

SPECIAL ISSUE



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AND  
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Institute of Applied Physics "Nello Carrara"  
ANNUAL CONFERENCE  
2015

Area della Ricerca di Firenze - Sesto Fiorentino, Febbraio 2015



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Institute of Applied Physics “Nello Carrara”  
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- Conservation and Diagnostic (Cultural Heritage),
- Laser
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- Biophotonics
- Sensors
- Solid State.

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# Preface

The "Nello Carrara" Institute of Applied Physics (IFAC) of the National Research Council of Italy (CNR) enjoys advanced scientific expertise in many areas of Applied Physics that allow it to develop valuable research and to produce enabling technologies, in particular in the domains of ICT, Photonics, Nanotechnologies, Advanced Materials, Biotechnology.

Together with the expertise in information engineering and mathematical modeling, to be used e.g. in the analysis and processing of signals and images, this pool of enabling technologies is expendable with high impact in several fields of application, which range from the development of innovative tools for earth observation and remote sensing to applications in biophotonics and nanomedicine, from diagnostics and restoration of the cultural heritage to the design of methodologies and services for improvement of quality of life and safety of citizens.

This booklet provides a glimpse on the research activities presently carried out at IFAC. The contributions, provided by IFAC research groups, are grouped according to the different application areas.

The occasion for this publication has been the 2015 Annual Conference of IFAC.

CNR Florence Research Area  
February 2015





**SPACE, AEROSPACE  
and  
EARTH OBSERVATION**

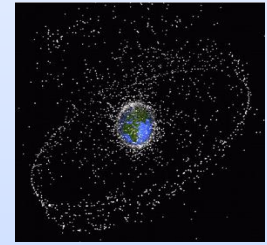


## The space debris

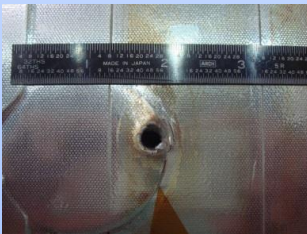
Space debris are all man made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non functional. Since the first artificial satellite, Sputnik 1, launched by the USSR on October 4, 1957, more than 5000 launches have occurred, placing nearly 7000 payloads in orbit. Currently there are about 3500 satellites and probes orbiting the Earth, together with about 1800 upper stages. Of all these spacecraft, only about 900 are operational. All the rest are space debris. Going down to smaller sizes the number of objects larger than approximately 10 cm in Earth orbit exceeds 20000 and the estimates of cm sized particles are of the order of 150 000. All these abandoned objects represent a serious risk for all the space assets and already lead to the disruption of operational satellites.

The IFAC group is working since many years in the field, covering different aspects of the space debris issue: telescope observations, orbit determination, orbital dynamics, collision risk evaluation, modelling of the long term evolution, reentry strategies from different orbital regimes. These activities have the final goal of finding effective mitigation measures to stop the growth of the debris population safeguarding the space for the future generations.

Members of the group are delegates, for the Italian Space Agency, within the the Inter-Agency Space Debris Coordination Committee (IADC) IADC Website, the main international governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space.



Computer generated image of the distribution of the catalogued space debris around the Earth (Courtesy: ESA Space Debris Program Office).



Entry hole created on Space Shuttle Endeavour's radiator panel by the impact of unknown space debris (left). The ESA Space Debris Telescope at Tenerife (right).



### Collaborations

The space debris research activities are pursued, mostly with European funding, in close collaboration with Italian and international partners including academies, research centers and industries such as: European Space Agency, University of Pisa (Italy), University of Rome "La Sapienza", University of Southampton (UK), IAPS-INAF (Italy), CNRS (France), Telespazio (Italy), SpaceDyS (Italy).

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## Astrodynamics and Planetary Science

The IFAC group is appreciated since many years for the research carried out in the astrodynamics and planetary science fields. Accurate models and algorithms are developed with the aim of describing, understanding and effectively exploiting the dynamics of small bodies orbiting in the Solar System.

Concerning artificial satellites, recent works include the design of trajectories associated with libration points in Sun-Earth and Earth-Moon system, end-of-life disposal options in different orbital regimes, asteroid retrieval trajectories, and interplanetary trajectories.

Moreover, the group is involved in the study of trajectories leading to asteroidal impacts to the Moon and the planets. Orbital and rotational dynamics and physical studies (through spectroscopical observations) of the small bodies of the Solar System are also carried out.

### Collaborations

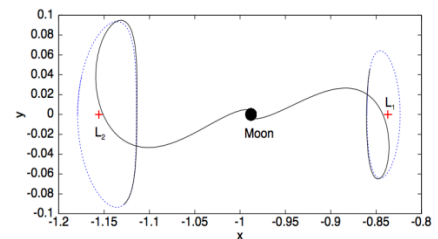
The research activities in this field are pursued, mostly with European funding, in close collaboration with Italian and international partners including academies, research centers and industries such as: European Space Agency, University of Southampton (UK), IAPS-INAF (Italy) IMCCE (France), Universitat Politècnica de Catalunya (Spain), University of Colorado at Boulder (USA), Università di Padova (Italy), INAF-Osservatorio Astronomico di Roma.

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Libration Point Orbits in the Earth-Moon system.



The Chelyabinsk meteor.



An impact crater on the Moon.

## Processing and control systems for mini&nano satellites

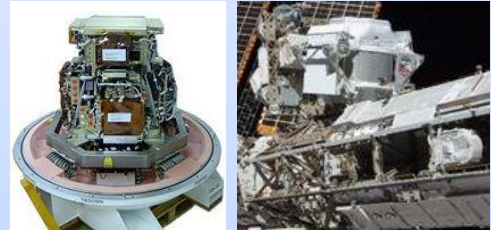
Small satellites (40-300 Kg) in LEO orbit are the tool to implement fast and cheap solutions for the Earth and space observations. New innovative design of the attitude control, power distribution and data processing make use of COTS electronic devices to overcome the cost and availability of space qualified components. Fail safe and redundant design and algorithm are necessary to maintain the reliability of the apparatus.

The following items have been studied and designed for space experiments in flight or to be launched:

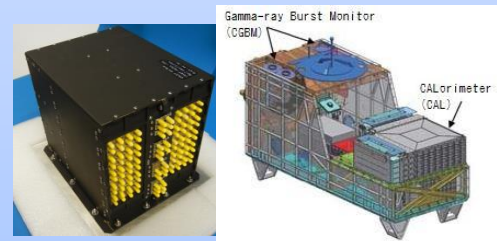
- Integrated solar/stellar sensors and feedback control for micro-thrusters satellite attitude control.
- Power distribution system and high voltage power supply for PMT and APD photo detectors.
- Parallel computing units based on DSP and semi-custom FPGA to process the data coming from custom front end chips for array of photodetector and charged particle detectors.

### With regards to enterprises...

The design of an optimized electronic apparatus (power consumption, reliability and computing efficiency) is the base of successful space mission. Design and implementation of the previous described apparatuses have been realized for PAMELA particle detector on RESURS DK satellite (ASI/INFN), for AMS I and AMS II on the ISS (ASI/INFN) and for CALET (calorimeter/gamma ray burst detector, to be launched) on KIBO (ISS).



PAMELA & AMS experiments based on particle magnetic spectrometers



CALET experiment based on particle calorimeter & gamma ray burst detector Cosmo

### Contact:

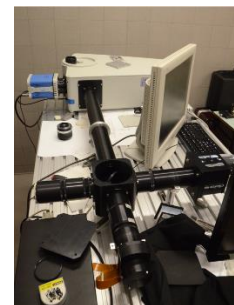
Sergio Ricciarini ([s.ricciarini@ifac.cnr.it](mailto:s.ricciarini@ifac.cnr.it))

## Compressive sampling technology for aerospace systems

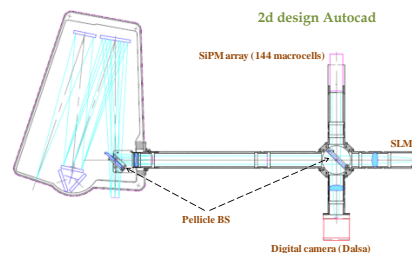
According to recent studies, the acquisition of a signal can be also performed at sampling rates much lower than the minimum frequency dictated by the Shannon's theorem: this concept is known as "compressive sampling" (CS). This technique can be applied to signals which show some correlation, that is they are sparse in some domain. The CS technique may offer many advantages for Earth Observation from aerospace platforms in order to obtain a high spectral/spatial resolution data even using a reduced number of detection elements, memory capacity and down-link bandwidth. For this purpose, a demonstrator has been implemented in the laboratory to assess the feasibility of the CS for Earth Observation and to investigate the main critical issues for the development of this technology. The demonstrator operates in push-broom configuration according to a scheme of direct modulation obtained with a 2D-array of mirrors or crystals or LCD controlled by electric actuators. The data acquisition - carried out using a single sensitive element - is repeated for different modulating spatial patterns; the image is then reconstructed by applying a suitable algorithm that takes advantage of the sparseness of the signal.

### With regards to enterprises...

The demonstrator has been developed within an ITB project of the European Space Agency.



Experimental set-up for the CS demonstrator.



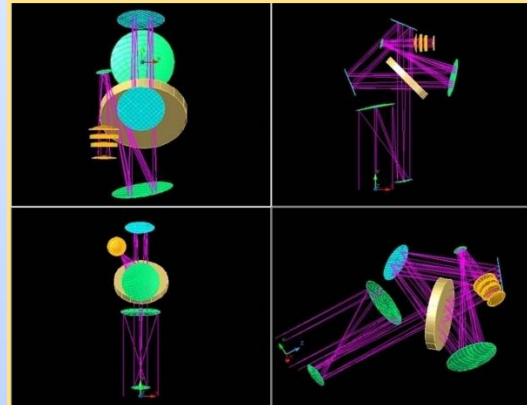
Optical design of the CS demonstrator.

### Contacts:

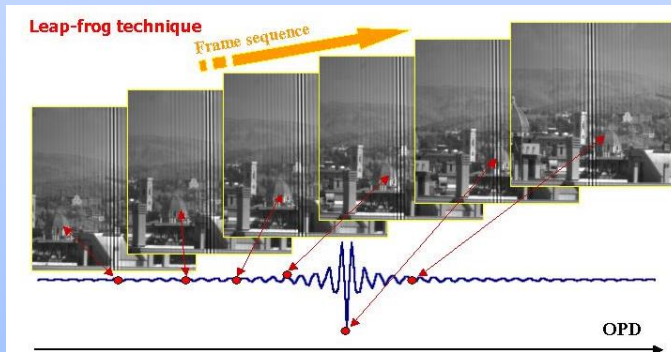
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## Image interferometer for aerospace platforms

The stationary image interferometer ALISEO (Aerospace Leap-frog Imaging Stationary Interferometer for Earth Observation) - in-house developed at IFAC - is distinctive for its "leap-frog" configuration, in which the image of the observed scene is modulated by an optical path difference (OPD). In this configuration, each point of the scene is seen with different phase delays and the interferogram of each point is reconstructed through the acquisition of a temporal sequence of images. With respect to a push-broom configuration, this method offers the advantage of providing an image for each acquisition, although it requires a more complex data processing for the reconstruction of the interferogram.



Optical design of the ALISEO demonstrator.



Working principle of the ALISEO interferometer.

The applications are typically those related to Earth Observation (environmental monitoring, natural resources, catastrophic events, etc..).

### With regards to enterprises...

The demonstrator has been developed within the MIOSAT program of the Italian Space Agency.

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## CalVal activities and the San Rossore test site

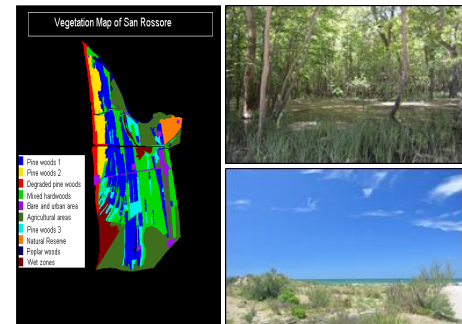
The San Rossore Natural Park, located on the Tuscany coast, North of Pisa (Italy), has been used over the last 10 years for many remote sensing campaigns devoted to coastal zone monitoring or validation/calibration activities. The considerable amount of collected data allows the characterization of the terrain (i.e. land coverage, green bio-mass) from remote sensing products (ground reflectance maps).

The presence of a measurement test site equipped with meteorological station and solar irradiometers, provides time series of ground measured data (total and diffuse ground irradiance, temperature, relative humidity, air pressure) as well as a database of natural and man-made relevant targets spectral reflectance. These data are used as ground truth in remotely sensed data processing.

The San Rossore area has been used as test site for the following European Space Agency campaign: Sen3Exp, CHRIS-PROBA project "Assimilation of biophysical and biochemical variables in biochemical and hydrological models at landscape scale", as well as for airborne campaigns performed using the following sensors: MIVIS, CASI, Daedalus, VIRS200, HyperSIM-GA.

### With regards to enterprises

IFAC performed calibration and validation tests on MIVIS images acquired by Compagnia Generale Riprese aeree (CGR SpA), on Daedalus data acquired by TELAER SpA, on HyperSIM-GA data by SELEX ES SpA.



Vegetation thematic map of San Rossore park and images of different zones.



Ground measurement instrumentation and eddy covariance flux tower (in collaboration with JRC- Ispra).

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Donatella Guzzi ([d.guzzi@ifac.cnr.it](mailto:d.guzzi@ifac.cnr.it))



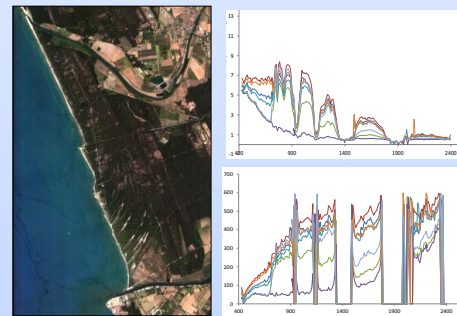
## Data correction and calibration for earth observation applications

Images acquired by aerospace sensors must be corrected for the effects of several factors, such as: lighting conditions, absorption and scattering due to atmosphere, sensor characteristics, etc.. Autonomous and iterative algorithms have been developed at IFAC to model, separate and remove these effects from the raw data. These procedures provide the following products: calibrated at-sensor radiance, atmospheric parameters, ground reflectance. IFAC has also a well-established know how in algorithms for the removal of spatially-coherent noise.

Another branch of activity concerns the development of test systems for star tracker sensors. These instruments, entirely designed and implemented at IFAC, are able to simulate real-time star field scenes in relative motion with respect to the star tracker sensor.

### With regards to enterprises...

Data correction and calibration procedures have been implemented and/or used in the frame of several projects (CTOTUS, OPTIMA) and measurement campaigns in collaboration with private enterprises (SELEX ES SpA, TELAIR S.T.A., CGR SpA). Collaborations have been established also with other enterprises such as: TELESPAZIO, SELEX ES, CGS, in the frame of the ASI-funded OPTIMA project (PRISMA mission). The star field simulator has been developed in the frame of the SAMS project - funded by Regione Toscana - with the partnership of SELEX ES SpA.



Ground reflectance image of San Rossore area (Pisa, Italy) and the spectra corresponding to the at-sensor radiance and reflectance of a representative pixel of the image.



Dynamic star-field simulator particular of control interface and collimator.

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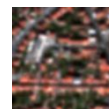
## Image Fusion by Pansharpening

New-generation space-borne imaging sensors operating in a variety of ground scales and spectral bands provide huge volumes of data having complementary spatial and spectral resolutions. The tradeoff of spectral and spatial resolution makes it desirable to perform a spatial resolution enhancement of the lower resolution multi-spectral (MS) data or, equivalently, to increase the spectral resolution of the data-set having a higher ground resolution, but a lower spectral resolution, typically a panchromatic (Pan) image. Most of methods follow a general protocol, based on two key points. The former consists of extracting the high resolution spatial information of the scene, not present in the MS image, from the Pan image; the latter incorporate such spatial details into the low-resolution MS bands, interpolated to the spatial scale of the Pan image, by properly modeling the relationships between the MS bands and the Pan image.

### With regards to enterprises

Pansharpening is currently used in photo analysis to spatially enhance satellite images. The algorithms developed by IFAC have been scored as the most efficient in international contests organized by Centre National d'Études Spatiales (CNES) and IEEE – Data Fusion Committee (DFC).

Original low spatial resolution MS image



High spatial resolution Pan image



Fused MS image obtained by pansharpening.

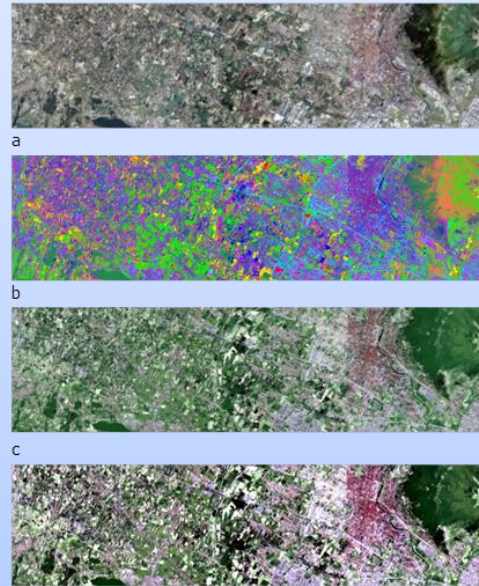
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Massimo Selva ([m.selva@ifac.cnr.it](mailto:m.selva@ifac.cnr.it))



## End-to-end simulation tools for hyperspectral images

In order to evaluate the performance of a hyperspectral sensor and to test the algorithms which will be used for data processing, a software tool for the simulation of hyperspectral data is recommended. For a realistic simulation of the hyperspectral data/images it is necessary to consider different effects: the interaction of the electromagnetic radiation with the soil and with the atmospheric constituents (gas and aerosols), both illumination and acquisition geometry, spatial and spectral variability of the simulated scenes, instrumental effects. In the framework of OPTIMA project funded by the Italian Space Agency, IFAC developed a tool for the simulation of hyperspectral images which is able to account for most of those phenomena. More specifically, the simulator is composed by three independent simulation blocks: the scenario builder, the atmospheric propagation calculator, and the sensor simulator. The tool was also upgraded by including a block for the simulation of solar-induced fluorescent targets.



(a) Ortho photo acquired over Firenze; (b) 10-classes thematic map obtained after ortho photo classification; (c) Ground reflectance map: 7.5-m spatial resolution, 2-nm spectral resolution; (d) At sensor radiance image: 30-Km swath, 30-m spatial resolution, 7-12-nm spectral resolution.

### With regards to enterprises...

The End-to-End simulation tool has been developed in the frame of the ASI-funded OPTIMA project (PRISMA mission). During the project, collaborations have been established with other enterprises such as: TELESPAZIO SpA, SELEX ES SpA, CGS SpA. This image simulation tool has been upgraded and used for the simulation of sub-nanometric spectral resolution images, including the solar-induced fluorescence contribution, view of possible applications in the frame of the ESA-funded FLEX mission

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## Theoretical analysis for the optimal exploitation of the information content of atmospheric indirect measurements

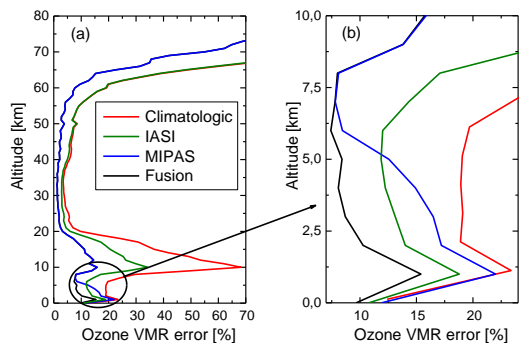
Many observation systems are presently operating on board space-borne and airborne platforms, as well as from ground-based stations, providing complementary and redundant measurements of a variety of atmospheric parameters. The use of potential synergies among these observing systems is a key element for the full exploitation of current and future missions with the purpose to provide target products of the best quality in terms of precision and accuracy, as well as spatial and temporal coverage and resolution. The Atmospheric Research Group at IFAC is active in theoretical studies aimed to individuate new approaches for the analysis of atmospheric indirect measurements with the purpose of an optimal exploitation of their information content.

Examples of results obtained in this research field are:

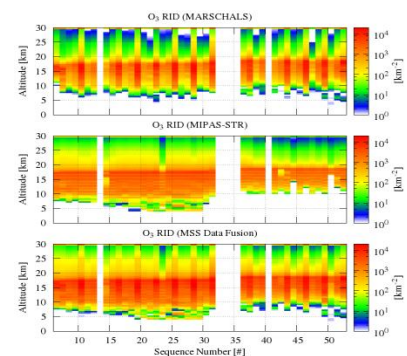
- Development of a retrieval solution (MEASUREMENT SPACE SOLUTION) that keeps separated the information of the observations and of the retrieval constraint.
- Definition of parameters that evaluate the INFORMATION CONTENT and the QUALITY of atmospheric measurements
- Development of algorithms to perform the DATA FUSION of atmospheric measurements acquired by different instruments in order to exploit the synergy of the measurements.
- Development of an algorithm to perform the AVERAGE OF ATMOSPHERIC VERTICAL PROFILES in order to minimize the effect of the retrieval constraints.

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Authors: Atmospheric Research Group



Quality of the ozone measurements of IASI and MIPAS and of their fusion in terms of the random errors.

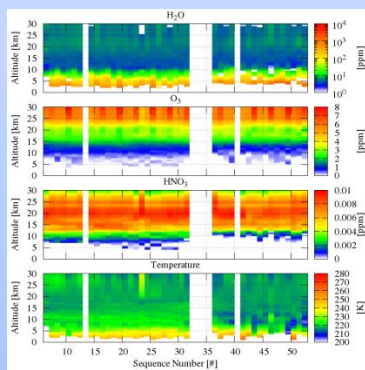


Cross-sections of the Relative Information Distribution of MARSCHALS, MIPAS-STR and fused Ozone data

## UTLS (Upper Troposphere Lower Stratosphere) study: MARSCHALS data analysis

The UTLS region is a pivotal region of the Earth's atmosphere due to the chemical, radiative and transport processes occurring at these altitudes and having a substantial impact on surface climate. In the UTLS Essential Climate Variables are most sensitive to changes in the distribution of radiatively active gases and clouds. Remote sensing measurements of this region pose, however, a very challenging problem both from the point of view of modelling the observed radiation and of retrieving the desired quantities from the observations.

MARSCHALS (Millimetre-wave Airborne Receivers for Spectroscopic CHARACTERisation in Atmospheric Limb Sounding) is a limb viewing instrument working in the millimeter and sub-millimeter spectral ranges (294-349 GHz). To demonstrate the measurement capabilities of the instrument, IFAC contributed to the development of a suite of codes, in which the most accurate modelling and the most advanced retrieval algorithms have been implemented.



Atmospheric retrieval products

MARSCHALS was deployed on-board the M-55 Geophysica stratospheric aircraft and from 2005 to 2011 many measurement campaigns have been analysed providing the vertical profiles of Temperature, HNO<sub>3</sub>, O<sub>3</sub>, H<sub>2</sub>O, CO and N<sub>2</sub>O. The instrument was flown in 2010 and 2011 as a demonstrator of the millimeter-wave limb sounder, as part of the preparatory studies for the PREMIER mission.

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Geophysica stratospheric aircraft

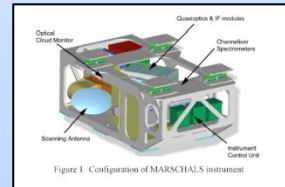
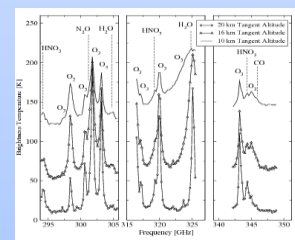


Figure 1 Configuration of MARSCHALS instrument

MARSCHALS configuration



MARSCHALS spectra

## Microwave Remote sensing of natural surfaces: I – Monitoring of the hydrological cycle on a global scale

The number of weather-related natural disasters, such as floods, avalanches, cyclones, drought and heat waves, is dramatically increasing. Such disasters are primarily due to environmental global changes and land degradation, which are mostly caused by human impact on the territory. A help in breaking this vicious cycle can be given by a more in-depth knowledge of two fundamental cycles of our planet: the global carbon and hydrological cycles.

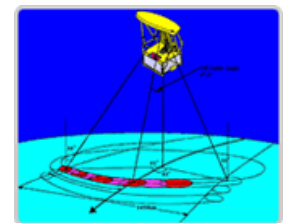
Microwave sensors have been proven to be sensitive to water contained in observed bodies and therefore can be used for retrieve information on the main parameters of the hydrological cycle, such as soil moisture, vegetation biomass, snow depth.

By using satellite microwave radiometers (e.g. AMSR-E/AMSR2, SMOS, SMAP, Aquarius), information on temporal evolution of surface parameter conditions can be assessed although at large spatial scale.

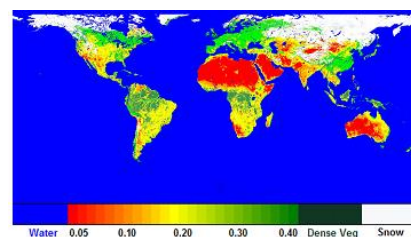
Innovative inversion algorithms (HydroAlgo), based on radiative transfer models and artificial neural networks (ANN), were developed at IFAC for estimating soil moisture, snow depth and vegetation biomass using multifrequency, multipolarization data.

### With regards to enterprises

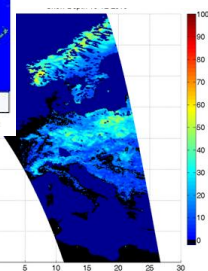
Developing of methodologies and instrumentations is performed in cooperation with national and international space agencies (ASI, ESA, NASA, JAXA,) and companies



AMSR2 microwave radiometer onboard GCOMW (JAXA)



Global soil moisture (April 2010) (up) and snow depth maps (Dec.2010) (right) from AMSRE data by using HydroAlgo (Santi et al., 2012)



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## Microwave Remote sensing of natural surfaces: II – Monitoring of the hydrological cycle on a local scale

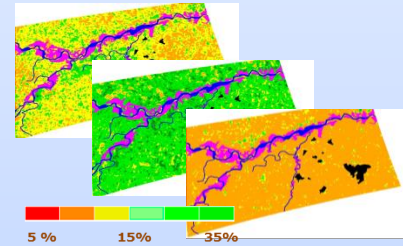
The monitoring of the hydrological cycle from satellite is crucial for many applications, such as agriculture, water management, forecast and management of environmental disasters. The estimate of soil moisture (a key hydrological and climatic variable), snow depth (a parameter significantly related to water resources, avalanches and flood forecast), and finally vegetation biomass (a key factor of the carbon cycle), and the knowledge of their temporal and spatial variations are therefore very important for environmental management activities.

SAR systems, with their high ground resolution (a few meters) and frequent revisit time (2-3 days), demonstrated to be very powerful sensors for parameter retrieval, which is impracticable from ground measurements, due to the high spatial variability of the target variables.

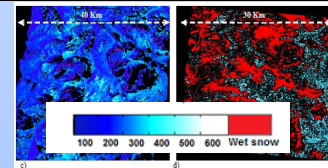
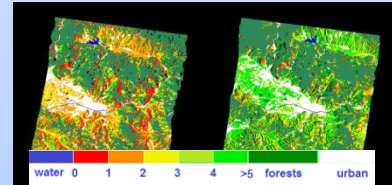
Radar signal (backscattering) was first simulated by using advanced e.m. models implemented. Innovative methodologies based on ANNs were developed at IFAC for deriving high resolution geophysical parameter and for generating maps of soil moisture, vegetation biomass and snow depth by using ALOS/PALSAR (L-band, 1.4 GHz), ENVISAT/ASAR, RADARSAT and Sentinel-1(C-band, 5GHz), TerraSARX and COSMO-SkyMed (X-band, 10 GHz) satellite SAR data.

### With regards to enterprises

Developing of methodologies and instrumentations is performed in cooperation with national and international space agencies (ASI, ESA, NASA, JAXA,) and companies



Soil moisture maps (November, April and June 2003/04) from ENVISAT data in Alessandria area



Wheat biomass (top - over Florence area in March and June 2012) and snow depth (bottom - Cordevole area in winter 2010) maps from Cosmo-SkyMed data

### Contact:

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## Microwave Remote sensing of natural surfaces: III – Monitoring of the vegetation biomass using GNSS-R signal

Global Navigation Satellite System (GNSS) Reflectometry could represent a valuable tool for the remote sensing of key bio-geophysical parameters. Previous experiments demonstrated the capability of GNSS bistatic scatterometers to measure variations in land surface reflectivity.

These systems have the advantages to operate at L band, an optimal frequency for monitoring both soil moisture and vegetation biomass, with potentially higher spatial resolution than microwave radiometry, due to the highly stable carrier and code modulations of GNSS signals which enables the use of Delay Doppler mapping.

Ground based and airborne campaigns conducted in Tuscany in the framework of ESA projects (Leimon, GRASS, and GNSSBio) demonstrated the capability of GNSS signal in retrieving forest biomass with an estimated sensitivity of 1.5 dB/(100 t/ha) and with a saturation higher than 150 t/ha. This points out the capabilities of GNSS-R as a remote sensing tool for forest biomass.

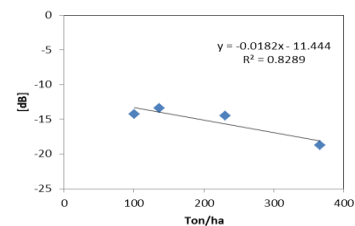
Model simulations have been carried out for better interpreting the results

### With regards to enterprises

Developing of methodologies and instrumentations is performed in cooperation with the European Space Agency (ESA) and a Spanish company – STARLAB Ltd.



GNSS\_R sensor installed on ground and on an ultra-light aircraft (detail of the GNSS antenna)



Sensitivity to of GNSS-R signal to forest biomass (Egido et al., 2014)

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## Microwave radiometers

Microwave radiometers are used on the monitoring of Earth surface and atmosphere since the 70's. These instruments have proven to be very sensitive and accurate for collecting electromagnetic measurements and deriving from them biogeophysical quantities (e.g. soil moisture, plant water content, snow depth, liquid water vapor).

Since the 80's the IFAC laboratories design and develop microwave radiometers to be used in experimental ground-based and airborne campaigns. Depending on the applications, the instruments are built in different configurations and different frequencies from L-band (1.4 GHz, 21 cm wavelength) up to Ka-band (37 GHz, 8mm wavelength) in the protected part of the electromagnetic spectrum. The instruments are tested and accurately calibrated in the IFAC laboratories and adapted to work autonomously in the most critical environmental conditions.

### With regards to enterprises...

Design and construction of the radiometers is performed in conjunction with companies (e.g. Pasquali Microwave Systems) and the European Space Agency (ESA).



L-band radiometer installed on the US tower at Concordia Station, Antarctica



X-band radiometer adapted for an ultralight airplane

### Contact:

Giovanni Macelloni ([g.macelloni@ifac.cnr.it](mailto:g.macelloni@ifac.cnr.it))

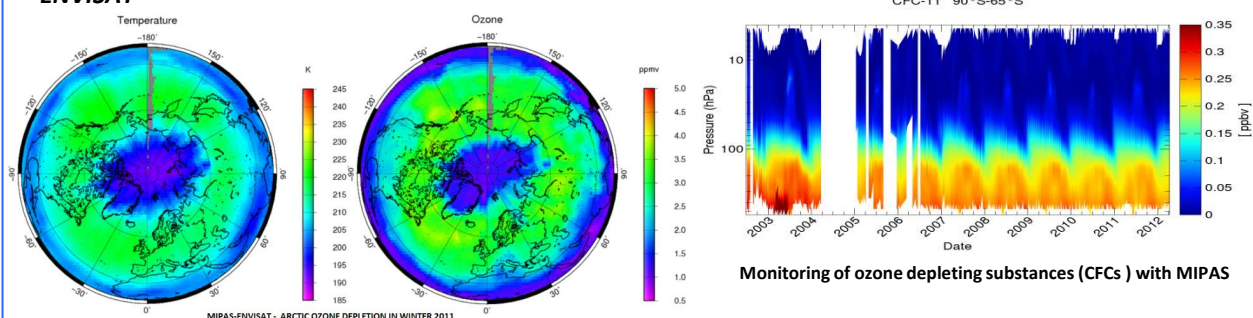
## Analysis of remote sensing measurements for the study of the atmosphere

Global challenges like the problems of ozone hole and climate change require the study of the chemistry of stratospheric ozone, the study of the earth radiation budget and the monitoring of Green House Gases. To this purpose, since 80s years passive remote sensing of the terrestrial atmosphere from stratospheric platforms and analysis of measurements from satellite sounding the radiation emitted by the atmosphere have been performed by the Atmospheric Research Group at IFAC. Forward and inverse modelling of the radiative transfer in the atmosphere allow the retrieval of geophysical parameters used for the monitoring and the study of composition of the stratosphere.

**An example of this activity has been the development of the scientific prototype for ESA near-real-time operational analysis of MIPAS on ENVISAT**



ENVIRONMENTAL SATELLITE (ENVISAT) hosting Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)



Anomalous very low temperatures and ozone hole in Arctic 2011 winter as measured by MIPAS

Monitoring of ozone depleting substances (CFCs) with MIPAS

Contact: Piera Raspollini ([p.raspollini@ifac.cnr.it](mailto:p.raspollini@ifac.cnr.it))

Authors: Atmospheric Research Group

## Microwave remote sensing of the cryosphere

Monitoring of the water cycle, and in particular the cryosphere, has been recognized by international organizations as paramount importance for understanding Earth climate. In particular, the cryosphere plays a crucial role in water supply for human and agricultural needs, hydrological risk reductions and energy production. Status of the cryosphere represents one of the most important indicators of the global warming and the monitoring of ice sheets (Antarctica and Greenland) is fundamental to estimate the sea level rising and its consequences on the human coastal settlements.

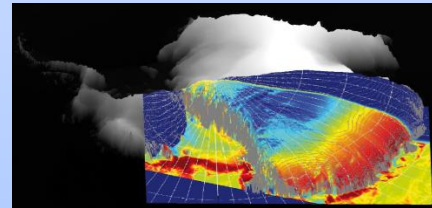
The research activity is based on active and passive microwave observation of Earth surface carried out by using ground, airborne and spaceborne sensors. Advanced methodology for deriving geophysical quantities are developed starting from microwave data and by using electromagnetic models and retrieval algorithms. Moreover the observation of the ice sheets contribute to the calibration and validation of satellite data.

### With regards to enterprises...

Developing of methodologies, instrumentations and is performed in cooperation with National and international space agencies (ASI, ESA, NASA) and companies.



Domex experiment for the monitoring of ice sheet and cal/vas of ESA SMOS mission at Concordia Station, Antarctica



Microwave brightness temperature of Antarctica.

### Contact:

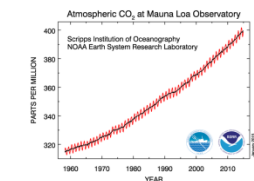
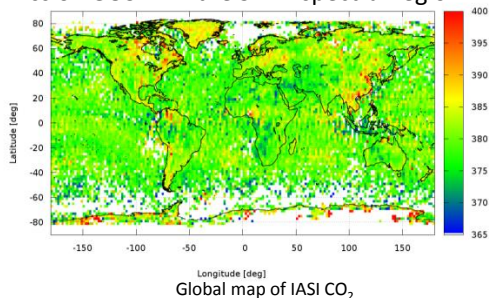
Giovanni Macelloni ([g.macelloni@ifac.cnr.it](mailto:g.macelloni@ifac.cnr.it))

## GHG (GreenHouse Gases) study: comparison of carbon dioxide retrieval from IASI on METOP-A and TANSO-FTS on GOSAT

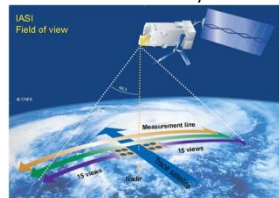
Carbon dioxide is the primary greenhouse gas released into the Earth's atmosphere by human activities. The balance of natural sources and sinks of carbon dioxide lead to stable values of about 280 ppm for atmospheric CO<sub>2</sub> concentration in pre-industrial times. Current levels of CO<sub>2</sub> in the atmosphere exceed the value of 400 ppm.

The study KLIMA-IASI, funded by ESA-ESTEC and coordinated by IFAC, represented an attempt to gain greater insight in the capabilities of passive remote sounding from space in the TIR spectral region to retrieve accurate information on the total amount of atmospheric carbon dioxide.

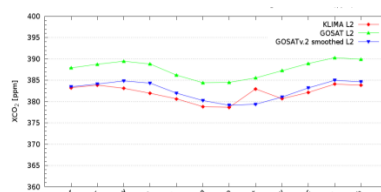
The research effort was conducted by investigating the potential of measurements acquired by the Infrared Atmospheric Sounding Interferometer (IASI), on-board the MetOp-A satellite, to provide CO<sub>2</sub> total column values with precision and accuracy comparable to 1 ppm on monthly averages over 1000x1000 km<sup>2</sup> areas and to compare the retrieved products with CO<sub>2</sub> operational products of the satellite mission GOSAT in the SWIR spectral region.



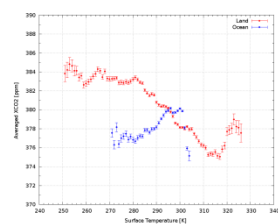
Carbon dioxide monthly mean



IASI instrument Field Of View



Comparison IASI vs GOSAT CO<sub>2</sub> products



IASI CO<sub>2</sub> vs surface temperature

Contact: *Samuele Del Bianco* ([s.delbianco@ifac.cnr.it](mailto:s.delbianco@ifac.cnr.it))

Authors: Atmospheric Research Group

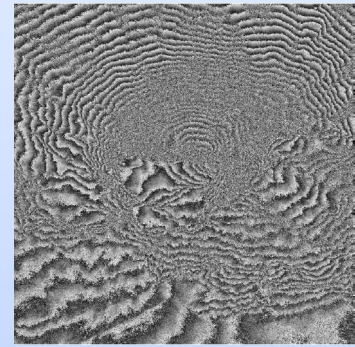
## Image Filtering

Digital filtering is usually applied in many applications in order to reduce the noise or enhance such specific features as edges, contours and targets. IFAC has been active in this field already before 1970 with significant results in linear filters first and in the development of adaptive filters, successively. Original rank filters have been defined and proposed to reduce impulsive noise. Several adaptive filtering schemes have been defined taking into account the advantages of such multiresolution decompositions schemes as Laplacian pyramids and wavelets. Fuzzy logic properties have been exploited to define adaptive filters to be applied when particular signal and noise models cannot be assumed.

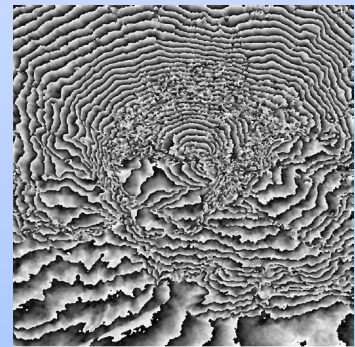
In the case a model exists, the estimation of its parameters assumes great importance for filtering. In this perspective modeling of signal dependent noise has been one of the key point of IFAC activity as assessed by several papers on this topic.

### With regards to enterprises

Filtering speckle noise present in synthetic aperture radar (SAR) images is being specifically considered in the framework of COSMO-SkyMed mission of the Italian Space Agency (ASI). Developing the algorithms for filtering false alarm from the data produced by Lightning Imager (LI) is in progress in the framework of the mission concerning Meteosat Third Generation (MTG) supported by EUMETSAT.



Topographic fringes of Mount Etna, Italy, from ERS-1/2 Tandem Mission



Fuzzy logic based filter. Window size is 5x5 with 8 prototype estimators.

### Contact:

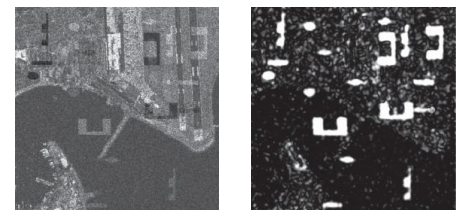
Stefano Baronti ([s.baronti@ifac.cnr.it](mailto:s.baronti@ifac.cnr.it))

## Nonparametric Change Detection for Multitemporal SAR Images

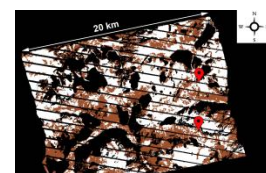
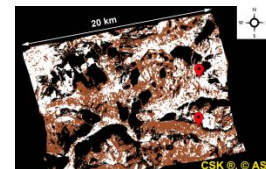
MS-ITCD (Mean Shift Information-Theoretical Change Detection) is a nonparametric algorithm for the automated detection of multitemporal changes in SAR images acquired in different times, for example before and after a meteorological event. In such a context, SAR images can be particularly useful, because of their insensitivity to weather conditions, especially in the case of cloud-cover situations. This method is particularly robust to noisy fluctuations due to speckle noise and co-registration inaccuracies. It can provide useful information on urban and suburban environments, but also parameters for water resource management, flood and landslide risk prevention. The algorithm in principle detects small changes, but can be also adjusted for the case of pervasive changes, as in the case of a snow cover map, computed before and during the winter season. The algorithm can work also in a simplified version, where the computational complexity is reduced to manage large size data. In the reported examples, it is applied to urban scenes and alpine areas, in order to retrieve both changes in anthropic environments and a snow cover map, respectively.

### With regards to enterprises...

Change detection is one of the most important application for monitoring the environmental evolution. The MS-ITCD method has been successfully applied to COSMO-SkyMed® data in the framework of COSMO-SkyMed-AO Project ID-2181 by the Italian Space Agency (ASI).



1-look SAR image with superimposed changes (left); change retrieval by the MS-ITCD algorithm (right).



Snow cover map of a COSMO-SkyMed® SAR image (top) compared with a reference optical Landsat map (bottom).

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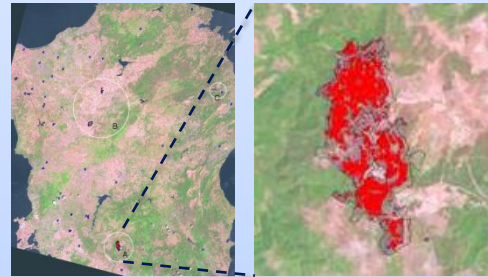


## Mapping and classification of burned areas by satellite images

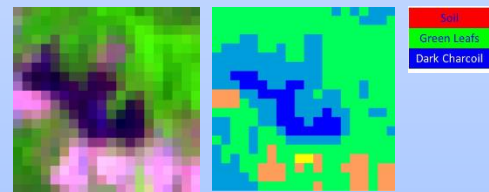
Periodic monitoring at regional/national scale of the areas affected by fire, is aimed at producing seasonal mapping of burnt areas and their fire severity for a better estimate of the damage and the risk of fire, as an aid to management policies for the recovery and restoration of territory. This task can be accomplished through the use of remote sensing images and the development of suitable techniques for processing and interpretation. The Burnt Area Detection (BAD) method, developed at IFAC-CNR, is a new procedure based on a multi-criteria expert approach realized through a decision tree classifier, which identifies with a very low level of error those pixels having a very high probability to lie within a burned area. The procedure was tested on Tuscany and large part of Sardinia regions acquired by SPOT-HRV, Landsat-TM/ETM+ and IRS1C/D-Liss3 satellite sensors, and it was found effective also on small dimensions fires. The assessment of the different severity levels of damage to the vegetation for each pixel was obtained by means of an Endmember Spectral Mixture Analysis procedure, that estimates the spectral % contribution of each of the spectral types representative of the environmental context (including charcoal and ash), to the radiance of each pixel.

### With regards to enterprises

Research activities developed under contracts with Telespazio S.p.A. in the framework of the RISK-EOS project (EC), and PRISMA-OPTIMA funded by Agenzia Spaziale Italiana ASI



Mapping of the areas affected by fire (highlighted in red) in the Sardinia region



Classification of Hyperion image of a fire affected area

### Contacts:

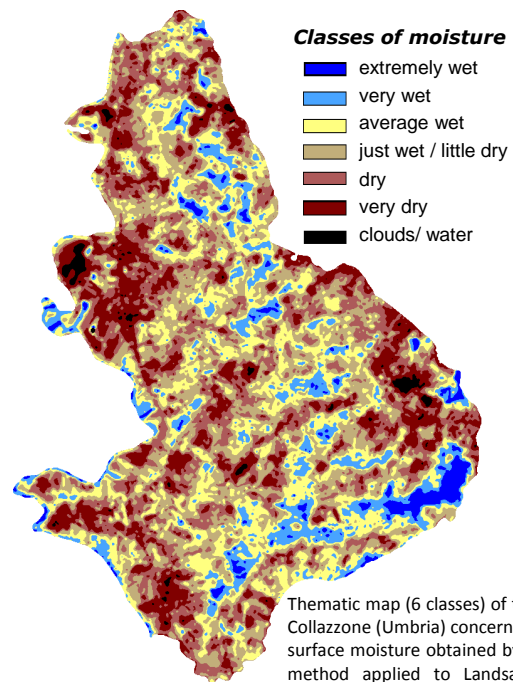
Roberto Carlà ([r.carla@ifac.cnr.it](mailto:r.carla@ifac.cnr.it))  
Leonardo Santurri ([l.santurri@ifac.cnr.it](mailto:l.santurri@ifac.cnr.it))

## Surface soil moisture evaluation by a multitemporal satellite approach

Soil moisture plays a very important role in many applications related to the management and exploitation of land resources (agriculture, forestry, etc.) and the monitoring and control of the areas affected by natural hazards such as landslides, floods and wildfires. Thus, the monitoring of soil moisture over extended areas is highly desirable. Conventionally, evaluation of soil moisture is based on local measurements. Therefore, the derivation of soil moisture maps by remote sensing assumes great importance to directly access soil characteristics over large areas within a short period. The MTVI method, developed at IFAC-CNR for surface soil moisture monitoring, is a multitemporal approach of the relationship between remotely sensed surface temperature ( $T_s$ ) and the vegetation coverage (VI). It takes advantage of the self-consistency of the relationship, but at the same time tries to improve its constraint for a better characterization and monitoring of surface soil moisture conditions over large and heterogeneous areas

### With regards to enterprises

The MTVI method has been developed in the framework of the MORFEO project, funded by Agenzia Spaziale Italiana (ASI), and coordinated by the CGS S.p.A. enterprise.



Thematic map (6 classes) of the area of Collazzone (Umbria) concerning the soil surface moisture obtained by the MTVI method applied to Landsat-TM/ETM images with spatial resolution of 30 m.

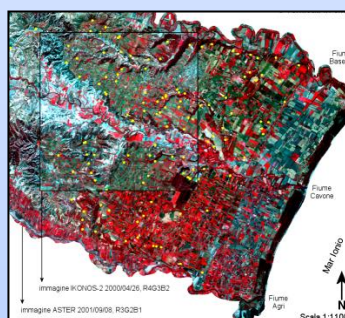
### Contacts:

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Katia Fontanelli ([katiafontanelli@gmail.com](mailto:katiafontanelli@gmail.com))  
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## Detection of archaeological sites through remote sensing information

Within the realm of landscape archaeology, it is commonly accepted that the spatial distribution of sites is largely dependent on a wide spectrum of environmental features. Hence, during the past years, predictive models based on environmental parameters have been increasingly applied in investigations attempting to both *explain* the location of sites already known, and *predict* where new sites are most likely to occur.

A deductive predictive method, based on an expert and heuristic approach and built on the basis of the past experiences of the authors, was developed at IFAC-CNR. It is based on morphological, pedological and hydrological parameters previously identified as being the most significant ones in describing the basic environmental context. The model was then used to predict the location of unknown archaeological sites in the study area, located in the region of Lucania (southern Italy). As a result 164 locations were identified as being suitable for human occupation. A few extensive field surveys were then carried out within the study area in order to verify the presence of the predicted sites. The surveys positively ascertained the presence of 133 new sites with different typologies and ranging in origin from the Palaeolithic Age to the Roman Age. The prediction also led to 31 failures, with an overall accuracy of approximately 81%



Map of archaeological sites identified and verified



Findings of Lucan Age



Archaeological findings : Greek classic Age (left); Middle Paleolithic Age (right)

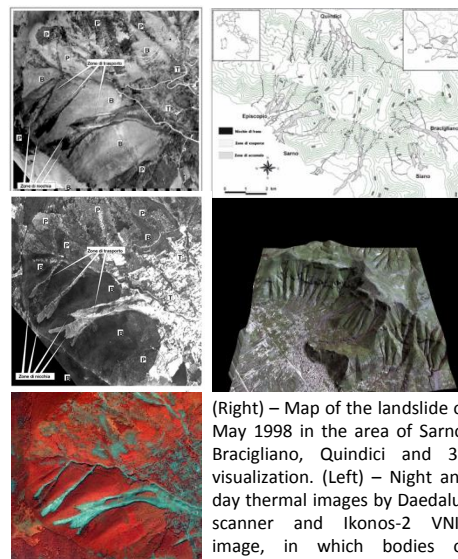
### With regards to enterprises

The research was undertaken and funded under projects of the National Council of Research of Italy

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## Remote sensing techniques for landslide analysis

Because of its geological-geomorphological history and climatic characteristics, the Italian territory is subject to natural disasters (earthquakes, floods, landslides, volcanic eruptions, avalanches, etc.) with a very high recurrence. To date, multispectral remote sensing satellite images with very high spatial resolution (VHR), even stereoscopic, are employed for the study and mapping of landslides mainly through traditional techniques of photo-interpretation. Preprocessing techniques, data fusion methods to improve the spatial detail, and stereoscopic tools are also widely used. Despite this, the full exploitation of the potentials of satellite remote sensing for the study and characterization of landslide phenomena, to date, does not seem to have yet reached a level of maturity, at least for the multiplicity of its objectives: identification, control or verification and monitoring. According to the considerations above, at IFAC-CNR is carried out a research activity aimed at identifying and evaluating innovative remote sensing methods for characterization and analysis of the territory as an aid to the analysis of areas with a high susceptibility to landslides. Such methods aim to integrate the traditional techniques (field observations, aerial photographs, ancillary data) and new tools for managing and processing data (GIS), together with the information extracted from imagery acquired by satellite and sensors of last generation, characterized by high radiometric, spectral, spatial and temporal properties.



(Right) – Map of the landslide of May 1998 in the area of Sarno, Bracigliano, Quindici and 3D visualization. (Left) – Night and day thermal images by Daedalus scanner and Ikonos-2 VNIR image, in which bodies of landslide, niche and channels areas are clearly recognizable.

### With regards to enterprises

Research developed in the framework of projects funded by Agenzia Spaziale Italiana ASI and under contract with C.G.S. enterprise.

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## Spectrally- and temporally-resolved fluorescence LIDAR technology

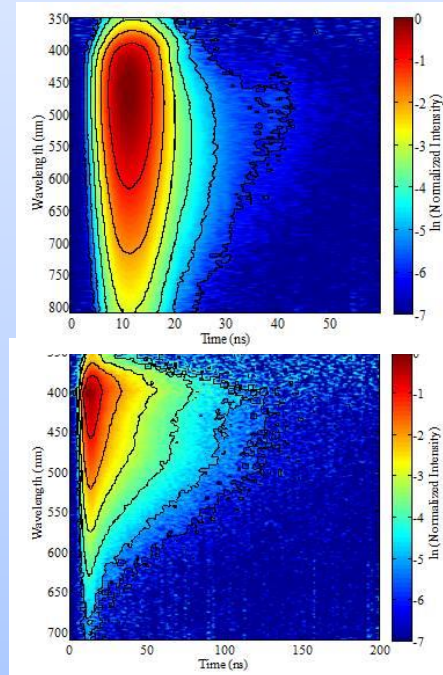
The fluorescence LIDAR is a remote sensing instrument that permits to investigate the laser-induced fluorescence properties of a target from a distance. A pulsed UV laser beam is sent to the target: the radiation interacts with the target's constituents and the emitted fluorescence is collected by a telescope and sent to a suitable dispersion and detection system, usually a multi-channel detector. The acquired fluorescence spectra contain valuable information about the chemo-physical properties of the target.

The technique is widely applied for the investigation of the marine environment (pollutants like hydrocarbons, colored dissolved organic matter, phytoplankton, etc.), agro-forestry studies and for assessing the health status of vegetation since the red fluorescence of chlorophyll *a* is closely linked to the photosynthetic process.

The fluorescence data can be additionally resolved in the time domain in order to measure the fluorescence lifetime and to get additional information on the different compounds that constitute the target.

### With regards to enterprises...

The fluorescence LIDAR has been already used within projects in close collaboration with Italian enterprises (e.g. FlyBY srl). It can be useful both for the characterisation of samples in the laboratory and for in-field deployment aimed at environmental studies.



Wavelength-time fluorescence LIDAR diagrams of crude oil (above) and marine diesel (below).

### Contact:

Valentina Raimondi ([v.raimondi@ifac.cnr.it](mailto:v.raimondi@ifac.cnr.it))





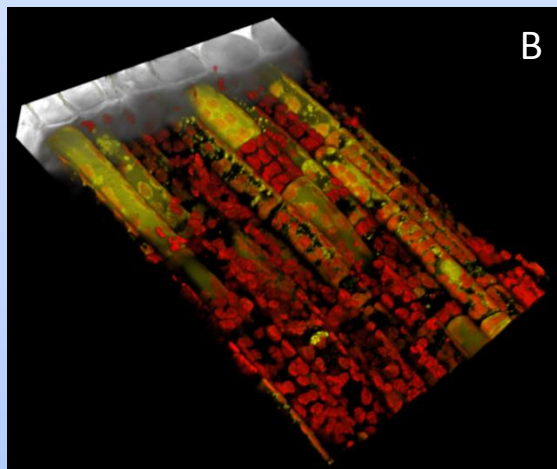
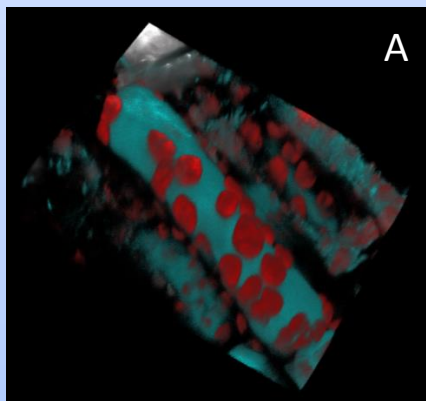
**ENVIRONMENT  
and  
FOOD QUALITY MONITORING**



### Fluorescence micro-localization of polyphenols in plant tissues

Multispectral fluorescence microimaging and microspectrofluorimetry represent useful tools to localize polyphenolic compounds in plant tissues. UV-excited blue autofluorescence can be used as proxy of hydroxycinnamic acids, while flavonoids can be detected as yellow fluorescence under blue excitation, once treated the sample with a specific fluorescence enhancer.

The information obtained are fundamental in eco-physiology studies to elucidate and understand the multifunctional role covered by these compounds in plants under different environmental conditions.



Multispectral fluorescence confocal 3D microimaging of a *Phyllirea latifolia* leaf cross section (adaxial tissues) as recombination of hydroxycinnamic acid (light blue) (A), flavonoid (yellow (B) and chlorophyll (red) (A and B) fluorescence images.

**Contacts:** G. Agati (g.agati@ifac.cnr.it)

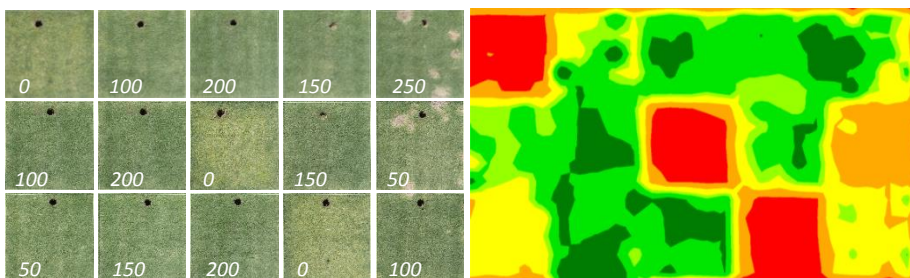
### Fluorescence as a Tool for Smart Agriculture

Non-destructive mapping of anthocyanins in the vineyard by using a fluorescence optical sensor, based on the detection of grape berry chlorophyll fluorescence more or less absorbed by pigments present on the berry external layers.

This technique allows for vineyard zoning to perform a selective harvest and consequently a separated vinification to produce high quality wines.



Fluorescence-based mapping of the leaf nitrogen content (increasing from the red to the green) for a precise sustainable control of fertilization.



Turfgrass (*Paspalum vaginatum*) under different nitrogen ( $\text{kg ha}^{-1}$ ) treatments.



Cabbage (*Brassica oleracea*).

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## LIF and LIDAR techniques for vegetation monitoring

Fluorescence is widely recognized as a powerful tool to investigate both photosynthetic activity and stress status in vegetation.

IFAC has a well-established know-how for the design and development of fluorescence-based instrumentation and methods to study vegetation, such as: portable optical fiber-coupled fluorospectrometers, suitable for leaf level studies, but also remote sensing instrumentation (fluorescence LIDAR) that can be used in the field for leaf and canopy level studies in standoff configuration.

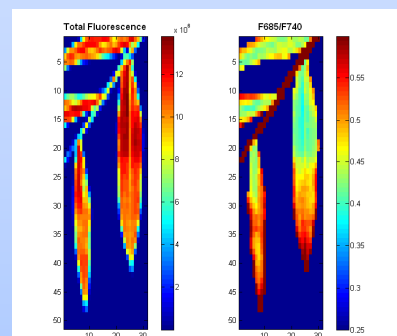
Solar-induced fluorescence of vegetation, and relevant algorithms for its retrieval from the infilling of the O<sub>2</sub>-A and O<sub>2</sub>-B Fraunhofer lines, has been also studied in view of global scale spaceborne monitoring of vegetation photosynthetic activity (ESA-FLEX candidate mission). In this frame IFAC has taken part in several ESA-funded measurement campaigns on vegetation deploying its instrumentation to provide fluorescence data relevant for the assessment of vegetation status.

### With regards to enterprises...

Fluorescence lidar instrumentation can be useful for agro-forestry applications such as: crop monitoring, precision farming, eco-physiological studies, etc..

Optical-coupled LIF instrumentation can be also used to acquire measurements in the field for diverse applications related to environmental monitoring (e.g. fluorescent pollutants in waters, plants, lichens, etc.).

Possibility to develop dedicated prototypes for similar applications requiring in-field deployment of very compact instrumentation.



Movable mirror for the fluorescence LIDAR mapping of corn crops (above) and LIF mapping of corn leaves (below).

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## Photonic Tasting of Food



Quality and safety inspection of intact food by means of absorption, fluorescence and Raman spectroscopies and multivariate data processing. The food is analyzed *as it is*, simply using a light beam, with these advantages:

- it is a *green* analytical approach, reagent-free and environmental-friendly
- multi-component analysis, non-destructive, real-time, and no-contact operation
- the same technology can be used along the entire supply chain, that is, *from-farm-to-fork*



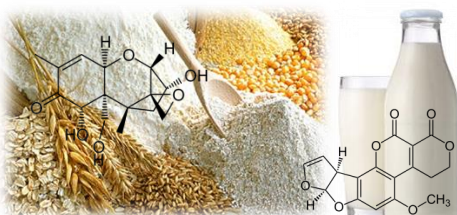
Extra virgin olive oil: detection of geographic region of production, nutraceutical indicators (fatty acids, polyphenols), and fakes by lower quality oils



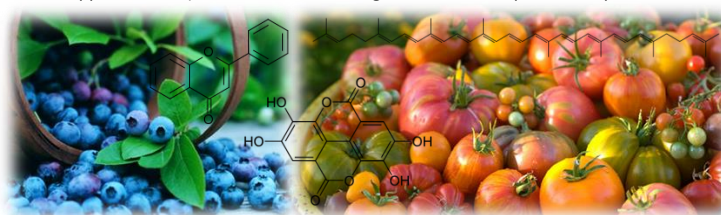
Beer: detection of alcoholic content during brewing process, identification of beer characteristics (Ale, Lager, Lambic, Doppelbock .....), and distinction of Belgian beers



Honey: distinction of botanic origin, detection of sugar profile and pollutants



Cereals: detection of mycotoxins and aflatoxins  
Milk: detection of aflatoxin M1



Fruits & vegetables: quantification of nutritional and nutraceutical indicators (sugars, carbohydrates, polyphenols, anthocyanins, lycopene, antioxidants .....)

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### Thermal IR techniques for environmental monitoring

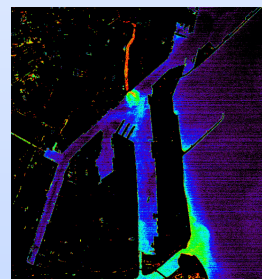
Thermal emission is the part of radiation emitted by a body as a function of its temperature. The acquisition of ground emitted radiation in Thermal Infra Red (TIR) bands (7 – 13 μm) reveals temperature differences in the observed surface and allows monitoring of their anthropogenic or natural causes.

TIR techniques represent an useful tool for temperature monitoring of inland and coastal waters, allowing applications in climatological studies, meteorological models, pollution monitoring and temperature anomalies such as waste disposal or ship wakes. IFAC has performed aerial acquisitions in TIR bands using MIVIS sensor onboard of a CASA 212 aircraft of Compagnia Generale Ripresearee (CGR).

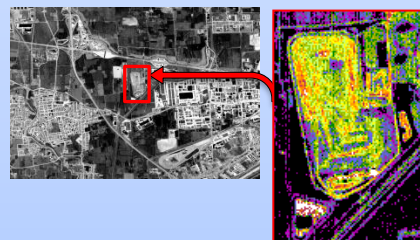
IFAC has also developed algorithms (Grey body emissivity, MaxEnTES) for the simultaneous determination of both the emissivity spectrum and the temperature of the observed surface.

#### With regards to enterprises

IFAC has performed aerial acquisitions in TIR bands using MIVIS sensor onboard of a CASA 212 aircraft of Compagnia Generale Ripresearee (CGR) in the frame of regional projects in the period between 2000 and 2005.



False color TIR image of Livorno harbour: in red a discharge channel to sea.



Grey scale thermal infrared (TIR) image acquired by MIVIS near Florence and false-colour of the discharge zone showing areas with different temperatures.

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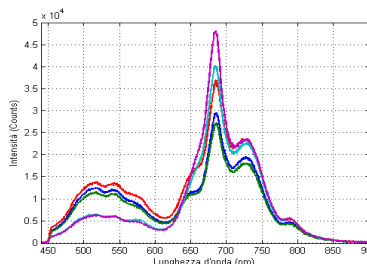
### LIF technology for in situ measurements in extreme environments

The LIF spectroscopy is a versatile technique widely used in various scientific fields and for diverse applications. One of the advantages of the technique is to be suitable for the development of very compact instrumentation to be used in the field. We developed at IFAC a specific expertise in the design and prototyping of extremely compact and portable Laser Induced Fluorescence (LIF) instrumentation to make measurements in the field, even in particularly harsh environmental conditions (e.g. Antarctica).

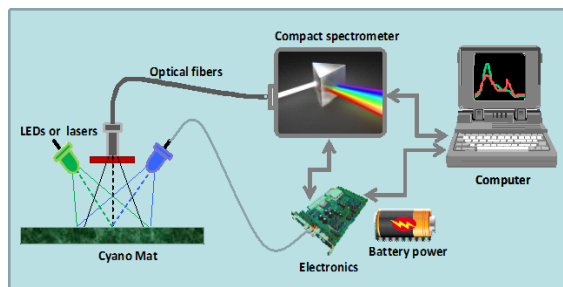
The prototype, specifically developed for acquiring measurements of Arctic and Antarctic terrestrial cyanobacterial crusts, uses a diode laser emitting in the UV to excite the fluorescence in the visible spectral region. The system is battery-powered and can be transported inside a backpack.

#### With regards to enterprises...

The instrument can be used to acquire LIF measurements in the field for diverse applications related to environmental monitoring (e.g. Fluorescent pollutants, plants, lichens, etc.). Possibility to develop dedicated prototypes for similar applications requiring in-field deployment of very compact instrumentation.



LIF spectra and micro-LIF image of terrestrial microorganisms.



Portable spectrofluorimeter: principle of operation.

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# CULTURAL HERITAGE



## Hyperspectral fluorescence LIDAR imager for cultural heritage

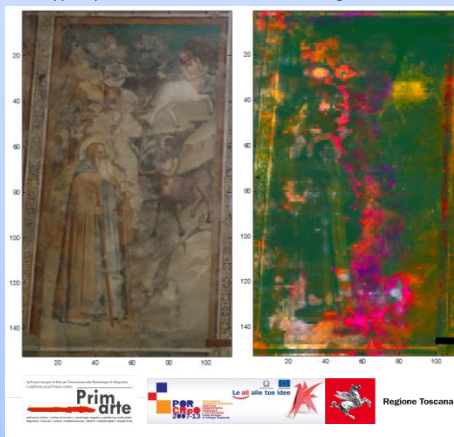
The fluorescence LIDAR technique - thanks to the use of an UV pulsed laser as an excitation source - makes it possible to carry out remote Laser-Induced Fluorescence (LIF) spectroscopy in the outdoor. The IFAC prototype, in-house developed at IFAC in collaboration with El.En. S.p.A., is able to provide hyperspectral (more than 500 channels) fluorescence images of the investigated surface from a distance of several tens of meters, e.g. the façade of an outdoor monument or a wall painting. The fluorescence data acquired using the fluorescence LIDAR can be also resolved in the time domain in order to measure the fluorescence lifetime and get additional information on the different compounds that constitute the examined surface. The fluorescence data are processed to generate thematic maps, which provide useful information to restorers and conservators for the detection and characterisation of biodeteriogens, of protective treatments, different lithotypes and, more generally, for the identification of materials in terms of their fluorescence spectral signatures and fluorescence lifetime.

### With regards to enterprises...

The fluorescence LIDAR has been developed specifically for applications to the field of the cultural heritage in collaboration with El.En. S.p.A.. The prototype has been used to carry out fluorescence measurements in the frame of several international and national projects (Casa di Augusto, TDT-bioart, PRIMARTE) in close collaboration with several Italian SMEs (Laboratori ARCHA srl, Elab Scientific srl, Faberestaurio snc, Nike restauro snc, ART-Test sas, Culturanuova srl, SOING Struttura e Ambiente srl).



The hyperspectral fluorescence LIDAR imager.



Hyperspectral fluorescence image of a mural painting.

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## UV-Vis-IR Applied Spectroscopy IFAC-CNR Laboratory



Fig. 1. micro FT-IR spectrophotometer.

The FT-IR spectrophotometer Nicolet Nexus 470 E.S.P.™, equipped with Continuum microscope (Fig. 1), enables to acquire IR spectra in transmittance, reflectance and ATR on extremely small areas of a sample under investigation. The use of the microscope makes it possible to collect IR data from 10 μm x 10 μm spots. In addition, micro-pellets die as well as Total Reflectance and Diffuse Reflectance accessories are available for the Nexus 470 spectrophotometer.

Three UV-Vis-NIR Perkin-Elmer double-beam and double-monochromator spectrophotometers are present at IFAC-CNR laboratory. They are equipped with an internal 60-mm integrating sphere (200-2500 nm range) and an external sphere (200-2500 nm range, Fig. 2) linked to the bench by optical fibers bundle. This configuration allows to analyse large objects placed near the instrument.



Fig. 2. Perkin Elmer Lambda 900 Spectrophotometer equipped with the external integrating sphere.



Fig. 3. Horiba FluoroMax-2 spectrofluorimeter.

The laboratory has a 2-D Horiba FluoroMax-2 spectrofluorimeter (Fig. 3). It can be used in diverse configurations to analyse liquid and solid samples. It is also equipped with a fiber optic bundle to perform measurements outside the sample-compartment of the spectrofluorimeter.

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## Microwave monitoring of frescoes and mural paintings

Moisture and soluble salts are the main causes of degradation of mural paintings, in particular, frescoes. Water is the 'driving force' of damage such as the detachment of the painted layer and the whitening of the painting due to the crystallization of salts. The patented (USA, UE, Italy) SUSI system, based on evanescent-field dielectrometry, measures the sub-superficial moisture content and detects the presence of salts as a consequence of the dielectric contrast between water and dry materials.



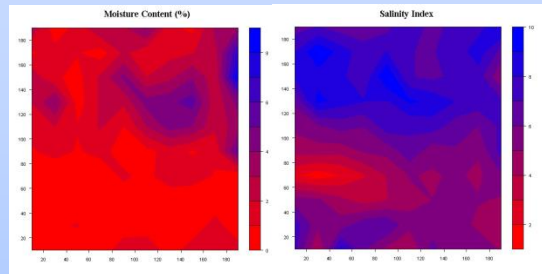
The SUSI® system detects moisture and soluble salts



SUSI diagnostics on a fresco painting

SUSI is applied for diagnostics and seasonal monitoring of walls of artistic interest and for studying the dynamics of water diffusion. The low-weight of the instrument allows an easy portability also in "difficult" environments such as on scaffolds.

Maps of moisture content and salinity help to understand the health conditions of a fresco.



Moisture content and salinity maps obtained by SUSI

### With regards to enterprises...

A spin-off company of CNR, Elab Scientific srl, has been founded based on the activities of microwave diagnostics.

Recent common research projects involving IFAC and Elab Scientific:

- PRIMARTE (2012-2015), Tuscany Region, Bando Unico R&S 2012
- TDT-BioArt (2009-2011) Tuscany Region, POR FESR 2007-2013
- RIMIDIA (2009-2011) Tuscany Region, POR FESR 2007-2013
- TEMART (2009-2011) Tuscany Region, POR FESR 2007-2013

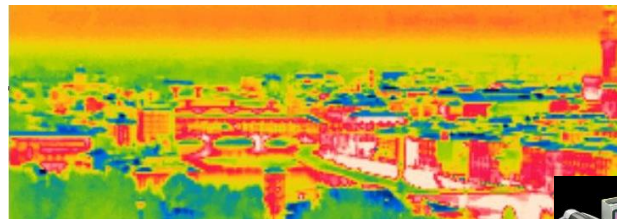
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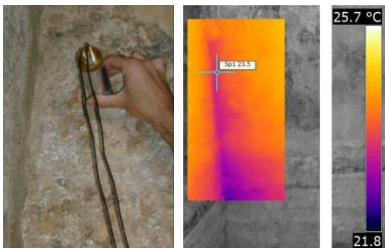
## Thermal infrared investigations in Cultural Heritage

The study of the temperature distribution obtained by means of an IR thermocamera gives information on:

- Rising damp in walls
- Water infiltration from roofs or windows
- Thermal bridges
- Detachments and other anomalies
- Sub-superficial texture of walls
- Energy efficiency of buildings



Florence landscape in the infrared



Using SUSI (left) for calibrating thermography (right)

By integrating thermography with techniques for the absolute measurement of moisture content MC (e.g. by SUSI, a microwave dielectrometry system developed by IFAC), a real quantitative investigation of the MC distribution is now possible.

### With regards to enterprises...

A spin-off company of CNR, Elab Scientific srl, has been founded based on the activities of microwave diagnostics and thermography.

Recent common research projects involving IFAC and Elab Scientific:

- PRIMARTE (2012-2015), Tuscany Region, Bando Unico R&S 2012
- TDT-BioArt (2009-2011) Tuscany Region, POR FESR 2007-2013
- RIMIDIA (2009-2011) Tuscany Region, POR FESR 2007-2013
- TEMART (2009-2011) Tuscany Region, POR FESR 2007-2013

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Saverio Priori ([s.priori@ifac.cnr.it](mailto:s.priori@ifac.cnr.it))



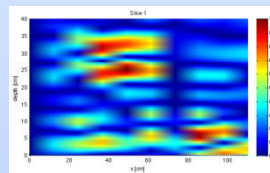
## RADAR and time domain reflectometry on architectural structures

RADAR-based instrumentation and methods are studied for diagnosing the structural integrity of wooden beams and other architectural structures.

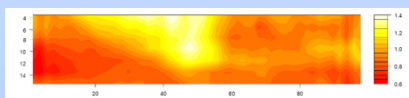
Systems operating at several microwave frequencies (1-6 GHz, 10GHz, 24 GHz) are developed, and algorithms for exploiting the multi-frequency and time-domain characteristics of the signal are studied and implemented.



Experimental X-band SFCW radar



Section of a tie beam (left) and tomographic image obtained by the microwave scanning along its longitudinal axis (right). Stationary phase-image of the beam section (below)



Wide-band microwave reflectometer

### With regards to enterprises...

A spin-off company of CNR, Elab Scientific srl, has been founded based on the activities of microwave diagnostics.

Recent common research projects involving IFAC and Elab Scientific:

- PRIMARTE (2012-2015), Tuscany Region, Bando Unico R&S 2012
- TDT-BioArt (2009-2011) Tuscany Region, POR FESR 2007-2013
- RIMIDIA (2009-2011) Tuscany Region, POR FESR 2007-2013
- TEMART (2009 2011) Tuscany Region, POR FESR 2007 2013

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## Alpha Bruker Optics Spectrophotometer for non-invasive in situ investigation of artworks

At IFAC-CNR laboratories a portable Alpha Bruker Optics FT-IR Spectrophotometer has been available since 2012. It allows to acquire spectra in Total Reflectance mode in a completely non invasive way in the 7500-375  $\text{cm}^{-1}$  range, thus covering the whole MIR and part of the NIR regions with a maximum resolution of  $2\text{cm}^{-1}$ . It can provide information on inorganic and organic materials, such as pigments, dyes, binding media, and fillers that constitute painting without any need of sampling. It was successfully employed in the study of traditional artworks, such as wall paintings (fig.1), panel and canvas paintings, and artworks of different supports. In addition, it was also successfully used on modern and contemporary artworks (fig.2) allowing the identification of many unconventional materials used by contemporary artists.



Fig. 2. Measurements on *La caverna dell'antimateria* by Pinot Gallizio at the Pecci Centre for Contemporary Art.

Furthermore, the compact design of the spectrophotometer makes it possible to work in situ and/or unfavorable situations (fig.2). The spectrophotometer can be used with different plug and play modules for collecting spectra in transmittance and Attenuated Total Reflectance (ATR) modes (fig.3).

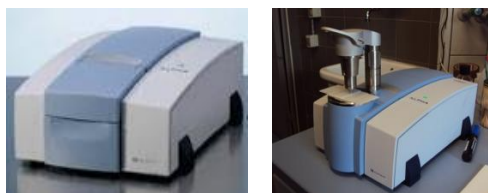


Fig. 3. Alpha Bruker Optics Spectrophotometer mounting Transmittance module (on the left) and ATR Module (on the right).



Fig. 1. Alpha Bruker Optics FT-IR Spectrophotometer at the San Marco Museum, Florence.

### With regards to enterprises ...

We can acquire spectra in laboratory and on site as well as process and interpret the collected data. We can support users in finding and defining their spectrophotometer configurations to fit their specific needs.

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## A prototype of Vis-NIR hyper-spectral scanner for non-invasive investigation on artworks

IFAC-CNR laboratories a new prototype of a high-performance hyper-spectral scanner operating in the 400 - 1700 nm range has been recently assembled (Fig. 1). The extension of the sensitivity up to 1700 nm improves the capability of materials identification as well as the possibility of revealing hidden features. The system operates with both high spatial and spectral sampling rates, thus providing data with a spectral resolution of about 2.5 nm in the Vis and 8 nm in NIR range, and high-resolution images (about 300 ppi). This technique consists on the acquisition of series of reflectographic images at different wavelengths by capturing sequences of quasi-monochromatic images, registered on almost contiguous narrow spectral bands.

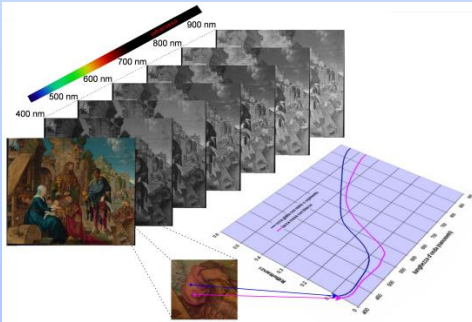


Fig. 2. From hyper-spectral data-set a sequence of quasi-monochromatic images and a collection of highly resolved reflectance spectra can be extracted.

The data-set acquired, named file-cube, contains both spatial and spectral information (Fig. 2). From each pixel of the imaged area it is possible to extract highly resolved reflectance spectra. Elaborated images and maps may be obtained by using statistical methods of data analysis. High spatial resolution is crucial to provide high-quality images usable for documentation and archiving. High spectral resolution is essential for discrimination and identification of pictorial materials.

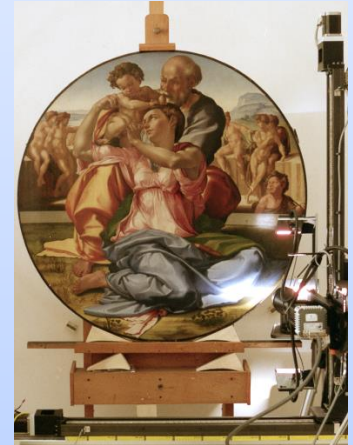


Fig. 1. IFAC-CNR hyper-spectral scanner at the Uffizi Gallery, Florence.

### With regards to enterprises ...

We can offer our hands-on in designing spectral imaging systems and hyper-spectral data processing and interpretation for specific application on artworks.

### Contacts:

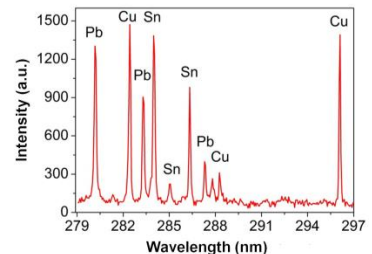
Marcello Piccolo ([m.piccolo@ifac.cnr.it](mailto:m.piccolo@ifac.cnr.it)),  
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## Portable laser induced plasma spectroscopy and authentication

A novel compact LIPS device has been developed, which provides real time measurements of the elemental depth profiles of the outer material layers of any object, at a pulse repetition rate of 3 Hz. This analytical instrument has been carefully calibrated for characterizing copper, silver, and gold alloys and then used for investigating a variety of knowledge and conservation problems of metal artefacts of cultural interest. Important compositional studies have been carried out on unique masterpieces such as Donatello's David and Pulpito della Resurrezione, Rustici's Predica del Battista, Danti's Decollazione del Battista, the Arringatore from the Tasimene, the Chimera from Arezzo, and other. Furthermore, the device has been successfully used for the first time in authentication studies of metal artefacts through the development of a novel analytical methodology, which allows discriminating between natural alteration phenomenologies and fraudulent patinations. The technique, which is based on comparative analyses of elemental depth profiles, is being applied in an overall authentication study of small bronzes, jewels, and coins from Florence's National Museum of Archaeology and Egyptian Museum, which belong to the antiquary collections of the Houses of Medici and Lorraine. Recently, this approach has been used for authenticating the "Ombra della Sera" the famous bronze figurine of the Museum Guarnacci of Volterra. The present analytical tool has also a significant application potential in material characterisations of industrial interest.

### With regards to enterprises...

We are exploring potential collaborations with industrial partners. At the same time, the LIPS device is extensively used in characterisation services to conservation institutions and restoration enterprises.



LIPS head (about 25×10 × 10cm) and a detail of a typical elemental spectrum of a copper alloy.

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## Laser techniques for conservation of cultural heritage

Significant contributions to the development and application of the laser treatments in conservation of cultural heritage have been provided since the beginning of nineties. Dedicated laser systems and suitable methodologies for addressing a variety of conservation problems have been developed, which were validated on a number of unique masterpieces. In some details, a novel approach to the typical ablation problems encountered in the restoration of stone, metal, and painted artefacts has been demonstrated, which is based on the optimisation of the laser pulse duration. The laser prototypes developed according to this general criterion have been engineered and then marketed by El.En. S.p.A., Calenzano, Italy. At the same time, several conservation problems concerning important artworks have been successfully addressed, thus validating novel operative protocols and promoting the methodological transfer to institutional laboratories and restoration enterprises. Thus for examples, successful applications were achieved on the facades of the Palazzo Rucellai (Firenze) and Mausoleum of Theodoric (Ravenna), I. della Quercia's Fonte Gaia, Ghiberti's Porta del Paradiso, Porta Nord, and San Matteo, N. di Banco's Santi Quattro Coronati and Assunta, Donatello's Attis and David, the Arringatore, the wall paintings of S. Maria della Scala (Siena), Castello di Quart (Aosta), catacombs of Santa Tecla and Domitilla (Roma), and other. Significant efforts have also been dedicated to the tutoring and dissemination activities.



Application examples of optimized laser treatments: a) plasterwork of the Loggia della Mercanzia (Siena); b) painted arcosolium in the cubicle "dei fornai", catacombs of Domitilla (Roma).

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### With regards to enterprises...

A laser system allowing to select the pulse duration between  $\sim 0.1$ - $1 \mu\text{m}$  has been patented: "Apparatus for the generation of variable duration laser pulses", by R. Pini, R. Salimbeni, S. Siano (PCT/IT2001/000612, US6842474 B2). Related collaborations have been established with El.En. S.p.A, a number of restoration enterprises and conservation institutions.

## UV, Vis, NIR fibre optic reflectance spectroscopy for analysing artworks

Fibre optic reflectance spectroscopy (FORS) in the ultraviolet (UV), visible (Vis) and near infrared (NIR) spectral regions is a non-invasive methodology useful for analysing works of art. In this spectral range (UV-Vis-NIR), electronic and vibrational transitions can be observed. The spectrum in the Vis range is the basis of colorimetric analysis that is exploitable to assess chromatic alterations (discoloration, yellowing, darkening, etc.) due to the ageing processes. FORS is primarily used to identify pigments and dyes, evaluate colour and colour changes, and to detect alteration in products.

FORS is based on the use of portable spectrophotometers equipped with optical fibres accessories. Thanks to the flexibility of optical fibres, any point of the object can be easily measured, without any constraints due to size or shape of the artwork.

Two Zeiss spectroanalysers, MCS 601 (190-1015 nm range) and MCS 611 NIR 2.2 WR (910-2200 nm range) models, are housed together in a compact and portable chassis, ideal for in situ analyses (fig. 1). The radiation is provided by a voltage-stabilized 20W halogen lamp (mod. CLH600). The radiation is sent to and collected from the investigated area by means of quartz optical fiber bundles.

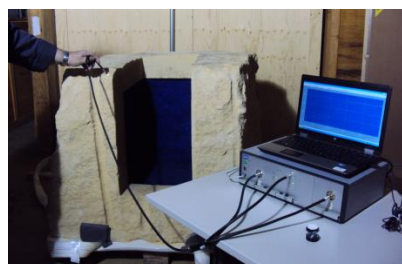


Fig. 2. FORS measurements on *Here and There* by Anish Kapoor at the Pecci Centre for Contemporary Art, Prato.

Beside applications on historical objects, FORS is also used on the analysis of modern and contemporary artworks (Fig. 2). It is a very useful tool, in conjunction with other techniques (XRF, FT-IR, Raman, etc.) for locating areas for micro-sampling, or in extending local data from micro-analyses to a broader scale, thus reducing the extent of micro-sampling.



Fig. 1. FORS device during a diagnostic campaign on the painting *Santo Stefano fra i Santi Jacopo e Pietro* by Domenico Ghirlandaio, Galleria dell'Accademia, Florence

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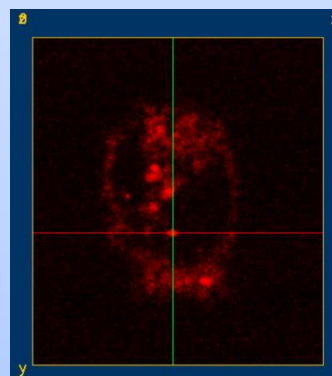
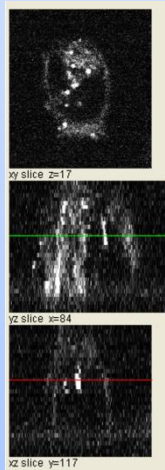
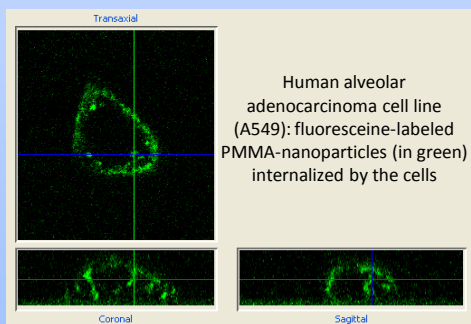
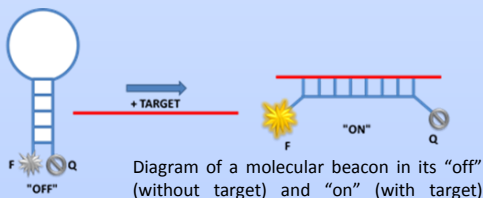


# HEALTH, NANOMEDICINE and SAFETY



### Intracellular optical nanosensing

The advent of optical nanoprobe for the quantitative determination of bioanalytes at the intracellular level is one of the most fascinating achievements in the field of nanoparticle and nanomaterial technology. Among this, oligonucleotide optical switches can work not only as nanoprobe but also as drugs capable to address specific RNA messengers thus preventing the overexpression of proteins associated with pathologic diseases. We focused our research on the use of carbon nanotubes (CNTs) and polymethylmethacrylate (PMMA) nanoparticles as intracellular nanocarriers for molecular beacons (MBs), selected fluorescent DNA probes as well as for the detection and localization of specific mRNAs. Survivin mRNA targeting MBs have been used with Atto647N and Blackberry 650 as fluorophore/quencher pair. The MB was anchored to the surface of CNTs and PMMA nanoparticles and the as obtained nano-composites were characterized in vitro.



Human alveolar adenocarcinoma cell line (A549): molecular beacon (in red) delivered into the cells by using PMMA nanoparticles as intracellular carrier

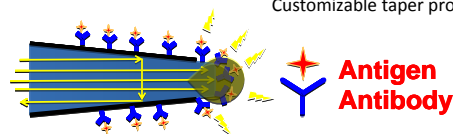
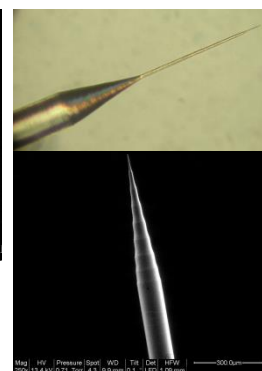
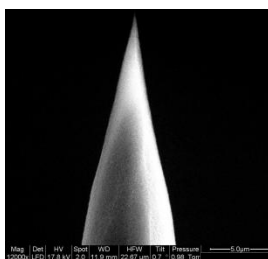
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### Silica nanotips for intracellular sensing

Detailed comprehension of cellular physiology is fundamental for the assessment of the interaction between cells and environmental pollutants or drugs, whose efficacy could therefore be better optimised and tailored.

Fibre nanotips can act as a flexible platform for intracellular applications: being able to guide excitation light inside the cells, they can probe single cells without inducing morphological damage or perturbing their physiological equilibrium, while their functionalised surface can act as high spatial resolution sensor.

We have developed a technology to produce nanometric sized (down to 40 nm) silica tips from optical fibres by chemical etching (patent pending) and to effectively functionalise their surface for selective response to particular biomolecules.



Tip surface functionalisation and antigen-antibody selective reaction

The **international patent** "Method of Fabricating Structures, Starting from Material Rods" has been deposited and is **pending**.

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 Stefano Pelli, Andrea Barucci, Franco Cosi, Giancarlo Righini, Francesco Baldini, Ambra Giannetti, Cosimo Trono, Sara Tombelli

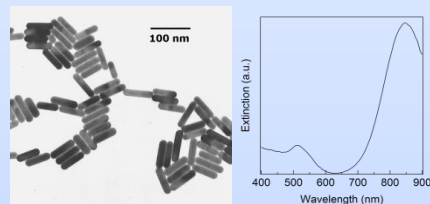
## Laser-assisted nanomedicine for tumor theranostics

The combination of pulsed and CW near-infrared laser light with plasmonic particles such as gold nanorods is gaining relevance for the photoacoustic imaging and photothermal ablation of cancer. Selective targeting of malignant cells with these contrast agents may rely on complementary biochemical and biological strategies, including the use of specific probes or the exploitation of cellular vehicles.

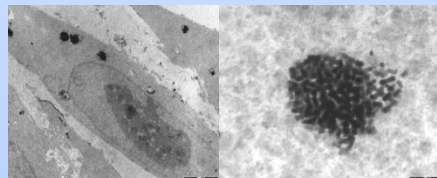
We have developed a platform of PEGylated gold nanorods with plasmonic bands around 800 nm, good biological profiles, stability and efficiency of photoacoustic and photothermal conversion as well as potential to passively accumulate into solid tumors by their enhanced permeability and retention. In order to enhance this potential, we are drawing advantage and inspiration from biological processes to modify these particles for active delivery. Examples include: (i) the conjugation with antibodies against cancer antigen 125 (CA125), which is a common biomarker for ovarian lesions; (ii) the termination with inhibitors of carbonic anhydrases 9 and 12 (CAIX and CAXII), which are expressed by hypoxic cells such as those found in the core of solid tumors; and (iii) by introducing macrophages as a versatile model of cellular vehicles that would phagocytose the particles and home to inflammatory lesions.

### With regards to enterprises...

These activities are being developed in collaboration with academic and corporate partners. The IP on the use of inhibitors of carbonic anhydrases in this context is owned by CNR. We can offer expertise in the design and development of any aspect of these activities.



Gold nanorods with optical absorption bands around 850 nm



Phagocytosis of targeted gold nanorods in cultured cancer cells

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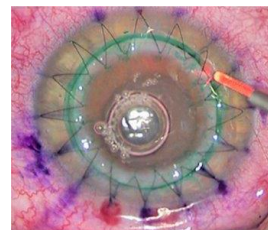
## Laser-assisted repair of biological tissues

We proposed new methods of laser-assisted repair of biological tissues (patented) to replace conventional suturing, based on laser induced activation of the endogenous collagen, which behaves like a thermally activated glue. Our method received the approval of the Italian Health Ministry to perform both pre-clinical and clinical experimentations in Ophthalmology and pre-clinical experimentations in brain microsurgery.

A recent optimization consisted in the introduction of new light-responsive hybrid bioadhesives for tissue repair that can be precisely bonded to a biological tissue by photothermal activation. These are easily-handly and resorbable medical dressings that are embedded with laser-activatable organic chromophores or nanochromophores. Laser illumination of the chromophores triggers a strong adhesion between the bioadhesive and the tissue.

### With regards to enterprises...

This laser-assisted procedure has been developed in collaboration with regional enterprises and hospitals, in the framework of several regional projects (OPTOMED Innovative Technology in Ophthalmology; OPTOWELD Development of ocular tissues laser induced suturing techniques; SALTO Innovative Technology for Laser Surgery of Ocular Tissues; MILORDS Minimally Invasive Laser Operations by Robots in Diagnosis/Surgery), and european projects (Bi-TRE, Biophotonics Plus)



Laser-induced suturing of the cornea during corneal transplant



Repair of a coronary artery in rabbits with a laser-activated biopolymeric film

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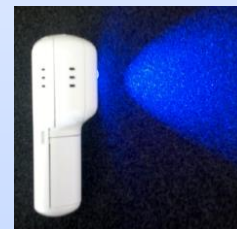
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## LED technologies for photocoagulation of abrasions and wound healing

We developed new technologies based on the use of high power blue-LEDs to repair abrasions and wounds. Haemostasis of superficial blood vessels is achieved through a photo-thermo-coagulation process, without any collateral damage to surrounding tissue.

We made two layouts of the photohaemostatic device based on LED technology: 1) a "Self-medication" layout, easily handled and ensuring high portability for first-aid situations; 2) a "Fiber" layout, where the LED source is coupled to a hand-held optical fiber, to be adopted in hospital environments by specialized personnel for ophthalmologic, dental and plastic surgery applications.

The main beneficiaries of the photo-haemostatic device are accidentally injured healthy people, as well as people suffering from bleeding disorders.



Miniaturized and engineered photohaemostasis device for self medication

### With regards to enterprises...

The photocoagulator device has been designed and developed in collaboration with the company Light4Tech and with the research center LENS, in the framework of two european projects (Light+ter, Development of a compact, low cost and easy to use device based on LED technology for non-invasive selective haemostasis to benefit the people suffering from coagulation problems; Light Patch, Led Technology in Photo Haemostasis).

The devices is patented: PCT/IB2007/054912, priority data: FI2006A000307, Applicant: Light4Tech Firenze S.r.l., title "LED DEVICE FOR THE HAEMOSTASIS OF BLOOD VESSELS". Authors: Roberto Pini, Francesca Rossi



The photocoagulation device engineered for hospital use

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## Advanced methods in laser biomedical imaging

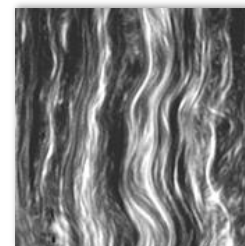
We have developed new non-invasive imaging and diagnostic techniques based on pulsed lasers for applications in biomedicine:

1) Multiphoton microscopy and in particular second harmonic generation (SHG) microscopy, which is a novel tool based on nonlinear light scattering. SHG imaging proves to be ideal to investigate pathological conditions of connective tissue such as the cornea and gain insight into the distribution and conformation of biological macromolecules of clinical relevance (in collaboration with INO and LENS).

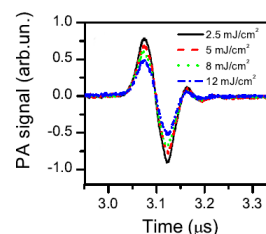
2) Photoacoustic (PA) microscopy and tomography for a variety of biomedical applications, including early detection of cancer (in collaboration with IFC). These methods rely on the analysis of ultrasounds that are generated by the rapid photothermal heating and thermoelastic expansion occurring upon absorption of pulsed light. The combination of optical excitation and acoustic detection allows one to reach far deeper penetration into biological tissue than wholly optical imaging techniques, while maintaining the high contrast and spectroscopic specificity of optical imaging. In this context, we are also testing the use of plasmonic particles as contrast agents to increase the sensitivity and spectroscopic specificity of PA signals.

### With regards to enterprises...

These activities are being developed in collaboration with academic and corporate partners. We can offer expertise in the analysis of SHG signals and the characterization of materials by photoacoustics.



SHG micrograph of collagen fibrils in a porcine cornea



photoacoustic transients induced by laser excitation of a biomimetic phantom embedded with gold nanorods

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## Light-sensitive implantable devices for "on demand" drug release

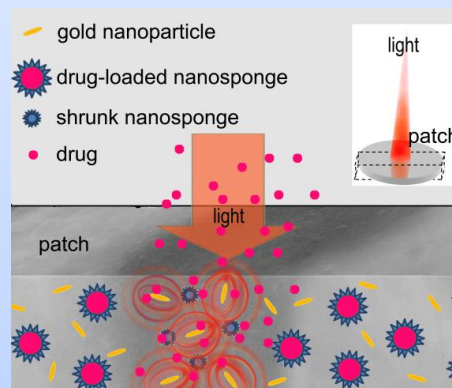
The system consists of a biocompatible film or patch containing a dispersion of gold nanoparticles, which act like light transducers, producing heat upon light stimulation, and of thermosensitive nanosponges, which serve as a reservoir for the drug molecules to be released. The temperature rise generated by the nanoparticles triggers a contraction in proximal nanosponges, thus promoting the expulsion of the drug to the external environment in a very controllable and localized way. The patches can be applied either on the skin or inside the body with high levels of safety and comfort.

The use of these devices may assist in performing advanced and personalized pharmacological therapies, in which the release of precise drug amounts to specific body regions is required.

### With regards to enterprises...

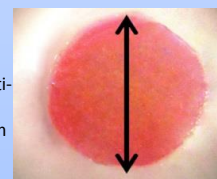
The IP of this invention is owned by CNR, which filed a patent, now under PCT application: "Matrix and device and use thereof for optically controlled release of chemicals", Inventors: P. Matteini, F. Ratto, R. Pini.

We can offer: technological development of the invention, as well as support for studies in vitro, in vivo and at clinical level.



Scheme of the light-sensitive device for controlled drug release

Example of a biocompatible patch for the release of the anti-cancer drug Doxorubicin (1 cm in size)



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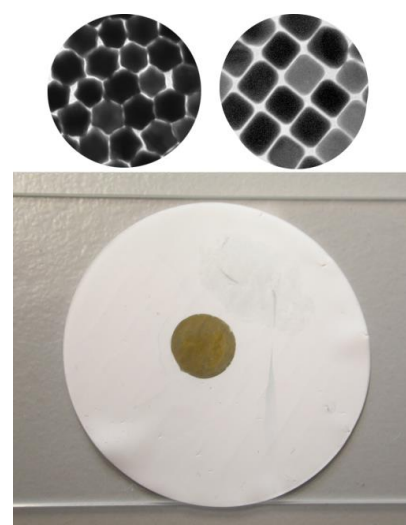
## SERS platform for detecting misfolded proteins

We propose a reliable approach for determining chemical identity and structural information from given aberrant proteins in physiological conditions and in trace concentration. The unique combination of sensitivity, selectivity and spectral multiplexing of Surface Enhanced Raman Scattering (SERS) coupled with the use of novel and powerful signal-enhancing plasmonic substrates represents a valuable option for the effective analysis of aberrant species. These species may include different forms (nontoxic monomeric to toxic oligomeric and protofibrillar forms) of amyloid beta and protein tau proteins, which impair the cognitive function of Alzheimer's disease patients.

In general, the proposed platform can find application in the chemical and structural characterization of biomarkers and early diagnosis of neurodegenerative diseases. Additionally, the SERS detection may eventually offer a valuable support for monitoring the disease progress and the response to new treatments.

### With regards to enterprises...

IFAC-CNR can offer technological development of the SERS platform, including preparation of 2D organized superassemblies made of preformed gold and silver nanocrystals as powerful SERS substrates for effective detection of biomolecules at the nano- to femto-molar scale.



TEM micrographs (up) and appearance (bottom) of 2D organized superassemblies of dodecahedral and cubic gold nanocrystals used for ultrasensitive SERS detection of misfolded proteins.

### Contacts:

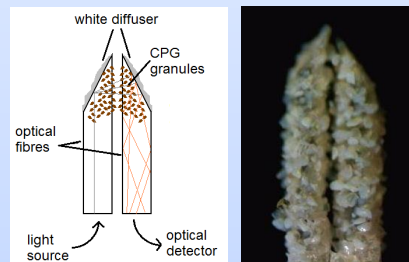
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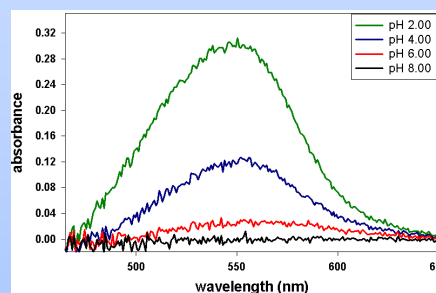
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### Miniaturized optical probe for invasive pH sensing in gastroesophageal apparatus

Monitoring pH for long periods, usually 24 h, in the stomach and in the esophagus may be essential in the diagnosis of gastroesophageal diseases. The clinical range of interest is quite extended, between 1 to 8 pH units. Methyl red, after its covalent immobilization on controlled pore glass (CPG), is characterized by a working range which fits well with the clinical one. A novel probe, suitable for gastro-esophageal applications, was designed in order to optimize the performances of the colored CPG. Two plastic optical fibers (core diameter 250 μm) are used, one connected to the optical source and the other one coupled to a detector. The distal end of each fiber is cut at an angle capable to assure the total reflection of the optical radiation at the fiber tip and the CPG granules with methyl red immobilized on them are fixed on the lateral external surface of the distal end of the plastic fibers. The requirements of the physicians for pH gastric measurements, accuracy of 0.1 pH units and response time 30 seconds, are well satisfied by the realized probe.



Sketch (left) and photo (right) of the novel fiber tip sensor for pH measurement



Absorption spectra vs pH

**With regards to enterprise...**

- Tuscany regional project (POR CREO FESR 2007-2013) with Cecchi srl (Firenze) "Dispositivo per la misura combinata di pH e contenuto biliare nell'apparato gastroesofageo"
- Brev.it FI2010A000237, "Sonda a Fibra Ottica e sensore di misura utilizzando detta sonda", F.Baldini, C.Trono

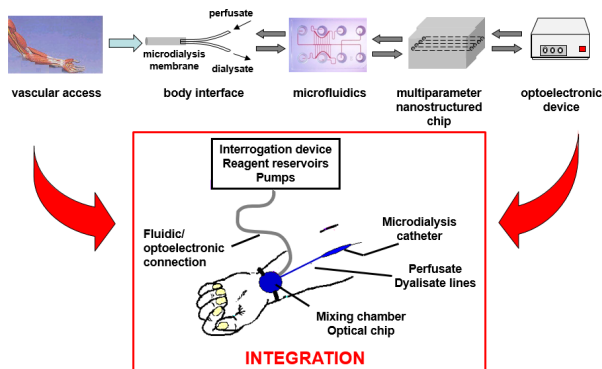
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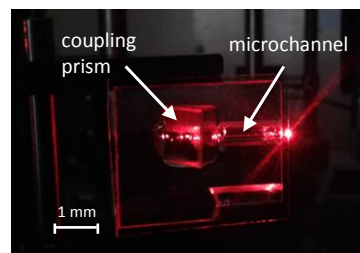
### Novel point-of-care-testing (POCT) device for the immunosuppressant measurement in transplanted patients

In transplanted patients, one of the most critical aspects is the correct dosage of the immunosuppressants, which have the difficult task of avoiding the transplant rejection by means of the partial inhibition of the immune response of the body to the transplanted organ. Standard of practice today is the discrete measurement of the drug plasma level measured just before each dose, generally administered every hour, by use of analytical techniques. Therefore there is a strong demand for a frequent and accurate monitoring of the immunosuppressants, characterized by a narrow therapeutic window, with a POCT device located close to the patient bed. On these bases, a novel therapeutic drug monitoring (TDM) POCT device for the *in-line* and *in-time* immunosuppressants measurement is under development. The transplanted patient will be connected to the device by an intravenous microdialysis catheter to allow 48-h online measurements. Heart of the device is a multi-parametric optical chip, which makes use

of the recent developments in nanotechnology to convert the concentration changes of the analytes in detectable luminescent signals.



Flow diagram of the proposed TDM – POCT device



First prototype of the optical chip with one microchannel illuminated by means of a coupling prism.

**With regards to enterprises....**

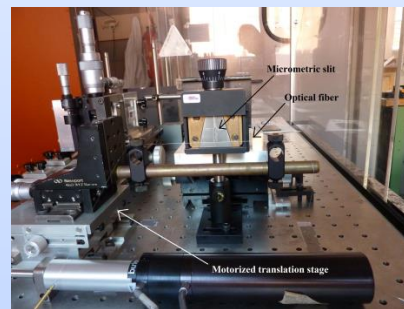
European Project NANODEM -Nanophotonic device for multiple therapeutic drug monitoring (contract 318372)involved companies: Datamed srl (Milano) and Chip & Shop GmbH (Jena, D)

**Contacts:**

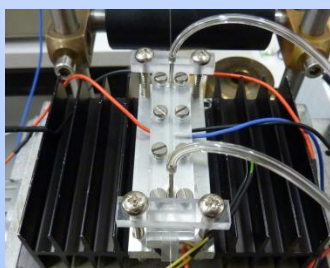
Francesco Baldini ([f.baldini@ifac.cnr.it](mailto:f.baldini@ifac.cnr.it))  
Romeo Bernini ([bernini.r@irea.cnr.it](mailto:bernini.r@irea.cnr.it))

## Optical fibre long period gratings for label free biosensing

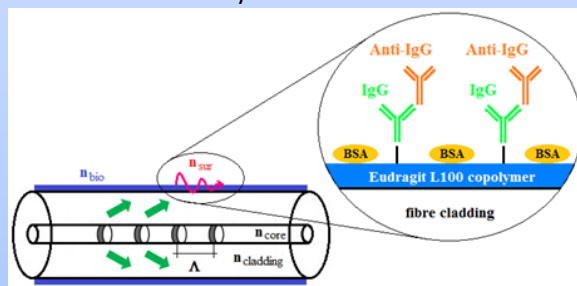
Optical fibre gratings, especially long period gratings, have been recently proposed as optical devices for biochemical sensing. A biochemical interaction along the grating portion induces a refractive index change and hence a change in the fiber transmission spectrum. This provides an alternative methodology with respect to other label-free optical approaches, such as surface plasmon resonance, interferometric configurations and optical resonators. The fibre biofunctionalization has been carried out by means of a novel chemistry using Eudragit L100 copolymer as opposed to the commonly used silanization procedure. Antigen-antibody interaction has been analysed by means of an IgG/anti-IgG bioassay. The biosensor was fully characterised, monitoring the kinetics during the antibody immobilization and the antigen interaction and achieving the calibration curve of the assay.



LPG writing apparatus



Thermostated flow cell for LPG characterization and bioassays development



Sketch of an example of biosensor based on an optical fibre LPG

### With regards to enterprise...

INDO-ITALY Collaborative Project: "Development of Long Period Grating based immunoassay for bio-sensing applications"

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## Numerical electromagnetic dosimetry

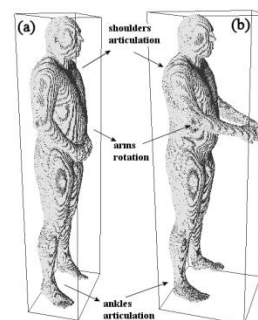
The exposure of a living organism or of a cell culture to electromagnetic fields causes the induction of physical quantities (called *basic dosimetric quantities*) within the organism or the culture itself. "Dosimetry" is the discipline that studies the determination of these quantities, whose knowledge is of great significance in scientific and technological research, in order to evaluate the safety of exposed subjects both in life and work environments.

However, the basic dosimetric quantities are very difficult to measure and therefore numerical calculation techniques are usually applied to determine their distribution in biological materials. This *numerical dosimetry* approach is conceptually divided into three main components: (1) modeling of the source of the electromagnetic fields; (2) modeling of the exposed biological organism or cell culture; (3) application of a suitable computational method.

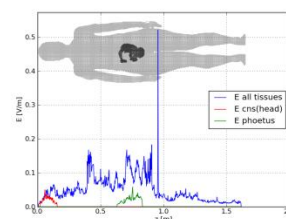
At IFAC-CNR, original solutions were developed for all these components. For what concerns component (1), numerous field sources were individually modeled and dedicated interpolation algorithms of measured data were developed. Concerning component (2), an original articulation process was studied to place a numerical body model in realistic postures. Regarding component (3), several 2D and 3D methods were implemented with particular attention to low and intermediate frequency ranges.

### Issues of possible interest for external clients

Numerical dosimetry is part of the current European regulatory framework as the last step of the exposure assessment process in working environments. In this context, collaborations have been activated between IFAC-CNR and companies such as Trenitalia or ENI, or with bodies of the Italian National Health Service (ASL7, Siena) and labor protection institutions (ISPESL, INAIL).



Articulation of the body model of a worker operating in front of a magnetic induction heater.



Electric field induced in the body of a pregnant woman by the magnetic field due to a laptop PC battery charger.

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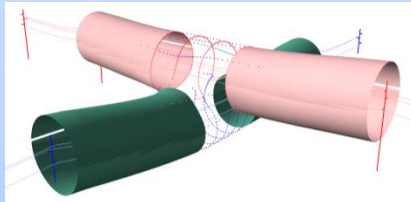
## Power Line Electromagnetic Impact Assessment

Since the approval, in July 2003, of a ministerial decree on the limitation of electric and magnetic fields dispersed by high voltage power lines, it had been necessary to investigate the issue of the calculation of such fields, in order to verify compliance with regulatory limits and identify areas subject to restrictions.

The assessment of the spatial distribution of the magnetic field dispersed by a system of power lines is accomplished by means of an integrated system, which includes the implementation of the *Regional Archive of Power Lines* (called "CERT" in Italian) as a data source for the calculation software.



Visualization of restricted-access areas in digital cartography



Determination of the iso-field surface at the intersection between two power lines

Numerical modeling of high-voltage (132 kV to 380 kV) power lines is possible entering line routes, profiles and technical diagrams in the CERT archive.

A software package called "PLEIA" (*Power Line Electromagnetic Impact Assessment*), developed at IFAC-CNR, accesses CERT data to evaluate the distribution of magnetic field in the environment. It supports several calculation modalities: one of them allows to determine the surface that delimits the volume, around a power line, within which a user-defined field level is exceeded.

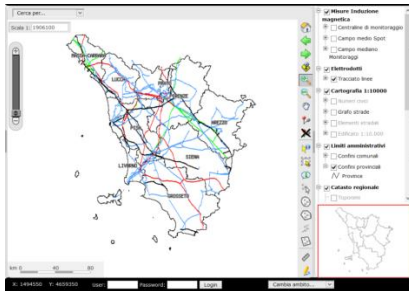
### Issues of possible interest for external clients

Design and implementation of open source based databases, particularly referring to PostgreSQL DBMS, with PostGIS as spatial extension.  
Design and development of client and server software applications, able to evaluate environmental impact and assess population exposure to electromagnetic fields.

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## Integrating Environmental Evaluation and GIS-based Systems

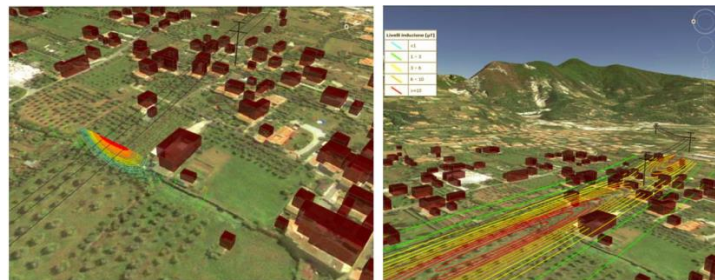


Power lines regional webGIS in Tuscany

A management system of a geographic portal, using "MapServer" as rendering engine and "p.mapper" as client framework, has been developed. It consists in a server-side application, based on a PostgreSQL database, that allows to handle:

- various types of data (shapefiles, raster, PostGIS, WMS and WFS layers);
- p.mapper GUI elements (in particular categories and layers);
- profiles, which are associated with users who access the system, so as to allow a selective display of data and related search options.

A specific set of tools has been developed in order to convert shape and DB stored data in KML/KMZ (Google Earth compatible) formats. This allows to share available geographic data through a popular and well known environment, according to provider's restraint policies.



Overlapping magnetic flux density evaluation and 3D buildings model in Google Earth

### Issues of possible interest for external clients

Design and implementation of MapServer based mapping systems, client and server side applications based on GRASS GIS.  
Design and development of webGIS software, able to expose environmental and geographical data in a web-based framework.  
Development of tools to integrate archive data with Google Earth environment.

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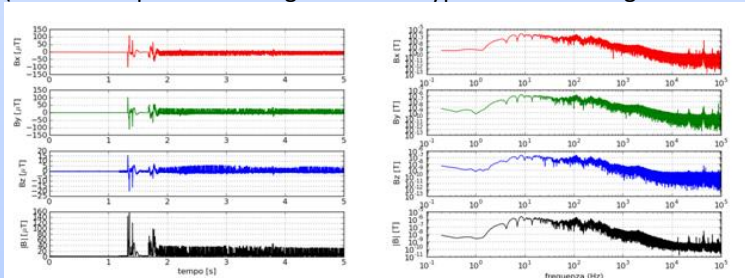
## Assessment of exposures to electromagnetic fields in industrial environments

Several industrial sectors are based on applications requiring or involving the emission of intense electromagnetic fields, which should be subject to precise limitations in order to ensure the safety of personnel.

The forthcoming transposition of the 2013/35 EU Directive (concerning occupational exposures to electromagnetic fields) results in a high pressure towards the development of methods and procedures for proper risk assessment in industrial facilities where electromagnetic sources are present (as for example for welding or various types of electromagnetic heating).



Measurement of electric and magnetic fields close to an industrial welding station



Complex magnetic field waveforms (time and frequency domains) produced by an industrial welding apparatus

This activity at IFAC-CNR has frequently met the needs or the interest of public radioprotection institutions, as well as of large companies such as Enel, Terna, Trenitalia or ENI, which have to face many complex and uncommon situations and require adequate and qualified technical and scientific support to properly address them.

Particularly complex cases, which require expertise and equipment not usually available in the institutions and consultancies that deal with radiation protection in the workplaces, are those involving source modeling, complex waveforms processing or dosimetric deepening.

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## Assessment of exposure to electromagnetic fields in healthcare facilities

The incessant introduction of new types of sources and the frequent review of national and international radiation protection standards require the continuous updating of methods for assessing human exposure to electromagnetic fields.



Probe set-up for detecting the apparently-variable magnetic flux density perceived by a subject moving in an intense magnetostatic field

Our operating unit at IFAC-CNR is involved in the set-up of specialized instrumental chains and in the development of numerical procedures for source modeling, signal processing (particularly in case of complex waveforms) and electromagnetic dosimetry.

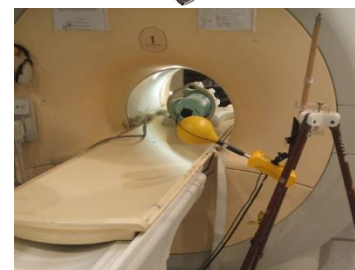
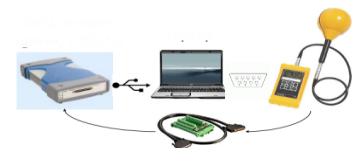
The healthcare environment is one of those in which they are used many devices that emit intense electromagnetic fields (e.g. magnetic resonance imaging (MRI), transcranial stimulation, electrosurgery).



Patient and operator exposure to the magnetic field emitted by an applicator for transcranial magnetic stimulation

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Instrumental chain and set-up for the measurement of electromagnetic fields close to the bore of an MRI scanner

This activity was often carried out in support of public bodies that deal with radiation protection, as part of national research projects funded and coordinated by ISPESL, INAIL and the Ministry of Health or in the context of a multi-year partnership with the Siena unit of the National Health Service.



## Fluorescence optical platform for sepsis analysis for Point of Care application

Sepsis is the first leading cause of mortality in intensive care units. Discrimination of viral and bacterial sepsis in intensive care patients and the fast identification of the origin of infections can be essential for the patient survival. It has been shown that every hour delay until administration of an effective calculated antibiotic treatment in septic shock increases mortality by 7%. Sepsis can be caused by numerous pathogens and the primary state of infection can be found in any major organ system. Therefore a single marker could not provide the high accuracy needed for fast and accurate guidance of treatment of sepsis patients, and a combination of markers should be considered the right approach. A novel optical platform, the channel array interrogation (CAI) system, was developed for multiparameter analysis and was applied to the simultaneous detection of procalcitonin (PCT), C-reactive protein (CRP) and neopterin, considered among the most important biomarkers for the sepsis. The heart of the system is a plastic multichannel chip, constituted by 13 microchannels (50  $\mu\text{m}$  high, 600  $\mu\text{m}$  wide, 10 mm long) through which the sample flows and which carries the necessary chemistry for the implementation of the assay on its surface. The chip is shown in Figure 1, and the the whole instrument is shown in Figure 2.



Fig.1. The PMMA optical chip

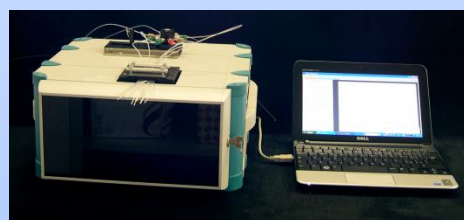


Fig.2. The CAI instrument

### With regards to enterprise...

Integrated European Project CARE-MAN - HealthCARE by biosensor Measurement And Networking (contract NMP4-CT-2006-017333). Prototype developed in strict collaboration with Datamed srl (Milano)

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ICT, PHOTONICS  
and  
MATTER



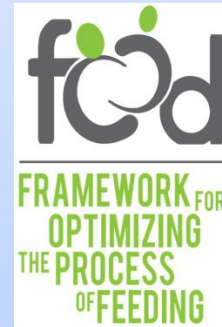
### e-Inclusion Lab

Building a bridge between humans and technology



"e-Inclusion" means both inclusive ICT and the use of ICT to achieve wider inclusion objectives. It focuses on participation of all individuals and communities in all aspects of the information society. e-Inclusion policy, therefore, aims at reducing gaps in ICT usage and promoting the use of ICT to overcome exclusion, and improve economic performance, employment opportunities, quality of life, social participation and cohesion. (Pt. 4 MINISTERIAL DECLARATION APPROVED UNANIMOUSLY ON 11 June 2006, Riga)

According to the Riga declaration the elnclusion Laboratory research team has been working for more than 20 years in the field of ICT with the aim of identifying both barriers and possibilities in order to improve quality of life and inclusion of all people in social life. The activity has been following the evolution of technology and all the changes of society relevant to it. Starting from the first activities, mainly experimental, related to the implementation of the first speech synthesizer in italian language (1985), based upon expertise on Digital Signal Processing, the research is now focused on the most recent scenarios related to Ambient Intelligence and its use by all people.



FOOD project logo

#### With regards to enterprises...

Design, implementation and testing of methodologies and services in the framework of several national and international projects such as: EU AAL project FOOD Framework for optimizing the process of feeding, MIUR Project D4All Sw integration and advanced HMI in design for AAL, MISE Project eKitchen



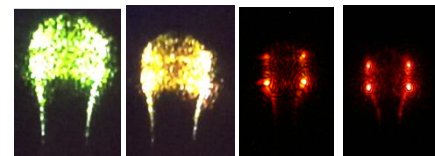
D4all project logo

#### Contact:

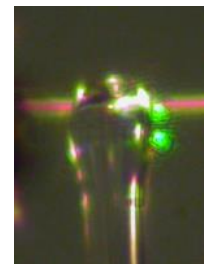
Laura Burzagli ([l.burzagli@ifac.cnr.it](mailto:l.burzagli@ifac.cnr.it))

### Whispering Gallery Mode Resonators (WGMR) for nonlinear optics

Optical resonators play an ubiquitous role in modern optics. A particular class of optical resonators is constituted by spherical dielectric structures, where optical rays are total internal reflected. Due to minimal reflection losses and to potentially very low material absorption, these guided modes, known as whispering gallery modes, can confer the resonator an exceptionally high quality factor Q, leading to high energy density, narrow resonant-wavelength lines and a lengthy cavity ringdown. These attractive characteristics make these miniaturized optical resonators especially suited for nonlinear optics applications. We have demonstrated, experimentally and theoretically, a variety of  $\chi^{(3)}$  nonlinear interactions in silica microspheres, consisting in third harmonic generation and Raman assisted third order sum-frequency generation (TSFG) in the visible. We have also demonstrated the feasibility of a nonlinear optical switch based on hybrid WGMR, based on  $\chi^{(3)}$  nonlinear interactions in organic coatings



Green, yellow, orange and red emission through Raman assisted TSFG, in this case the generated signal is a standing wave.



Third harmonic signal generated in a silica WGMR, in this case the generated light is directional, as expected

#### With regards to enterprises...

On the nonlinear switch topic, we collaborate with Moscow State University (Prof. Murzina) We can offer: fabrication of WGMR and characterization of the final devices.

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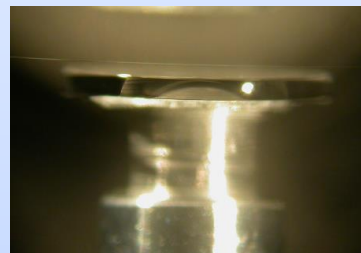
## Ultra-high Q crystalline optical micro-resonators for RF Photonics

The combination of long cavity lifetime and small mode volume make Whispering Gallery Mode (WGM) optical micro-resonators an ideal device for enhancing light-matter interactions. Crystalline WGM resonators have gained increasing attention since the possibility of getting very high Q factors ( $Q \geq 10^9$  in Calcium Fluoride,  $\text{CaF}_2$ ) was demonstrated. Additional properties specific of crystals like for instance enhanced non linear or electro-optical properties have played an additional role for the implementation of high performance devices. Resonators made in lithium niobate, for instance, can be used for the realization of a number of specific components including single and multi-order tunable filters, electro-optic modulators, or frequency converters.

The optoelectronic oscillator (OEO) is a device that produces spectrally pure RF electrical signals at tens of gigahertz based on photonic techniques, and thus overcomes some of the inherent limitations of the conventional electronic devices. The use of optical storage elements allows for the realization of extremely high Qs and thus spectrally pure signals. The typical optical fiber delay line can be replaced by a high-Q WGM optical resonator in order to implement ultra-compact, low noise OEO.

**With regards to enterprises...** We have joint R&D international projects with Selex ES (Italy) and Thales R&T (France) on high performances optoelectronic microwave oscillators.

We are able to provide high-Q crystalline disks fabricated in different materials like  $\text{CaF}_2$  and Lithium Niobate



$\text{CaF}_2$  disk with a Q factor close to  $10^9$  corresponding to a resonance linewidth of 200 KHz.

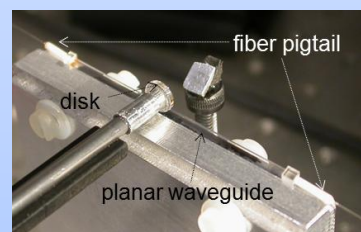


Photo showing a lithium niobate disk coupled to a fiber pigtailed lithium niobate waveguide.

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## Whispering Gallery Mode Resonators (WGMR) based biosensors

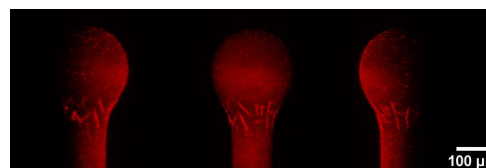
Optical microresonators are an efficient tool for the realisation of optical biochemical sensors, based on the measurement of the refractive index changes induced by the interaction of the investigated analyte with a selective layer immobilised on the microresonator surface. We have developed a biosensor based on silica microspherical resonators able to recognize specifically thrombin or VEGF protein and an immunosensor. The protein binding was optically characterized in terms of specificity in buffer solution or in 10% diluted human serum. Simulation of the protein flow was found in good agreement with experimental data. The aptasensor was also chemically regenerated and tested again, demonstrating the reusability of our system.

We are also developing a sensing platform based on microbubble resonators made from silica capillaries, which allow an intrinsic microfluidics separated from the external light coupling system.

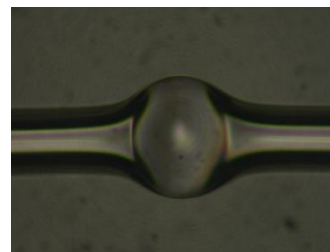
### With regards to enterprises...

On this topic, we collaborate with Fondazione Bruno Kessler (Dr. Pederzoli) at Trento, IQAC-CSIC (Dr. Marco, Barcelona, Spain), and we are partner of the Sens4Bio FIRB Giovani project.

We can offer: fabrication of WGMR and characterization of the final devices



Three different projections of aptamer-modified microsphere incubated with rhodamine-labelled thrombin



Microbubble resonator with OD ~ 205 nm, created from a capillary with OD ~ 122 nm and wall thickness ~ 21 nm

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## Development of innovative diode-pumped solid-state lasers based on ceramic materials

One of the most important achievements in recent years in the field of solid state lasers is the introduction of transparent polycrystalline materials, *i.e.* ceramics, doped with rare earths.

Ceramics are currently having an unquestioned success because of, if compared with single crystals, they support higher level of doping with more controlled distributions, and in turn, they can withstand higher thermo-mechanical stresses. Ceramics can be produced with complex structures and large size, which are difficult or impossible to obtain with monocrystals, and the same time, with a reduced cost.

In the last years we have developed several laser prototypes based on Yb-doped ceramics as YAG, LuAG,  $\text{Lu}_2\text{O}_3$ , and  $\text{Sc}_2\text{O}_3$ , which are considered technological keystones for high power laser systems in the infrared region for many and many applications .

### With regards to enterprises...

On this topic, we collaborate with: ISTECCNR, Faenza; Institute of Physics Academy of Sciences of the Czech Republic in Prague; Department of Physical Chemistry of Luminescent Materials, Claude Bernard University, Lyon, France.

We can offer well established experience in the development of solid state diode pumped lasers and their applications for sensors, environmental diagnostics and industrial applications.



Yb:YAG ceramic element emitting laser radiation. Turquoise fluorescence is due to the pump up-conversion

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## Portable 3D digital microscopes

Compact 3D digital microscopes for in situ micro-morphological characterizations of a variety of surfaces have been developed. The novel devices exploit a simple set up including an optoelectronic group (CCD camera and objective), a translation stage, and a PC for data acquisition and elaboration. The 3D reconstruction of the surface under examination is achieved through the elaboration of a sequence of pictures (usually 50-100), which are collected while translating the focal point of the objective along the optical axis z. Fields of view range between 1-10 mm with corresponding vertical resolutions between some microns to some tens of microns can be achieved using suitable objectives. The microscope head can optionally be mounted on (x, y) translation axes in order to investigate wider zones by merging 3D reliefs of adjacent areas. The present low-cost micro-3D devices have a significant application potential in various fields: industry, health, environment, and cultural heritage. Thus for examples, in dermatology they can allow accurately examining and monitoring the micro-morphologies of the skin diseases, as well as assessing the effectiveness of surgical therapies. In archaeometry, 3D digital microscopes can provide information on the authenticity and the state of conservation of the object under study and support the assessment of the effectiveness of the cleaning treatments.



Palm-sized 3D digital microscope and application examples: a) examination of skin, b) observation of a painted surface during laser cleaning.

### With regards to enterprises...

A PCT patent application has been submitted for the present class of 3D digital microscopes: "Microscopy optoelectronic device with focus scanning", by S. Siano, A. A. Mencaglia, I. Cacciari (PCT/IB2012/053905). Related collaborations have been established with El.En. S.p.A and Actis S.r.l of Calenzano, Italy. We are available for further partnerships.

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## Study of scintillators materials with time-resolved optical spectroscopy

Radiative recombination processes were studied in the new class of inorganic single crystal scintillators, so called multicomponent garnets  $(\text{Gd,Y,Lu})_3(\text{Ga,Al})_5\text{O}_{12}:\text{Ce}$ , which provide the highest light yield in the group of high density fast oxide scintillators. The technique of the measurement of luminescence decay under excimer or nitrogen laser excitation and detected by photomultiplier in current regime coupled to digital oscilloscope appeared extremely useful to monitor the delayed recombination processes due to thermal ionization or tunneling processes in the excited state of  $\text{Ce}^{3+}$  center, Fig. 1.

Luminescence decay measured over 4-5 orders of dynamical and time scales provides unique possibility to observe well both processes in a single curve and compare quantitatively their intensity ratios and temperature dependences.

### With regards to enterprises

This kind of scintillator materials can be employed in homeland security, environment monitoring and medical imaging (computed tomography) fields.

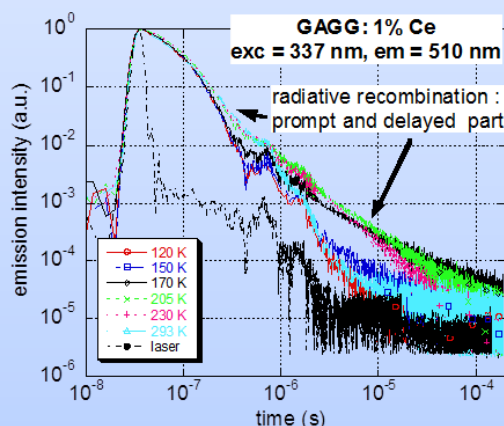


Fig. 1- Temperature dependence of photoluminescence decay of  $\text{Ce}^{3+}$  center in  $\text{Gd}_3\text{Ga}_3\text{Al}_2\text{O}_{12}$  single crystal host

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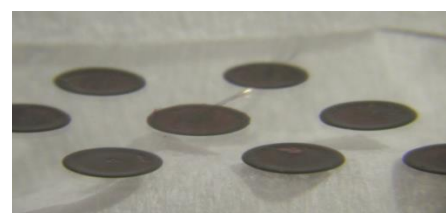
## Optical drawing of liquid droplets via plasmon resonance of gold nanorods

Lab-on-a-chip systems are of great interest in biotechnological and chemical applications. The approach of a droplet-based system has the advantage to be compatible with wall-free structures, so that the operations can conveniently performed on the surface of a planar substrate.

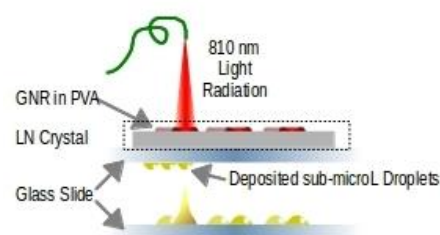
We have realized (in co-operation with INO, Naples) a laser-assisted electro-hydrodynamic technique for drawing microlitre droplets. The technique is based on the successful combination of a near infrared source with the plasmon resonance of gold nanorods patterned onto the surface of a pyroelectric lithium niobate crystal. The stimulation of the pyro-electrohydrodynamic effect is performed optically by a compact laser source launched in fibre. The needed thermal gradient is ensured by the efficient photothermal conversion of the gold nanorods during the plasmon resonance induced by laser illumination. This allows to generate the pyroelectric effect with high precision and selectivity and the induced electric field is able to exert a significant hydrodynamic pressure onto an underlying reservoir, thus leading to the dispensing of small droplets ( $\sim 10 \mu\text{m}$ ) from a base plate to a target plate. The method has been applied to different kinds of liquids, including oil and water with a rather fast response.

### With regards to enterprises:

We are looking for companies in the field of biomedical and analytical diagnostics, sensors, micro-optics, etc. interested in the development/exploitation of the technology. More details on: de Angelis et al. Applied Physics Letters 103, 163112 (2013)



View of the pattern of gold nanorods film on the lithium niobate crystal plate



Drawing of the droplets dispenser.

### Contacts:

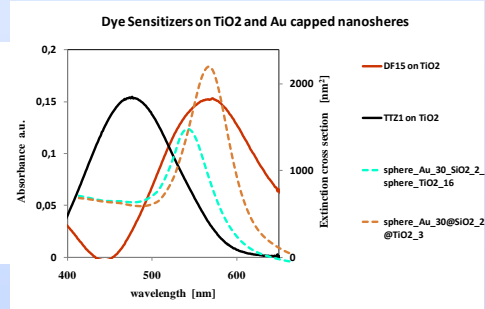
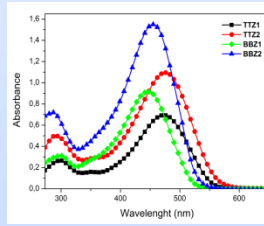
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## P\_DSSC Plasmonic enhancement in Dye-Sensitized Solar Cells

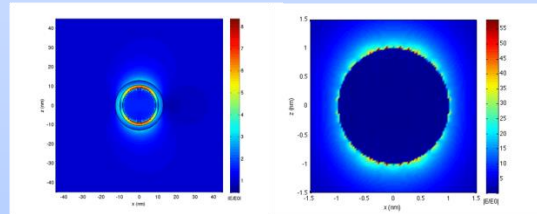
Dye-sensitized solar cells (DSSCs) have emerged as one of the most promising technologies for the construction of cheap, silicon-free photovoltaic devices. DSSCs are based on the use of light-harvesting dyes to sensitize the surface of a nanocrystalline semiconductor (usually  $\text{TiO}_2$ ).

Our research focuses on the device optical and chromatic properties simulation and optimization by plasmonic effects of selected dyes synthesized by ICCOM (G. Reginato, L. Zani). The extinction properties were simulated for several types of metallic nanoparticles by means of commercial and open source softwares, starting from gold nanospheres with dimensions and capping (Si and  $\text{TiO}_2$ ) from realized compounds from literature and at ICCOM (A. Ienco). Disperse particles and aggregates were considered for best exploiting all the possible practical realizations, over rigid, nanostructured and flexible substrates.

**With regards to enterprises**, in collaboration with ICCOM, we have already presented projects with Italian companies working on new generation PV (Tozzi, Renewable Energy, Aurel Innovation), and were selected for funding in Progetti Premiali for Made in Italy with the leadership of ITIA.



Absorption extension of dyes by plasmonic effects produced by gold spheres capped with silica and titania, and capped with silica on titania nanospheres



Near-field enhancement maps for gold nanospheres with different capping and dimensions at wavelengths of maximum extinction

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## Energy localization in e.m. beams propagation

Recently, many papers have been devoted to the study of the propagation of localized waves, specifically of Bessel beams. One possible use of these beams is related to the GPR apparatus for the detection of buried objects of a non-metallic nature. As compared with plane waves the Bessel beam has a gain in intensity of the reflected field. Therefore, the detection of buried objects, such as landmines or archaeological findings could be facilitated. Moreover, this type of apparatus could be used for the detection of everything that renders a material inhomogeneous, such as defects inside solids, air bubbles in plastic materials, or water leaks inside walls. All the applications mentioned above require the use of beams of high energy well localized in the space. On the basis of a suitable vectorial treatment, it is possible to evaluate the energy flux that a Bessel beam can supply and, more important, to understand how to increase this quantity and how to concentrate it, in a given region of space.

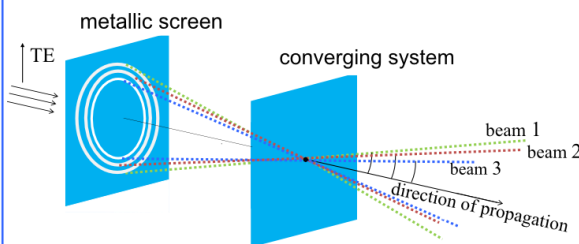


Fig. 1 – Sketch of the experimental setup in order to produce well localized energy flux.

For a system constituted by three beams (see Fig. 1, one ring = one beam), we will have an increase in the energy along the axis of propagation (see Fig 2), if each beam is in phase with respect to the others, namely if the optical path among the beams differs by one wavelength (or an even number of wavelengths).

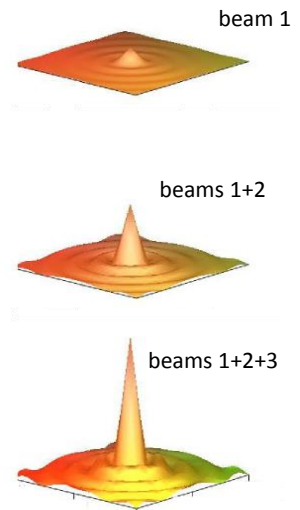


Fig. 2 - Energy flux of the field coming from for one (upper), two (middle) and three rings (lower).

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