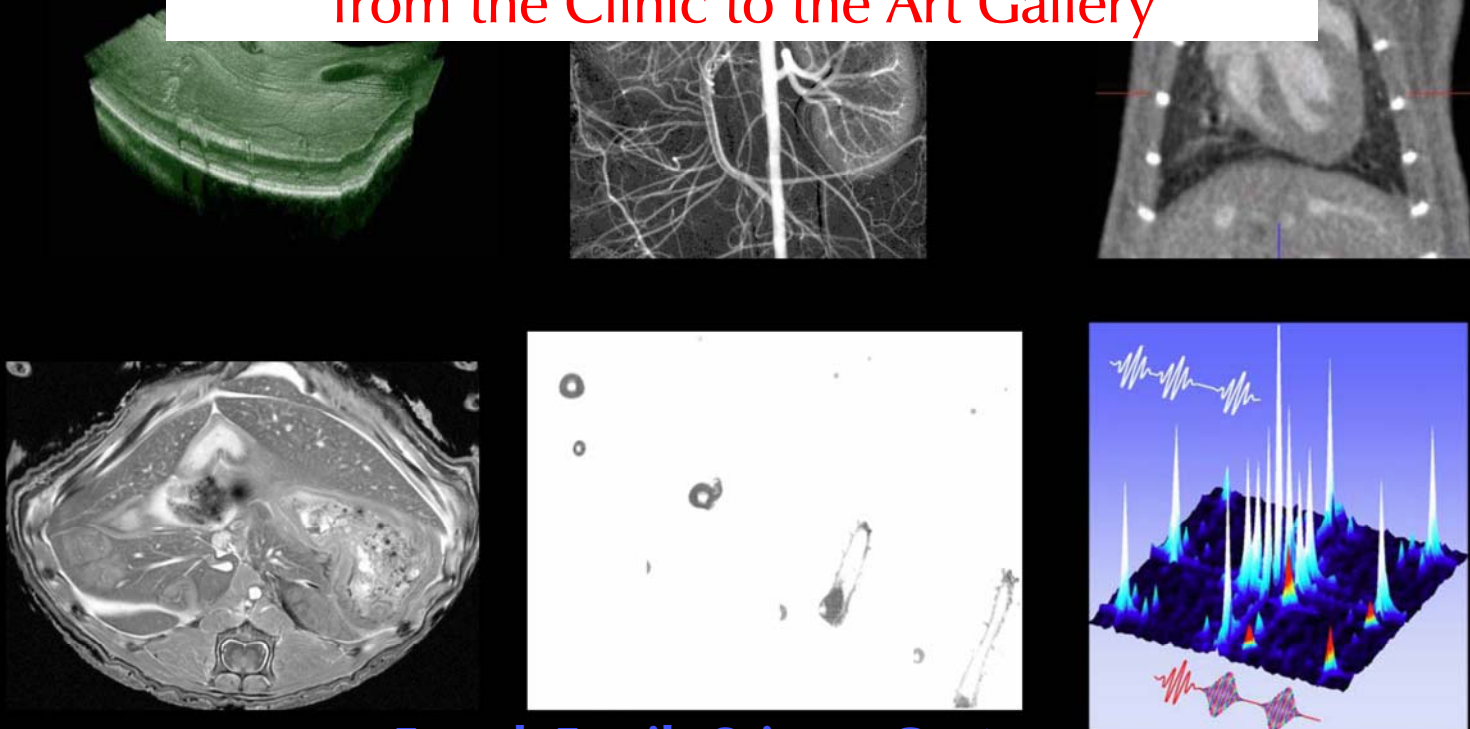CMBI
CENTER FOR MOLECULAR AND BIOMOLECULAR IMAGING

DUKE UNIVERSITY
DUMC

Frontiers in Optical Imaging:
Data Collection and Data Mining,
from the Clinic to the Art Gallery

French Family Science Center
Duke University
December 9 & 10, 2012

Duke
UNIVERSITY

Warren S. Warren
James B. Duke Professor of Chemistry, Physics, Radiology, and Biomedical Engineering
Director, Center for Molecular and Biomolecular Imaging

December 9, 2012

Welcome to the Center for Molecular and Biomolecular Imaging 2012 conference, "Frontiers in Optical Imaging: Data Collection and Data Mining, from the Clinic to the Art Gallery." This meeting highlights challenges and opportunities in modern optical imaging (broadly defined). Dramatic advances in imaging methods, hardware, and image processing concepts have led to a wide range of novel clinical applications: the fundamental challenges are creating useful contrast, enhancing sensitivity, and extracting important information from the large datasets that can be generated. Over the last few years, it has become apparent that a strong synergy exists between these clinical efforts and parallel programs in disparate fields, including cultural heritage science, visual studies, environmental analysis. The goal of this meeting is to bring together disparate communities with distinct expertise, and thus identify promising opportunities which transcend disciplinary boundaries.

CMBI is a Provost-level organization which unites several different schools at Duke (interconnecting Trinity College of Arts and Sciences, the Pratt School of Engineering, the Medical School, and the Nicholas School of the Environment) to support the transformative and inherently interdisciplinary nature of modern imaging science. This has a natural connection with one of Duke's greatest strengths, which can best be appreciated on *Google Maps*. If you locate the French Family Science center at 124 Science Drive, and go to the 200 foot scale, you will find all of physics, biology, chemistry, engineering, and computer science, and virtually all of the basic science buildings of the medical school. This extremely unusual proximity can, and does, foster strong connections between departments. It is the aim of this Center to support and strengthen these connections. To this end, our meetings have widely varying themes and foci that we hope will continue to intrigue the best and brightest across the imaging spectrum.

These meetings don't happen spontaneously. I am very grateful for the continuing efforts of Mike Conti (CMBI Manager), for helping to organize the meeting, and to the CMBI steering committee for their thoughts and guidance.

Sincerely,

Warren S. Warren

CMBI
CENTER FOR MOLECULAR AND BIOMOLECULAR IMAGING

Frontiers in Optical Imaging:
Data Collection and Data Mining, from the Clinic to the Art Gallery
December 9 & 10, 2012

French Family Science Center Room 2231

Evening Session: December 9, 2012

5:00PM	Registration and Poster Setup	
6:00PM	Warren Warren (Director, CMBI)	Welcome and Introduction
6:15PM	Eric Potma (University of California, Irvine)	Biomolecular Imaging with Coherent Nonlinear Vibrational Microscopy
6:45PM	Jesse Wilson (Duke University)	Pump-probe Microscopy: Using Information on Pigment Photodynamics to Detect Melanoma
7:15PM	Reception – French Family Science Center Atrium	

Morning Session: December 10, 2012

8:00AM	Breakfast – French Family Science Center Atrium	
9:00AM	John Simon (University of Virginia)	Measuring Absorption Cross-Sections of Melanosomes Using Photo-emission Electron Microscopy
9:30AM	Mauro Maggioni (Duke University)	On the Complexity of High-dimensional Data: From Hyperspectral Images to Molecular Dynamics Data
9:50AM	Eric Monson (Duke University)	Enabling Art History Visualization
10:10AM	Break	
10:30AM	John Delaney (National Gallery of Art)	Application of Visible and Infrared Imaging Spectroscopy to the Study of Old Master Paintings
11:00AM	David Dunson (Duke University)	Bayesian Learning from Pictures: Paintings and Brains
11:20AM	Tana Villafana (Duke University)	The Science in Art: Applications of Pump-Probe Microscopy
11:40AM	Adele De Cruz (Duke University)	The Restoration of a Roman Urn with the Er:YAG Laser

12:00PM	Lunch – French Family Science Center Atrium

Afternoon Session: December 10, 2012

1:30PM	Garth Simpson (Purdue University)	Synchronous Digitization: Spanning the Duty Cycle – Dynamic Range Abyss
2:00PM	Geoffrey Rubin (Duke University)	Three-Dimensional Visualization in a Clinical Setting
2:20PM	Arthur Dogariu (Princeton University)	Real-time Standoff Detection and Imaging: From Air Lasing to CARS
2:50PM	Break	
3:10PM	Amy Oldenburg (UNC – Chapel Hill)	Imaging Structure and Function of the Airway Using Optical Coherence Tomography
3:40PM	Francisco Robles (Duke University)	Molecular Imaging Using Spectroscopic Optical Coherence Tomography

Biomolecular Imaging with Coherent Nonlinear Vibrational Microscopy

Eric Potma, PhD
Associate Professor of Chemistry
University of California, Irvine

Professor Potma received his degree in chemical physics from the University of Groningen in the Netherlands, and performed his postdoctoral work at Harvard with Prof. Sunney Xie. The Potma research group focuses on coherent anti-Stokes Raman scattering microscopy (CARS), developing the technique for rapid vibrational imaging of living cells in order to unveil the molecular secrets of microscopic biological systems.

Abstract:

Optical imaging with spectroscopic vibrational contrast is a label-free solution for visualizing, identifying, and quantifying a wide range of biomolecular compounds in biological materials. Both linear and nonlinear vibrational microscopy techniques derive their imaging contrast from infrared active or Raman allowed molecular transitions, which provide a rich palette for interrogating chemical and structural details of the sample. Yet nonlinear optical methods, which include both second-order sum-frequency generation (SFG) and third-order coherent Raman scattering (CRS) techniques, offer several improved imaging capabilities over their linear precursors. Nonlinear vibrational microscopy features unprecedented vibrational imaging speeds, provides strategies for higher spatial resolution, and gives access to additional molecular parameters. These advances have turned vibrational microscopy into a premier tool for chemically dissecting live cells and tissues. This presentation discusses the molecular contrast of SFG and CRS microscopy and highlights several of the advanced imaging capabilities that have impacted biological and biomedical research.

Pump-probe Micrsocopy: Using Information on Pigment Photodynamics to Detect Melanoma

Jesse Wilson, PhD
Department of Chemistry
Duke University

Dr. Wilson received his degree in electrical engineering from Colorado State University, where he studied vibrational Raman spectroscopy with Prof. Randy Bartels' group. He has been working on pump-probe microscopy and melanoma diagnosis since joining the Warren lab in 2010. He was recently awarded JenLab Young Investigator Award at Photonics West for his work on *in vivo* two-beam multiphoton microscopy of intratissue eumelanin and pheomelanin.

Abstract:

Efforts to detect and treat early stage melanoma, before it metastasizes and becomes fatal, require pathologists to predict whether a biopsied lesion would have developed into a malignancy if it were left in place. Our research focuses on changes in melanin pigment chemistry that accompany malignant transformation. We have combined pump-probe spectroscopy with a laser-scanning microscope to provide a comprehensive in vivo picture of pigmented lesions that will help to differentiate early-stage melanoma from benign conditions. We will also discuss applications to other biological systems and our solutions to the unique data analysis challenges raised by pump-probe microscopy.

Measuring Absorption Cross-Sections of Melanosomes Using Photo-emission Electron Microscopy

John Simon, PhD
Professor of Chemistry
Executive Vice President and Provost
University of Virginia

Professor John Simon received his PhD degree in Chemistry from Harvard University. After performing his postdoctoral research at UCLA, he joined the faculty at the University of California – San Diego, where he spent 13 years before joining Duke University's department of Chemistry and eventually becoming Vice-Provost for Academic Affairs. In 2011 he joined the University of Virginia, where he was named Executive Vice President and Provost. Professor Simon's research uses photoemission electron microscopy (PEEM) to identify and characterize melanins.

Abstract:

An approach for using photoemission electron microscopy to enable direct measurement of the absorption cross-section from intact melanosomes isolated from various tissues will be described. In particular, we will examine the absorption coefficients, εc, of intact iridal stroma melanosomes isolated from dark brown and blue-green human irides for the spectral range $\lambda = 244 - 310$ nm. These iridal stroma melanosomes were chosen because different colored irides produce organelles of varying eumelanin:pheomelanin ratios with similar size and morphology. Similar absorption spectra are found for the two types of melanosomes. The experimental spectra will be compared with both the extinction coefficient spectra obtained on soluble synthetic model systems and the monomeric precursors to each pigment.

On the Complexity of High-dimensional Data:
From Hyperspectral Images to Molecular Dynamics Data

Mauro Maggioni, PhD
Professor of Mathematics, Computer Science, and
   Electrical & Computer Engineering
Duke University

Prof. Maggioni received his degree in Mathematics from Washington University, St. Louis, where he worked on harmonic analysis and wavelet transforms with Prof. G.L. Weiss' group. After a year developing software for robotic chemistry in the United Kingdom, Prof. Maggioni joined the faculty at Yale University where he worked in applied mathematics before joining Duke in 2006. His recent work has focused on the construction of multi-resolution structures on discrete data and graphs, connecting aspects of classical harmonic analysis, global analysis on manifolds, spectral graph theory and classical multiscale analysis.

Abstract:

Data sets arising in a wide variety of applications are often called ``large'' and "high-dimensional". ``Large'' refers to the number of data points (e.g. images are in a collection; configurations of a molecule in a long trajectory from molecular dynamics simulations), ``high-dimensional'' to the number of numbers representing each data point (e.g. pixel values in an image; atoms in molecule). These numbers often have very little to do with the ``intrinsic complexity'' of the data, which should govern the statistical and computational complexity of our attempts to model and compute with the data. I will discuss geometric techniques that allow us to define and to extract information about the intrinsic complexity of high-dimensional data and produce data sketches: compressed representations with tunable guaranteed accuracy. We show with concrete examples that this intrinsic complexity may be much smaller than expected, and may be extracted with randomized algorithms that run in time proportional to the intrinsic complexity of the data.

Parts of this work are joint with W.K. Allard, G. Chen, A.V. Little, M. Crosskey (Duke); C. Clementi, M. Rohrdanz, W. Zheng (Rice).

Enabling Art History Visualization

Eric Monson, PhD
Research Scientist, Visualization Technology Group
Duke University

Dr. Monson received his degree in applied physics from the University of Michigan, where he studied nano-scale fluctuations in near-field microscopy with Prof. Raoul Kopelman's group. He joined Duke in 2002 and has since worked with both the Physics and Computer Science departments to better understand imaging and pattern analysis problems. Dr. Monson is currently working with the Visualization Technology Group, enabling researchers to better discover relationships and correlation in their data.

Abstract:

Many of us with a background in imaging do what we do because of the thrill of seeing, and finding new ways to see, the previously unseeable. A few years ago I moved away from experimental biophysics to work with Duke's Visualization Technology Group, and although I don't use direct imaging technology any more, I am still visually exploring formerly unseen worlds. In this talk I will focus on my collaborations in the past year with Art History graduate students, trying to incorporate technology into their scholarship. For this work, sample preparation is replaced with data gathering, cleaning and storage methods. Imaging is replaced by information visualization techniques that can reveal hidden patterns in their data. And, just as in scientific imaging, challenging scholarly questions drive novel advancements in the technology we use to probe deeper into the world around us.

Application of Visible and Infrared Imaging Spectroscopy to the Study of Old Master Paintings

John Delaney, PhD
Senior Imaging Scientist, Scientific Research Department
National Gallery of Art

Dr. Delaney received his degree from The Rockefeller University and completed post-doctoral studies at the University of Arizona and The Johns Hopkins University School of Medicine. He is currently the Andrew W. Mellon Senior Imaging Scientist at the National Gallery of Art, where his research focuses on the development of in situ imaging methods for art conservation and understanding of the optical properties of varnishes.

Abstract:

Imaging Spectroscopy, the collection of spatially coregistered images in hundreds of contiguous spectral bands, was first developed for remote sensing of the Earth. In this talk we present findings demonstrating the application of imaging spectroscopy in conservation science to identify and map artists' materials (pigments and binders) as well as improve the visualization of preparatory sketches and compositional paint changes. Several novel hyperspectral cameras, operating from the visible to near-infrared (400-2500 nm) have been used to collect diffuse reflectance spectral image cubes from a variety of works of art. Results will be presented illustrating this approach to the study of works by Pablo Picasso, Carlo Crivelli, Lorenzo Monaco and Giorgione. Unlike hyperspectral cameras designed for remote sensing these cameras are optimized for the low light levels required to safely image vulnerable works of art, including drawings and illuminated manuscripts. These novel types of technical images offer the conservator and art historian new insights into the construction of paintings.

Frontiers in Optical Imaging:
Data Collection and Data Mining, from the Clinic to the Art Gallery

Bayesian Learning from Pictures: Paintings and Brains

David Dunson, PhD
Professor of Statistical Science
Duke University

David Dunson is currently Professor of Statistical Science and Computer and Electrical Engineering at Duke University. He came to Duke in 2008 after a decade at the National Institutes of Health (NIH). His research focuses on Bayesian statistical and machine learning methods motivated by high-dimensional and complex applications. A particular emphasis is on nonparametric probability models and on joint modeling of high-dimensional data of different types, including images, functions, shapes, text and other complex objects. His work is driven by improving practical performance in challenging applications ranging from environmental health studies and genomics to a recent expanding interest in neurosciences and imaging.

Abstract:

It has become common to collect very fine resolution imaging data in a rich variety of applied domains ranging from the fine arts to neurosciences. The scale of the data makes image processing and inference a daunting problem. In this talk, I discuss two motivating applications. The first focuses on detecting cracks from multi-modal images of the Ghent Alterpiece. By accurately detecting cracks, we can remove the cracks and use in-painting to obtain a digital restoration of the painting as an aid to art historians and reconstruction experts. Although the human eye is good at picking out cracks, the complexity of the painting makes it challenging for standard imaging processing methods, with a novel Bayesian tensor factorization approach providing state of the "art" performance. The second application relates an individual's brain connectivity graph, extracted from multi-modal MRI images, to their creativity. Again, we face a daunting dimensionality problem, which bogs down computation and degrades performance for existing methods. A Bayesian multi-resolution dictionary learning approach is both substantially faster and more accurate than competitors, leading to good predictions of creativity.

Joint work with Ingrid Daubechies, Bruno Cornelis, Joshua Vogelstein and Francesca Petralia

December 9 & 10, 2012

The Science in Art: Applications of Pump-Probe Microscopy

Tana Elizabeth Villafana
Center for Molecular and Biomolecular Imaging
Duke University

Tana is a graduate student working with the Center for Molecular and Biomolecular Imaging. She has been the lead researcher in the Art Imaging Initiative, and the primary link between Duke and the North Carolina Museum of Art. Her current work is studying the utility of pump-probe microscopy in imaging historical mediums, including pigments, pottery, historical documents, and mummified skin.

Abstract:

The interplay of art and science is subtle, but important. Art conservators need strong support from the scientific community in order to address the many issues that arise during preservation. Uncovering the ideal or original state of an object is vital to ensuring its proper restoration. For a painting, this may include identifying the nature and source of the pigments; the thickness and composition of layers that give rise to the texture and depth of the final appearance, or even identifying degradation pathways and products of certain aged pigments. For pottery, low- and high-fired pieces require different treatments, which will also depend on the nature of the glaze and the chemical components of the clay. Optical pump-probe microscopy provides three-dimensional, chemical specific images of historical pigments, with far reaching applications for conservation science. Demonstrated applications here include the geo-sourcing of lapis lazuli, a historically important blue pigment, completely non-destructive depth imaging on a 14th century painting, differentiation of earth pigments applied to inferring pottery firing conditions, and distinction between cadmium yellow and its degradation products in a cross section taken from The Joy of Life by Henri Matisse.

The Restoration of a Roman Urn with the Er:YAG Laser

Adele De Cruz, PhD
Center for Molecular and Biomolecular Imaging
Duke University

Prof. De Cruz received her degree in conservation from the Institute of Fine Arts in Florence. She has worked in the conservation sciences at the Vatican Museums in Rome, the Opera del Duomo in Pisa, and most recently at the North Carolina Museum of Art. Her recent work has expanded the boundaries of the role of lasers in fine arts conservation and restoration.

Abstract:

This Roman funerary urn, 67-100 CE, was acquired by the St. Louis Art Museum in 1922 and never exhibited because of the intractable encrustation on the surface of the marble. It was sent to the conservation laboratory at Duke University for cleaning with the Erbium:YAG laser at 2.94um. Testing demonstrated that the encrustation was a combination of organic materials which over the millennia had transformed to oxalates. The Er:YAG laser successfully removed much of the encrustation, leaving behind some discoloration that is now a permanent part of the marble.

Synchronous Digitization: Spanning the Duty Cycle – Dynamic Range Abyss
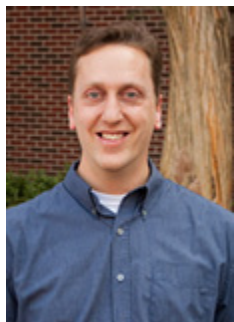
Garth Simpson, PhD
Professor of Chemistry
Purdue University

Prof. Simpson received his degree from the University of Colorado, Boulder, with Prof. Kathy Rowlen's lab. He performe his postdoctoral work at Stanford University before joining the faculty at Purdue University. His research focuses on nonlinear optical imaging, especially using chiral crystals to improve precision and reduce measurement time.

Abstract:

Direct digitization of the voltage transients from every laser pulse provides access to algorithms for maximizing the signal to noise (S/N) in nonlinear optical imaging based on detection with a single "universal platform". For measurements based on trace light detection (e.g., CARS, SHG, TPEF), statistical analysis is shown to allow S/N approaching the theoretical maximum throughout an LDR limited by the dark counts of the detector on the low end and by the intrinsic nonlinearities of the photomultiplier tube (PMT) detector on the high end. Measurements based on detection of subtle modulation of a large signal (e.g., SRG, SRL, homodyne SHG) are also compatible with the same measurement platform, providing significant signal to noise advantages over detection by lock-in amplification. Applications in second harmonic generation (SHG) microscopy are described demonstrating quantitation over a >four-decade linear dynamic range. Comparison of homodyne SHG measurements based on polarization-modulation resulted in significant S/N improvements, enabled in part by algorithms that are inaccessible in conventional lock-in detection. High information-density data acquisition (up to 3.2 GB/s of raw data) enables the smooth transition between these modalities on a pixel-by-pixel basis on four data channels and the ultimate writing of much smaller files (few kB/s).

Three-Dimensional Visualization in a Clinical Setting

Geoffrey Rubin, MD
Professor and Chair of Radiology
Duke University

Dr. Rubin received his degree from the University of California, San Diego, School of Medicine. He is currently the Chair of the Department of Radiology, where he performs research in pulmonary imaging, along with his clinical and administrative duties.

Real-time Standoff Detection and Imaging: From Air Lasing to CARS

Arthur Dogariu, PhD
Research Scholar, Department of Mechanical and
 Aerospace Engineering
Princeton University

Dr. Dogariu received his degree in physics from the College of Optics & Photonics at the University of Central Florida. He performed his postdoc work at UC-Santa Barbara and worked with NEC Research Institute before joining Princeton. His current research covers a broad range of imaging technologies, including remote sensing, atomic spectroscopy, and wave propagation in dispersive media.

Abstract:

Many applications such as environmental, industrial, or homeland security require the development of methods of probing the atmosphere remotely. We will present our remote sensing capabilities, including Radar REMPI (Resonantly-Enhanced Multi-Photon Ionization), and a recently demonstrated remote air laser. High gain stimulated emission can be achieved by focusing an UV laser in air to produce and excite oxygen atoms. We study the backscattered emission and conclude on its lasing properties. The standoff air laser can be used as a remote detector for molecular and atomic species which affect the optical propagation of the pump laser either directly, or via optical stimulation.

Other applications require the standoff detection and imaging of solid targets. We demonstrate the use of Coherent Anti-Stokes Raman Spectroscopy (CARS) for real-time standoff molecular detection of chemical, biological, and explosive traces. In particular, explosive threat detection requires a standoff detection system capable of selectively distinguishing trace amounts of explosive residues on external surfaces in a non-destructive way. We investigate the real-time imaging capability for wide area detection by using a Line-CARS configuration and fast hyper-spectral imaging algorithms.

Imaging Structure and Function of the Airway Using
Optical Coherence Tomography

Amy Oldenburg, PhD
Assistant Professor of Physics and Astronomy
Biomedical Research Imaging Center
University of North Carolina at Chapel Hill

Prof. Oldenburg received her degree in physics and performed her postdoctoral work at the University of Illinois at Urbana-Champaign, where she developed optical coherence tomography imaging systems. She created the Optical Coherence Imaging Laboratory after joining the faculty at UNC Chapel Hill in 2008. Her current research ranges from visco-elasticity imaging to work with magnetically-labeled platelets.

Abstract:

Optical coherence tomography (OCT) is uniquely suited for studying the human airway, as it can provide depth-resolved imaging on a scale from a few micrometers, to study processes such as muco-ciliary clearance, up to several centimeters to map the airway anatomy. Related to imaging on the microscale, the maintenance of airway health is linked to the body's ability to remove inhaled pathogens that become trapped in airway mucus. The viscoelastic properties of mucus are strongly linked to the rate of muco-ciliary clearance, and mucus thickening in diseases such as COPD and cystic fibrosis leads to chronic lung infection. We present a method for imaging viscoelastic properties with OCT by monitoring the rotational diffusion of plasmonic gold nanorods (GNRs). Methods in dynamic light scattering are employed to infer viscoelastic medium properties from the fluctuating, cross-polarized light scattering signal of GNRs. At the same time, ultrahigh-resolution OCT offers real-time visualization of muco-ciliary clearance, affording quantitative measures of the mucus thickness, clearance rate, and ciliary beat frequency.
On the centimeter scale, an anatomical OCT (aOCT) instrument is being developed for structural airway imaging in children suffering from upper airway obstructions. This instrument pushes the boundaries of long-range imaging under the limitations endemic to working within the small bore (1.2mm) of a pediatric bronchoscope. Our hope is that real-time aOCT of the airway geometry during respiration will enable improved airflow models with higher predictive value.

Molecular Imaging Using Spectroscopic Optical Coherence Tomography

Francisco Robles, PhD
Department of Chemistry
Duke University

Dr. Francisco (Paco) Robles received his PhD in Medical Physics at Duke University, working on optical coherence tomography with Prof. Adam Wax's group. His current work in the Warren lab focuses on novel microscopy methods for functional and molecular contrast in order to achieve earlier and better diagnoses.

Abstract:

The behavior of light after interacting with a biological medium reveals a wealth of information that may be used to distinguish between normal and numerous disease states. This may be achieved by imaging the morphology of tissues, and/or by more sophisticated methods that provide molecular specificity. To this end, we have developed tools that provide insight into the wavelength-dependent scattering and absorptive properties of tissues with high spectral resolution, as well as micrometer spatial resolution. Our approach consists of a novel form of spectroscopic optical coherence tomography (SOCT), which utilizes a dual window processing method to overcome the resolution trade-off that is associated with other processing methods, and it employs the visible region of the spectrum to enhance the sensitivity to chromophores, such as hemoglobin. Recent works that investigate the wavelength-dependent scattering and absorbing properties of samples for molecular imaging will be discussed.