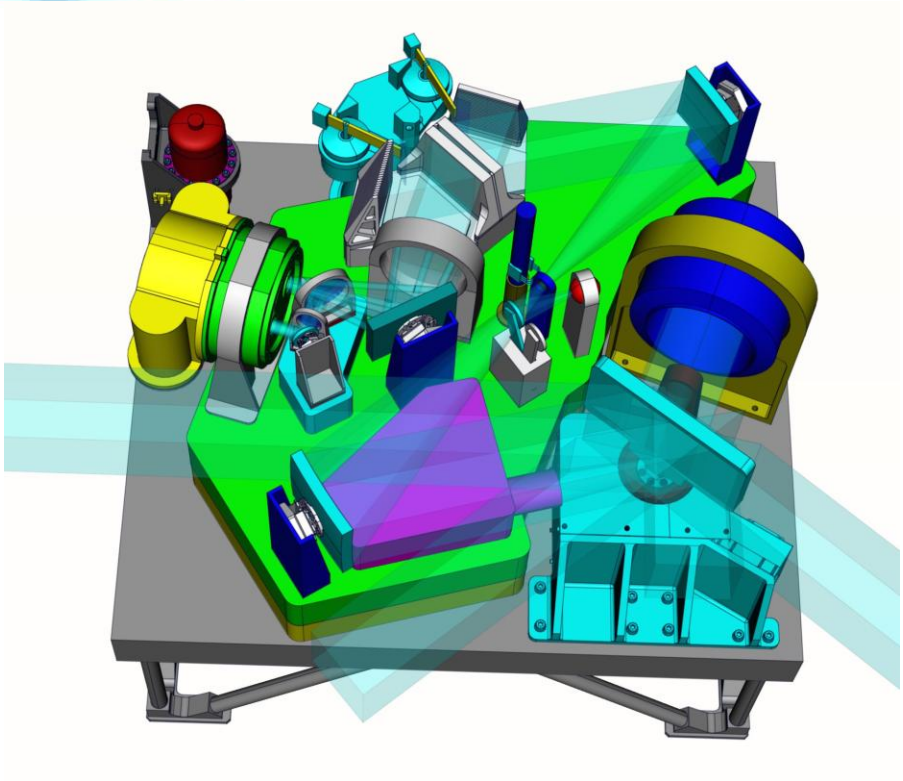


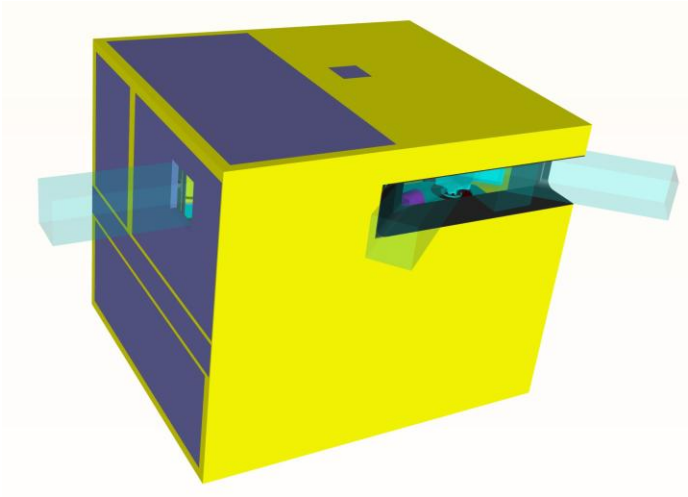


Breadboard of the SIFTI cryostat design cooled down by AIR LIQUID pulse tube
Designed and developed by ThalesAleniaSpace

- The LWIR focal plane is cooled down to 60 K with pulse tube cryogenic cooler

A first feasibility study : SIFTI for CO and O3 measurements





- Power ≤ 200 W
- Mass ≤ 100 Kg
- No onboard processing

Static interferometer status and prospective

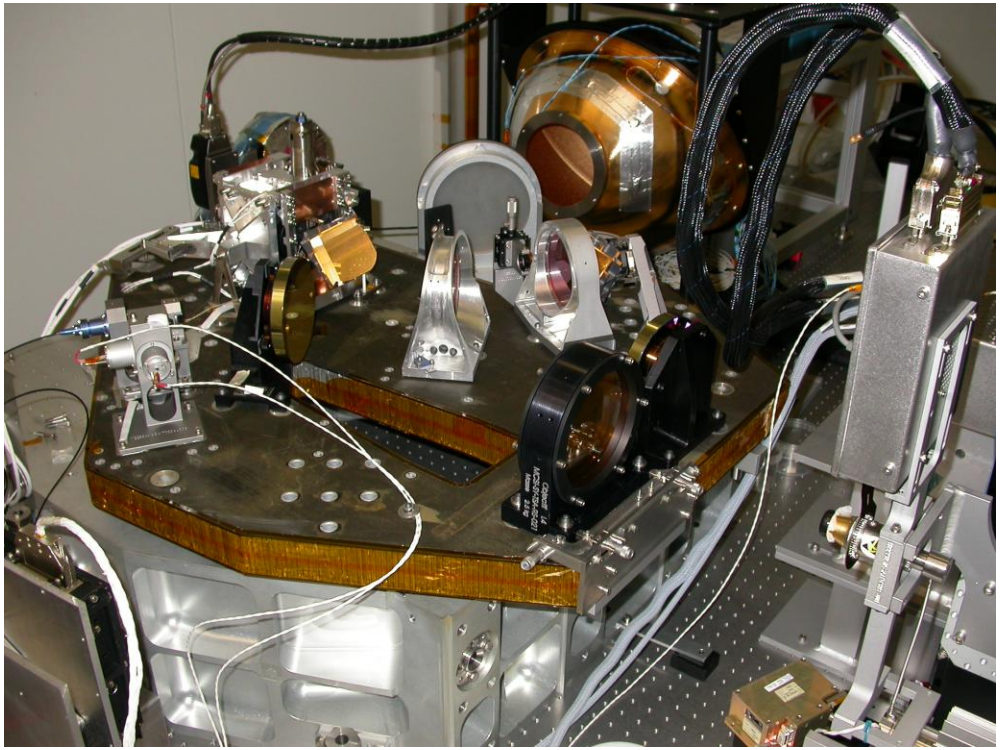
- The A phase of SIFTI allowed :
  - The establishment and consolidation of an instrument specification fitting the principle of Atmospheric Model Inversion from Interferograms
  - The selection of a high performance and compact instrument, fully static in Normal Operation
  - Thoroughly analysis and establishment of detailed performance budgets
  - The demonstration of the effectiveness of this high spectral and radiometric instrumental concept to fulfil atmospheric sounding needs
- Futures developments in static interferometer
  - To develop a SIFTI complete proof of concept from a representative interferometer breadboarding.
  - Adaptation of SIFTI static concept to any mission combining high spectral and radiometric performance requiring resource and cost saving approach
    - Different options to be traded: 4 phases modulation, field widened interferometer…
    - Concept simplification for SWIR mission

- Ongoing advanced projects and technological developments
  - Imaging Fourier Transform Spectrometer
    - An instrument test bench to validate Imaging FTS technologies
    - An upgrade of the IASI LASER source

A test bench to validate Imaging FTS technologies

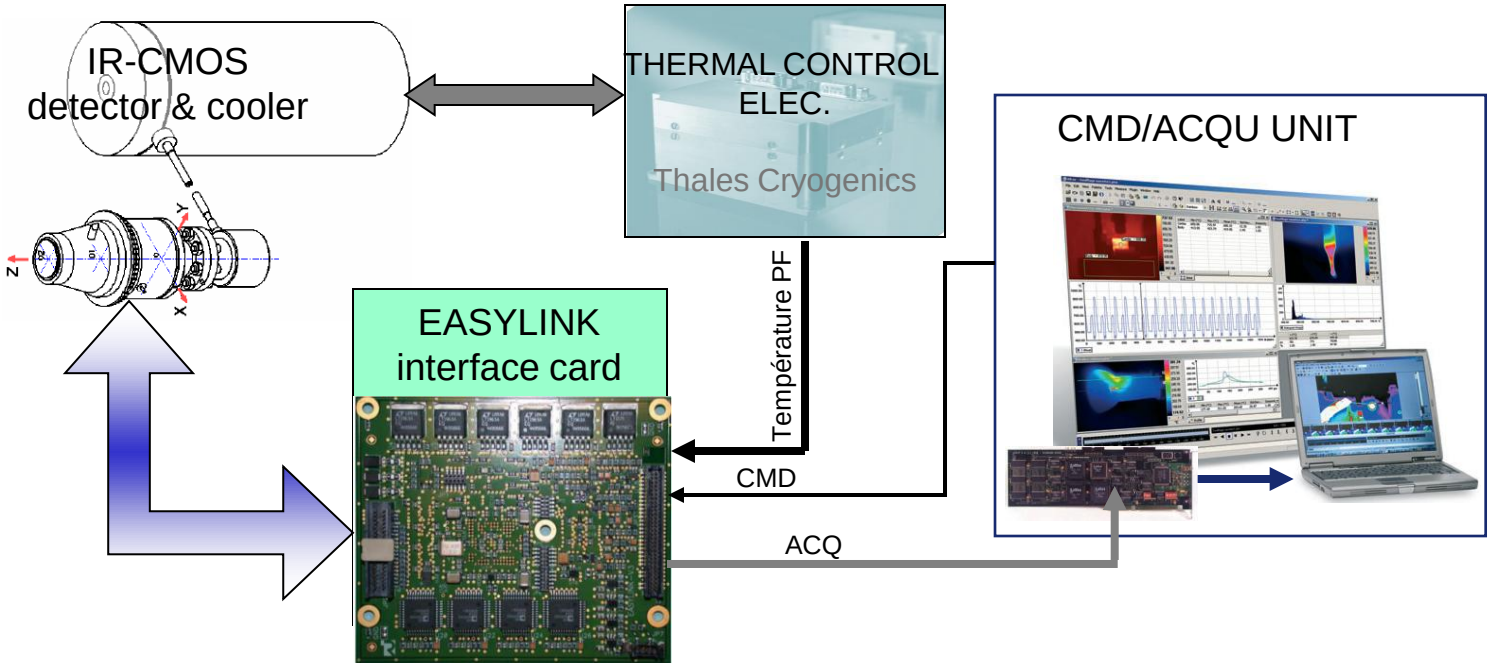
- The challenge of Imaging FTS is to associate imaging functions to a sounder without losing the sounding performance
  - The first step is to integrate a 2D array detector and develop sampling technologies and associated algorithms

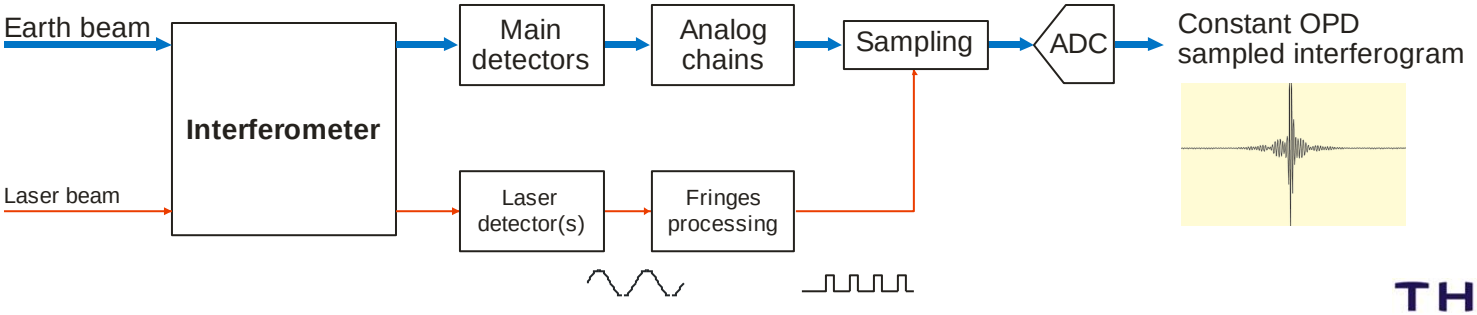
- The IFTS test bench is a flight design evolution of IASI interferometer with:
  - A calibrated SOFRADIR MARS detector (cut-off 11 µm) associated to a fast acquisition system
  - A new metrology system to test different acquisition sampling concepts
  - A IASI LASER source



A test bench to validate Imaging FTS technologies

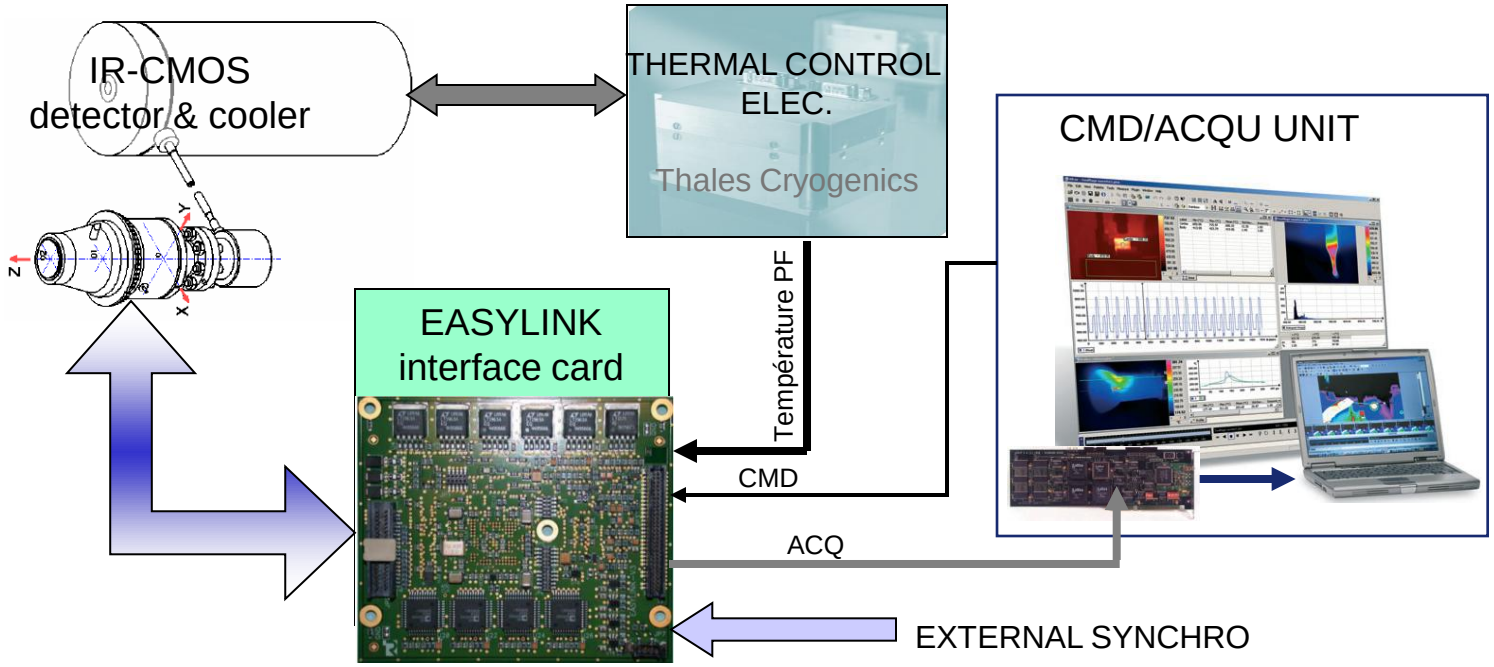
Equal time sampling with post-processing configuration

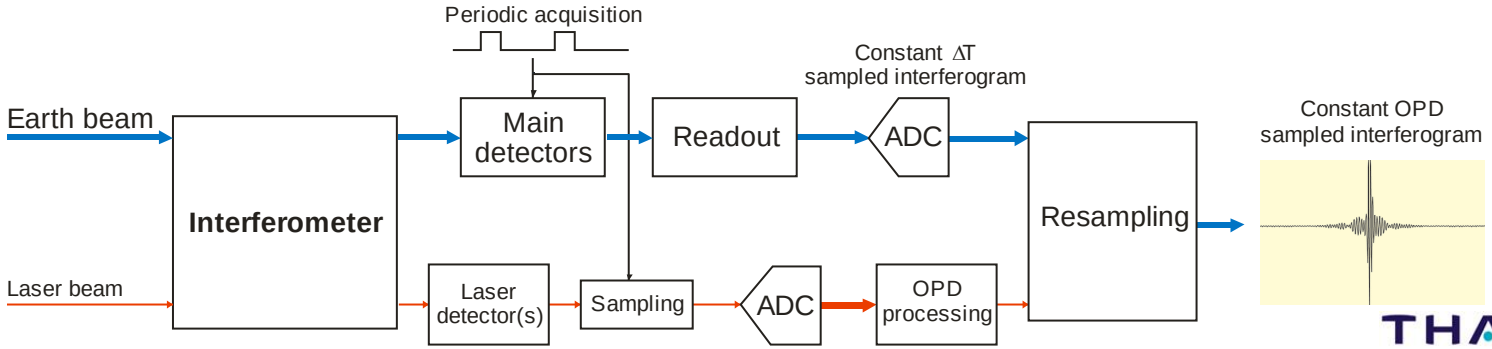




A test bench to validate Imaging FTS technologies

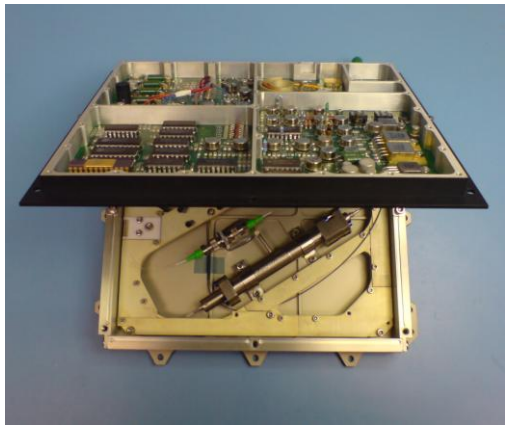
Equal OPD sampling (interferometer clock triggering)





An upgrade of the IASI LASER source

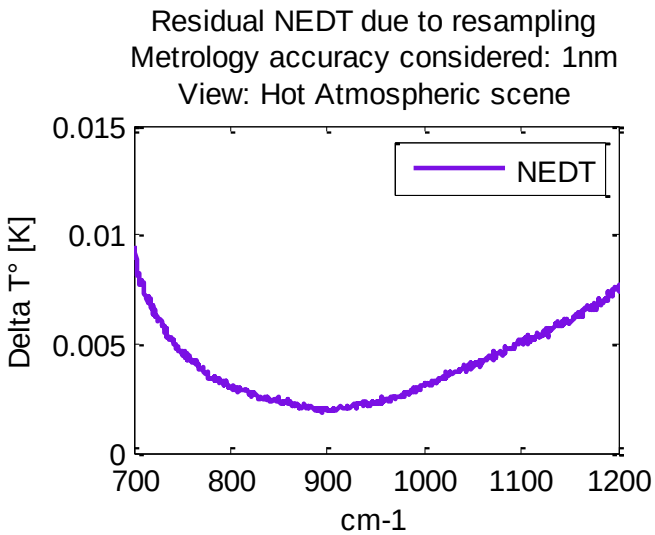
- Improved laser based on the IASI stabilization concept
  - Accurate temperature control (gross control)
  - Laser current enslaved on a gas cell absorption ray (fine control)
  - Low noise laser current source
  - Updated to solve the obsolescence's
  - Power delivered on a removable PM fiber



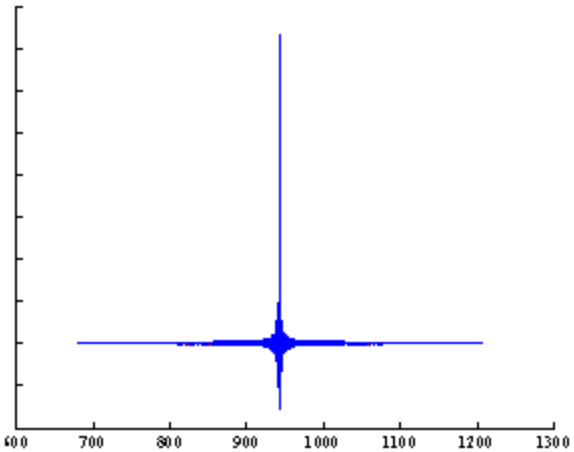
- The new TAS laser can opportunely be reused for new generation of atmospheric sounders
  - 1550nm band, ray width about 450kHz
  - Coherence length over 500m
  - User power range from 1 to 50mW
  - Long term stability $(\Delta\lambda/\lambda) < 10^{-7}$
  - Short term stability $(\Delta\lambda/\lambda) < 10^{-11}$
  - Power consumption : 5 W

IFTS Processing characterisation

- IFTS test bench is associated with a development tool to optimize sampling strategies, on board and on ground processing
  - Used for algorithms optimization and prediction of tests.
  - It includes performance diagnostics index such as:
    - Spectral response shape error index and centroïd shift
    - NEDT noise on Atmospheric or Blackbody scenes



The simulation of interferogram resampling result on a residual error of about 10mK

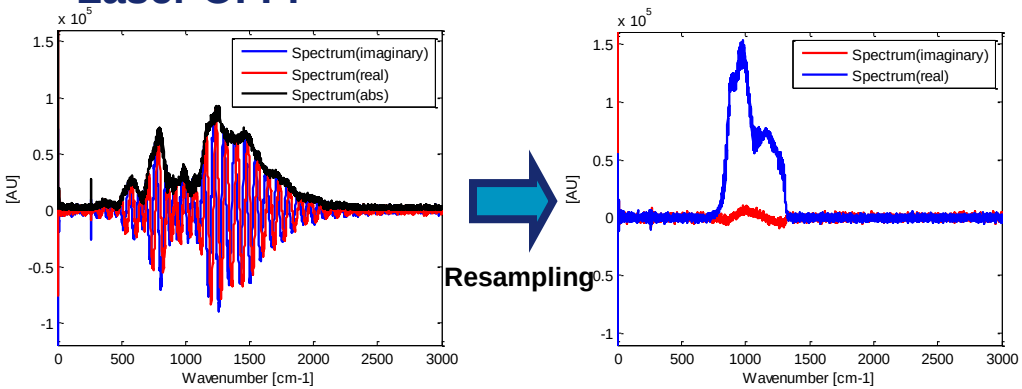


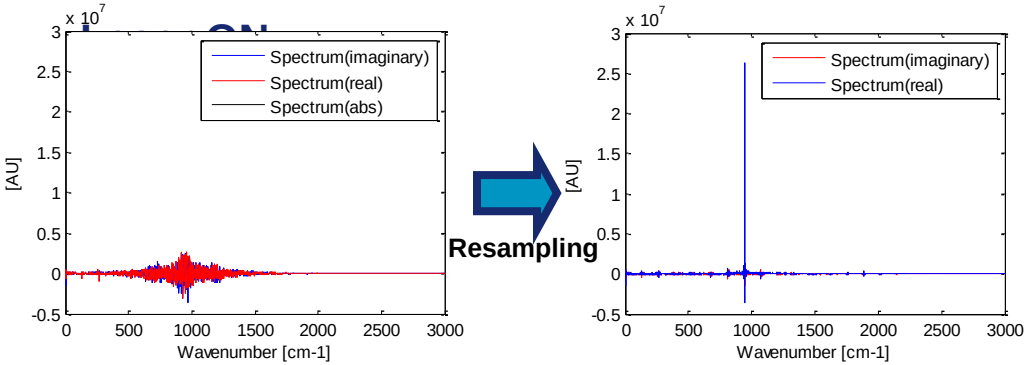
Simulation of IHOS ISRF measurement

IFTS test bench first results

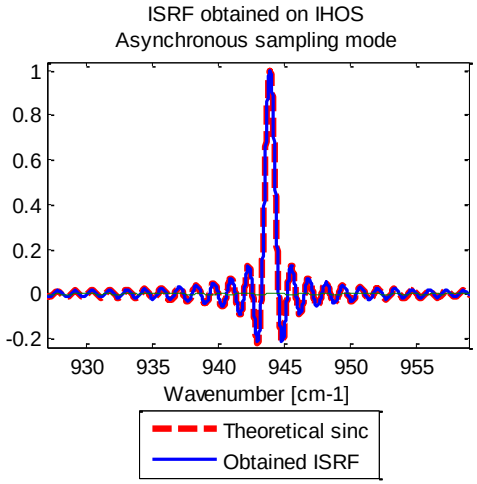
Resampling process performance:

Laser OFF:





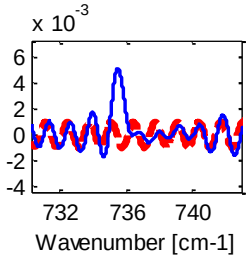
Obtained ISRF:



ISRF obtained at 943 cm^{-1} : very close to a sinc

- Shape error of 0.035, mainly due to measurement noise

Algorithm robustness test: <1% residual ghosts under 25% sinusoidal fluctuations of CC speed



IFTS test bench status and perspective

- Ongoing trade off between acquisition principles :
  - Equal time sampling with post-processing
  - Equal OPD Sampling (interferometer clock triggering)
- Acquisition improvement expected in 2010:
  - Test LASER source improvement : speckle reduction
  - Detector and cryogenic cooler optimisation
- Test bench adaptation to LEO conditions (PREMIER objective) are expected from 2010

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- Ongoing advanced projects and technological developments
  - From IASI to IASI-NG :
    - IASI performance a valuable basis for IASI-NG
    - IASI flight survey
    - From IASI to IASI-NG

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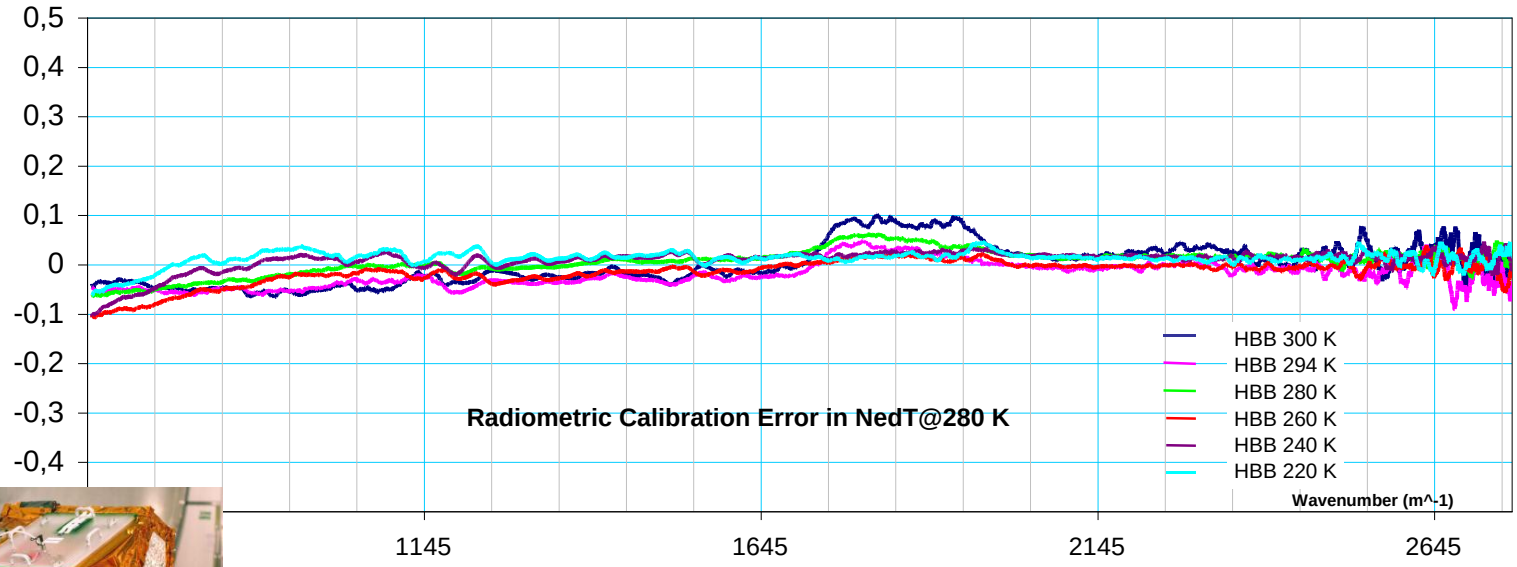
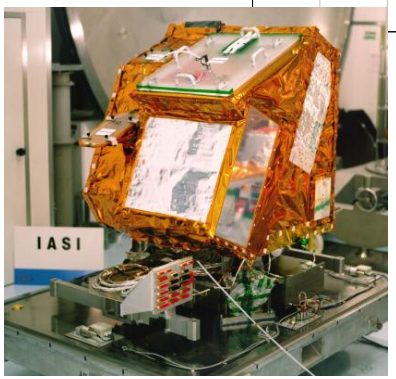
IASI performance a valuable basis for IASI-NG

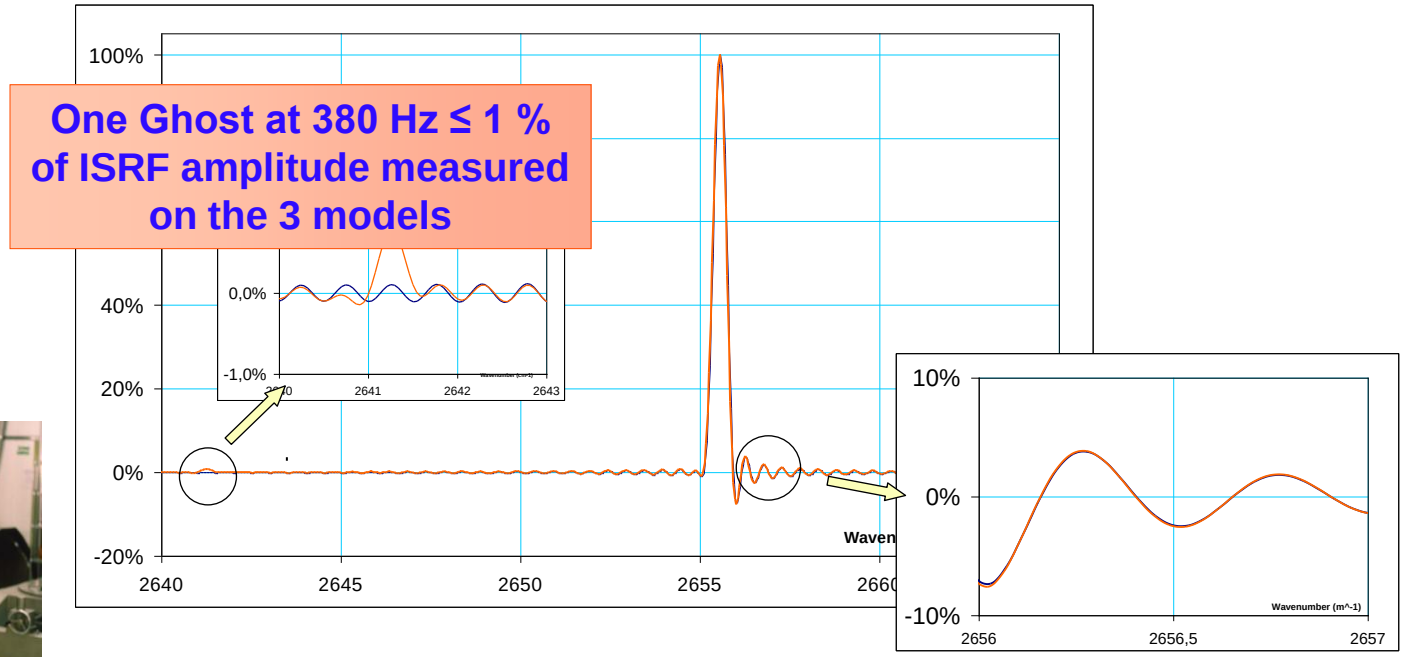
- High radiometric calibration performance at IASI output
  - On ground post processing : non blackness & scan mirror reflectivity

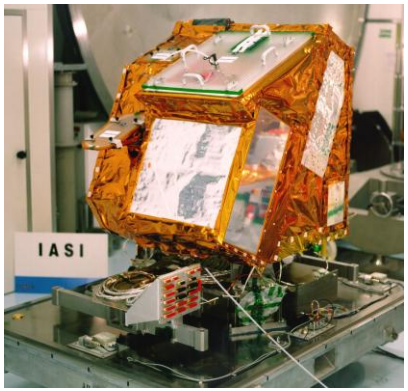




IASI performance a valuable basis for IASI-NG

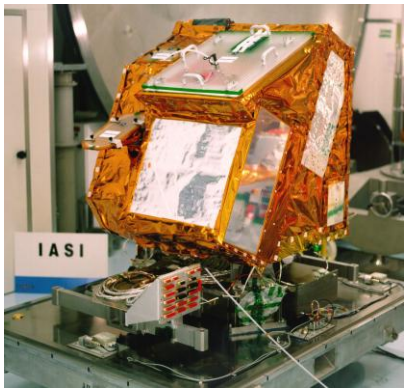
- High radiometric calibration performance at IASI output
  - On ground post processing : non blackness & scan mirror reflectivity
- A quasi perfect matching between ISRF model and ISRF measurements

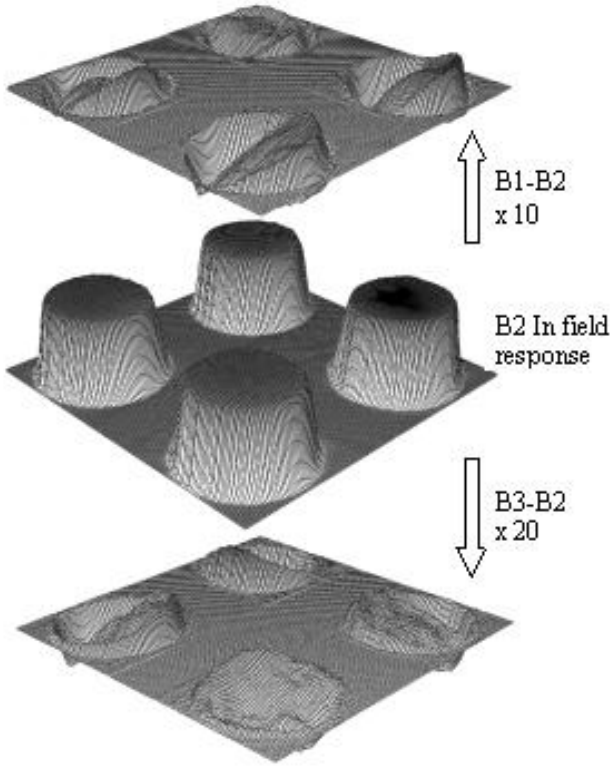




IASI performance a valuable basis for IASI-NG

- High radiometric calibration performance at IASI output
  - On ground post processing : non blackness & scan mirror reflectivity
- A quasi perfect matching between ISRF model and ISRF measurements
- A well mastered field response of IASI pixels of the 3 bands



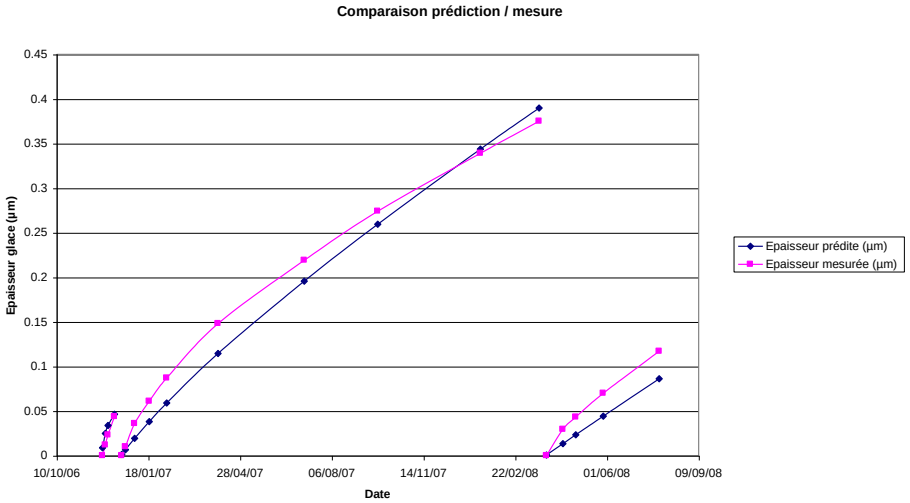


IASI flight survey

- In flight anomaly investigations and corrections: the TAS main contribution was the modification of the on board management system
  - Addition of a “DPS auto-restart” function which allows an automatic restart of the instrument in operational mode in case of SEU on the Data Processing System
  - Improve the instrument availability
- Analyse of IASI in orbit behaviours once a year (REVEX)
  - Trend analysis of telemetries, sub-systems behaviours and performances: ageing effects on thermal control, contamination, performances.
- Support to CNES for maintenance of on ground models
  - Analysis of annual good health tests
  - Support for PLM vacuum test
    - IASI preparation and GSE maintenance
  - Analysis of impacts for IASI of “electronic component alerts”
    - Participation to “Working Groups”
  - Support for launch preparation and IASI SIOV

IASI flight survey

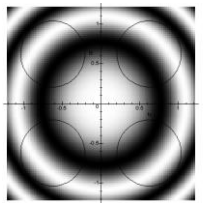
- IASI thermal behaviour analysed for the 18 first months in orbit
  - Very close to the expected one
  - Very low ageing impacts
    - No increase of the detector temperature expected for the nominal life time (5 years)
- Water ice contamination analysis
  - Close to predictions
  - One more decontamination phase will be necessary before the end of life
    - A total of 3 decontaminations phases for 5 years of operations
  - Optimisation of an initial decontamination phase applicable to the next IASI model



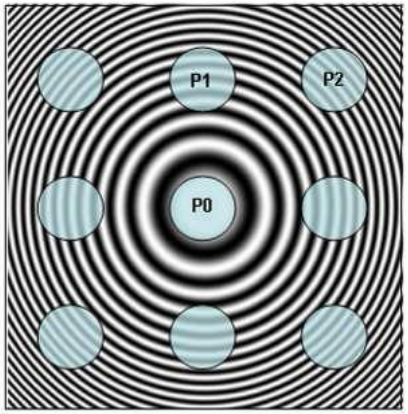
From IASI to IASI-NG

- IASI-NG spectral and radiometric resolution x2 improvement requires to make a gain in throughput and spectral resolution.

IASI



IASI-NG



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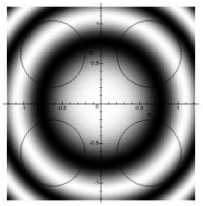
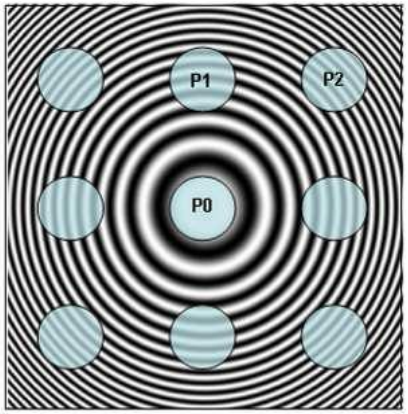
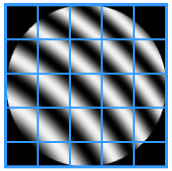


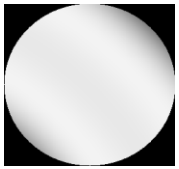
IASI-NG



- Two instrumental concepts are challenged:
  - An IFTS like concept where the sounding points are over sampled according to the interference fringes figure.
  - A Field widened FTS concept where an active optics placed in the focal plane (GENZEL concept) compensates the WFE induced by the pupil displacement due to the moving cube corner.



Fringe sampling with an IFTS like concept



Fringe pattern with a Field Widened Interferometer

- Interesting times ahead !
  - IASI-NG : phase A has started beginning 2010
  - PREMIER : phase A starts in February 2010
  - SIFTI : proof of concept breadboarding is expected in 2010
  - IRS-MTG…