Inverse Transport Theory and Tomography
May 16–21, 2010

MEALS

*Breakfast (Buffet): 7:00–9:30 am, Sally Borden Building, Monday–Friday
*Lunch (Buffet): 11:30 am–1:30 pm, Sally Borden Building, Monday–Friday
*Dinner (Buffet): 5:30–7:30 pm, Sally Borden Building, Sunday–Thursday
Coffee Breaks: As per daily schedule, 2nd floor lounge, Corbett Hall
***Please remember to scan your meal card at the host/hostess station in the dining room for each meal.**

MEETING ROOMS

All lectures will be held in Max Bell 159 (Max Bell Building accessible by walkway on 2nd floor of Corbett Hall). LCD projector, overhead projectors and blackboards are available for presentations. Note that the meeting space designated for BIRS is the lower level of Max Bell, Rooms 155–159. Please respect that all other space has been contracted to other Banff Centre guests, including any Food and Beverage in those areas.

SCHEDULE

Sunday

16:00	Check-in begins (Front Desk - Professional Development Centre - open 24 hours)
	Lecture rooms available after 16:00 (if desired)
17:30–19:30	Buffet Dinner, Sally Borden Building
20:00	Informal gathering in 2nd floor lounge, Corbett Hall
	Beverages and a small assortment of snacks are available on a cash honor system.

Monday

7:00–8:45	Breakfast
8:45–9:00	Introduction and Welcome by BIRS Station Manager, Max Bell 159
9:00–9:40	**Anthony Davis**, *3D Optical Tomography of the Earths Particulate Atmosphere: A Challenge for the Next Generation of Satellites and Algorithms*
9:40–10:20	**Pedro González**, *Combining diffuse optical tomography and spectroscopy to detect and characterize lesions in tissues*
10:20–10:50	Coffee Break, 2nd floor lounge, Corbett Hall
10:50–11:30	**Kim Arnold**, *Optical tomography in epithelial tissues*
11:30–12:10	**Alison Malcolm**, *Time-reversal determination of acoustic scattering properties*
12:10–13:00	Lunch
13:00–14:00	Guided Tour of The Banff Centre; meet in the 2nd floor lounge, Corbett Hall
14:00	Group Photo; meet on the front steps of Corbett Hall
14:15–14:55	**Lihong Wang**, *Photoacoustic Tomography: Breaking through the Optical Diffusion Limit*
14:55–15:30	Coffee Break, 2nd floor lounge, Corbett Hall
15:30–16:10	**Sarah Patch**, *Thermoacoustic Tomography — Contrast Mechanism over Large Fields of View*
16:10–16:50	**Otmar Scherzer**, *Photoacoustic tomography taking into account attenuation*
16:50–17:50	Discussion I: *Inverse Transport*
17:50–19:30	Dinner

Tuesday

7:00–9:00	Breakfast
9:00–9:40	**Sean Holman**, *Microlocal methods in polarization tomography*
9:40–10:20	**Alexandre Bukhgeim**, *Some Tomography Problems on the Plane*
10:20–11:00	Coffee Break, 2nd floor lounge, Corbett Hall
11:00–11:40	**Hongkai Zhao**, *Radiative transport equation based optical imaging*
11:40–13:30	Lunch
13:30–14:10	**Mikko Salo**, *Attenuated geodesic ray transform on simple surfaces*
14:10–14:50	**Matti Lassas**, *X-ray tomography and discretization of inverse problems*
14:50–15:30	Coffee Break, 2nd floor lounge, Corbett Hall
15:30–16:10	**Vadim Markel**, *Broken Ray Tomography*
16:10-16:50	**Kui Ren**, *Numerical investigation of a nonlinear inverse source problem for the Boltzmann-Poisson system*
16:50–17:20	**Nicholas Hoell**, *The Method of Complexification*
17:30–19:30	Dinner

Wednesday

7:00–9:00	Breakfast
9:00–9:40	**Yaroslav Kurylev**, *Collapse of Riemannian manifolds and stability of the inverse bounadary spectral problem*
9:40–10:20	**Gen Nakamura**, *Time resolved diffusive optical tomography*
10:20–10:50	Coffee Break, 2nd floor lounge, Corbett Hall
10:50–11:30	**Peter Kuchment**, *Detection of small low emission sources on a large random background*
11:30–12:10	**Ting Zhou**, *Reconstructing electromagnetic obstacles by the enclosure method*
12:10–13:30	Lunch
	Free Afternoon

Thursday

7:00–9:00	Breakfast
9:00–9:40	**Andreas Hielscher**, *From Mice To Man: Towards Clinical Utility of Optical Tomographic Imaging*
9:40–10:20	**Hongyu Liu**, *On Approximate Acoustic and Electromagnetic Cloaking*
10:20–10:50	Coffee Break, 2nd floor lounge, Corbett Hall
10:50–11:30	**Roger Zemp**, *Multiple Illumination Photoacoustic Tomography*
11:30–12:10	**Ian Langmore**, *Importance sampling and Adjoint Hybrid Methods in Monte Carlo Transport*
12:10–13:30	Lunch
13:30–14:10	**Alexandre Jollivet**, *Stability in inverse transport theory*
14:10–14:50	**Alexandru Tamasan**, *Gauge equivalence in inverse stationary transport*
14:50–15:20	Coffee Break, 2nd floor lounge, Corbett Hall
15:20–16:00	**Tanja Tarvainen**, *Approximation error approach for compensating for modelling errors in diffuse tomography*
16:00–16:30	**Francois Monard**, *An accurate solver for forward and inverse transport*
16:30–17:30	Discussion II: *Tomography*
17:30–19:30	Dinner

Friday

7:00–9:00	Breakfast
9:20–10:30	Informal Discussion III
10:30–11:00	Coffee Break, 2nd floor lounge
11:30–13:30	Lunch
Checkout by 12 noon.	

** 5-day workshops are welcome to use BIRS facilities (2nd Floor Lounge, Max Bell Meeting Rooms, Reading Room) until 3 pm on Friday, although participants are still required to checkout of the guest rooms by 12 noon. **

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ABSTRACTS
(in alphabetic order by speaker surname)

Speaker: **Alexandre Boukhgueim** (Wichita State University)
Title: *Some Tomography Problems on the Plane*
Abstract: The purpose of this talk is to provide an overview of basic analytic and numerical tools for solving inverse two-dimensional problems for the transport equation and elliptic equations that were developed in last several years. In particular we shall discuss the problem of recovering the attenuation coefficient and the right hand side of the transport equation; and the problem of reconstruction of the refractive index for the Helmholtz equation.

Speaker: **Anthony B. Davis** (CalTech)
Title: *3D Optical Tomography of the Earths Particulate Atmosphere: A Challenge for the Next Generation of Satellites and Algorithms (with Paul von Allmen, and David J. Diner)*
Abstract: Clouds (liquid and solid water particles) and aerosols (dust, sulfates, salt, carbon, organics, etc.) have a huge radiative impact on the Earth's climate balance. Yet their quantities and optical properties are still very hard to predict in the global climate models that are put to task for the Intergovernmental Panel on Climate Change (IPCC) process. Remote sensing of these atmospheric particulates is therefore a major part of several current and future missions by NASA, ESA and other space agencies world-wide. At present, the remote sensing community views the atmosphere as a horizontal 2D array of "pixels" where the radiative transfer that determines the observed radiances unfolds strictly in the vertical: it is "1D" from the spatial perspective. So the atmospheric columns associated with the pixels are deemed either cloudy or clear (i.e., aerosols-only) and processed accordingly to infer physical properties. In reality of course the atmosphere and the radiative transfer are 3D, and this is observed in superb detail by Multi-angle Imaging Spectro-Radiometer (MISR) on NASA's flagship Terra satellite, now over 10 years in orbit. There are many reasons—and we will mention some—for the atmospheric remote sensing community to transcend the old plane-parallel/1D paradigm and embrace a 3D "tomographic" perspective.

In this talk, several MISR anaglyphs will be shown (green/red glasses provided). We will then survey the recent steps that have been taken toward fully-3D cloud/aerosol remote sensing, i.e., atmospheric tomography. Both active and passive techniques have been explored covering the EM spectrum from the visible to the microwaves. We will focus more on the short (solar/laser) wavelengths and demonstrate that there are interesting analogies between atmospheric and medical imaging. Once the technical challenge and observational resources are understood, the Earth's particulate atmosphere may inspire new applications for advanced methods in inverse transport theory as well as in physics-based tomography.

Speaker: **Pedro González** (University of Carlos III de Madrid)
Title: *Combining diffuse optical tomography and spectroscopy to detect and characterize lesions in tissues*
Abstract: We combine diffuse optical tomography (DOT) for detecting and localizing an inhomogeneity in tissue and diffuse optical spectroscopy (DOS) for characterizing the spectrum of that inhomogeneity. For detecting and localizing an inhomogeneity, we reduce the number of unknowns substantially by seeking only the location and size of the obstacle. Then, we seek to recover an unknown specific tumor component of that inhomogeneity from spectral data. In doing so, we develop a method for distinguishing between a tumor and normal tissue. We demonstrate the utility of this theory with numerical simulations.

Speaker: **Andreas Hielscher** (Columbia University)
Title: *From Mice To Man: Towards Clinical Utility of Optical Tomographic Imaging*

Abstract: Optical tomography (OT) is an emerging biomedical imaging modality that employs visible and near-infrared light to probe biological tissues. Unlike many other medical imaging modalities, such as X-ray imaging or positron emission tomography, OT does not relay on potentially harmful radiation. Furthermore, the high contrast of many optical markers promises disease detection on the molecular level. However, this technology still has to overcome some major hurdles before true clinical utility can be achieved. For example, it is well established that he most accurate image reconstruction schemes are based on the equation of radiative transfer (ERT). But the accuracy comes at the cost of long computation times. Besides a general overview on how to implement ERT-based reconstruction algorithms, I will focus in this talk on various method that accelerated the image reconstruction process. PDE-constrained algorithms, SPN methods and parametric reconstruction techniques will be discussed. Furthermore, instrumentation that incorporates digital-signal-processing (DSP) chip technology has significantly increased the signal-to-noise ratios, and ever-smaller signals can be detected in shorter times. This opens the doors to novel applications in dynamic optical tomography. I will present practical examples encountered in clinical and preclinical imaging such as monitoring of tumor growth and regression, effects of anti-angiogenic drugs in pediatric cancer treatment, breast cancer screening, and detection of arthritis. An overview of our most recent advances in machine learning approaches to computer-aided diagnostic (CAD) for OT image classification concludes the talk.

Speaker: **Nicholas Hoell** (Columbia University)
Title: *The Method of Complexification*
Abstract: We introduce a technique for recovering a sufficiently smooth function from its ray transform over a wide class of curves in a general region of Euclidean space. The method is based on a complexification of the underlying vector fields defining the initial transport and recasting the problem in terms of complex-analytic function theory. Explicit inversion formulas are then given in a unified form. The method is then used to give inversion formulae for the attenuated ray transform.

Speaker: **Sean Holman** (Purdue University)
Title: *Microlocal methods in polarization tomography*
Abstract: We consider the non-linear problem of polarization tomography on a Riemannian manifold. In three dimensional Euclidean space this corresponds to a physical problem of recovering some electrical properties of a medium from polarization measurements, but we consider a generalization to arbitrary dimensions introduced by Novikov and Sharafutdinov. Using microlocal methods we are able to show generic injectivity for a linearization of this problem near arbitrary background media in greater than three dimensions, and the same in three dimensions with some additional hypotheses. These results for the linearized problem lead to local uniqueness results for the non-linear problem.

Speaker: **Alexandre Jollivet** (Université de Cergy-Pontoise)
Title: *Stability in inverse transport theory*
Abstract: We give stability estimates for the reconstruction of the optical parameters in the stationary or non stationary linear Boltzmann transport equation from angularly and spatially resolved measurements and angularly and spatially resolved boundary sources. Then for the nonstationary case we give uniqueness and stability results for the reconstruction of those parameters from angularly averaged and spatially resolved boundary measurements and isotropic spatially resolved boundary sources. These results are of interest in optical tomography. The problem of the reconstruction of the optical parameters from internal angularly averaged measurements in the stationary case will be also addressed and is of interest for photoacoustic tomography.

Speaker: **Arnold Kim** (UC Merced)
Title: *Optical tomography in epithelial tissues*
Abstract: We describe a method to reconstruct a small, point-like absorbing obstacle contained within the top layer of a two-layer halfspace from boundary measurements of backscattered light. This problem is a

model for detecting early stages of cancer development in thin epithelial tissues that reside on top of thick stromal tissues. By using the fact that this epithelial layer is relatively thin, we construct an asymptotic approximation for the solution of the direct problem that allows for an analytical reconstruction formula.

Speaker: **Peter Kuchment** (Texas A&M University)
Title: *Detection of small low emission sources on a large random background*
Abstract: The problem to be addressed is the plausibility of detecting presence of a geometrically small and low emission source, when the background noise about thousand times exceeds the source signal. This problem, arising in applications, is akin to the one of the well known Single Photon Emission Tomography (SPECT) in medical imaging, except that the signal here is much weaker than in SPECT, while the noise is much higher. It will be discussed what kinds of detectors could be appropriate and what mathematical approaches can be used for detection. Results of numerical experiments confirming validity of the suggested techniques will be also presented. The work was done with a team of graduate and undergraduate students at Texas A&M University (M. Allmaras, D. Darrow, Y. Hristova, X. Xun).

Speaker: **Yaroslav Kurylev** (University College London)
Title: *Collapse of Riemannian manifolds and stability of the inverse bounadary spectral problem (joint with M. Lassas and T. Yamaguchi)*
Abstract: We consider a class of n-dimensional Riemannian manifolds of bounded geometry which allows the 1-dimensional collapse. This collapse gives rise, in particular, to (n-1)-dimensional Riemannian orbifolds with non-trivial weight function. We show the uniqueness of the inverse spectral problem for the associated weighted Laplacians on Riemannian orbifolds. We also show that the stability, in the Gromov-Hausdorff metric, of the inverse spectral problem for the original class of Riemannian manifolds

Speaker: **Ian Langmore** (Columbia University)
Title: *Importance sampling and Adjoint Hybrid Methods in Monte Carlo Transport*
Abstract: Boundary measurements of photon transport are simulated using a Monte Carlo scheme. Various importance sampling techniques are used. These are seen to be approximations of a zero-variance technique that employees a deterministic adjoint solution. Methods are tested numerically in a complicated 2-D domain with a small boundary detector. Applications to inverse problems are considered.

Speaker: **Matti Lassas** (University of Helsinki)
Title: *X-ray tomography and discretization of inverse problems*
Abstract: In this talk we consider the question how inverse problems posed for continuous objects, for instance for continuous functions, can be discretized. This means the approximation of the problem by infinite dimensional inverse problems. We will consider linear inverse problems of the form $m = Af + \epsilon$. Here, the function m is the measurement, A is a ill-conditioned linear operator, u is an unknown function, and ϵ is random noise. The inverse problem means determination of u when m is given. In particular, we consider the X-ray tomography with sparse or limited angle measurements where A corresponds to integrals of the attenuation function $u(x)$ over lines in a family Γ. The traditional solutions for the problem include the generalized Tikhonov regularization and the estimation of u using Bayesian methods. To solve the problem in practice u and m are discretized, that is, approximated by vectors in an infinite dimensional vector space. We show positive results when this approximation can successfully be done and consider examples of problems that can appear. As an example, we consider the total variation (TV) and Besov norm penalty regularization, the Bayesian analysis based on total variation prior and Besov priors.

References:

[1] M. Lassas, S. Siltanen: Can one use total variation prior for edge preserving Bayesian inversion?, Inverse Problems 20 (2004), 1537-1564.

[2]. M. Lassas, S. Saksman, S. Siltanen: Discretization invariant Bayesian inversion and Besov space priors. Inverse Problems and Imaging 3 (2009), 87-122.

[3] M. Rantala, S. Vanska, S. Jarvenpaa, M. Kalke, M. Lassas, J. Moberg, S. Siltanen: Wavelet-based reconstruction for limited angle X-ray tomography. IEEE Transactions on Medical Imaging 25 (2006), 210-217.

[4] S. Siltanen, V. Kolehmainen, S. Jarvenpaa, J. Kaipio, P. Koistinen, M. Lassas , J. Pirttila, E. Somersalo: Statistical inversion for X-ray tomography with few radiographs I: General theory. Physics in Medicine and Biology 48 (2003) 1437-1463.

[5] T. Helin, M. Lassas: Hierarchical models in statistical inverse problems and the Mumford-Shah functional, arXiv:0908.3396v2.

Speaker: **Hongyu Liu** (University of Washington)
Title: *On Approximate Acoustic and Electromagnetic Cloaking*
Abstract: In this talk, we shall be concerned with acoustic and electromagnetic cloaking via transformation optics. Our recent study on approximate cloaking from a regularization viewpoint will be presented.

Speaker: **Alison Malcolm** (MIT)
Title: *Time-reversal determination of acoustic scattering properties*
Abstract: In many applications, sequestering CO2 underground for example, determining whether or not the medium has changed is of primary importance, with secondary goals of locating and quantifying that change. We consider an acoustic model of the Earth as a sum of a smooth background velocity, isolated velocity jumps and random small scale fluctuations. Although the first two parts of the model can be determined precisely, the random fluctuations are never known exactly and are thus modeled as a realization of a random process with assumed statistical properties. We exploit the so-called coda of multiply scattered energy recorded in such models to monitor for change and to localize and quantify that change, by examining the shape and frequency content of correlations of the coda at different locations in the medium. This results in an extension of time- reversal detection methods, at least numerically, to regimes in which the separation of scales is not strictly satisfied.

Speaker: **Vadim Markel** (University of Pennsylvania)
Title: *Broken Ray Tomography*
Abstract: The CT tomography based on the Radon transform inversion and the diffuse optical tomography can be viewed as two extreme limiting cases of the more general problem of inverting the radiative transport equation (RTE). The former imaging modality is applicable in the regime when scattering can be neglected while the latter modality is used when multiple scattering is dominating. We have recently proposed an imaging approach which is applicable in the intermediate regime of weak scattering when the optical depth of the medium is a few times the transport mean free path, ℓ^*. The method makes use of the broken-ray transform of the medium. The approach combines the advantages of CT (only mild ill-posedness and linearity of the inverse problem) with certain features which are characteristic of the diffuse optical tomography (multiple projections are not required, back-scattering measurements are sufficient and simultaneous reconstruction of the absorption and the scattering coefficients is feasible). A generalization of the filtered backprojection formula to the case of broken rays has been derived and tested in simulations.

Speaker: **Francois Monard** (Columbia University)
Title: *An accurate solver for forward and inverse transport*
Abstract: In the transport regime of the linear transport equation (radiative transfer), propagating singularities correctly in numerical simulations is a challenging yet crucial problem. The lack of doing so usually results in blurring effects and/or artifacts on reconstructions. We propose here an accurate and robust method for solving the steady-state linear transport equation, where the emphasis has been put on making sure that the information travels accurately across the domain. The method is the classical discrete ordinates/source iteration method, where the propagation problems are solved on a computational grid that is rotated in order to be aligned with the direction of propagation. We will present the main features of the code as well as its use in some inverse transport problems. Joint work with Guillaume Bal.

Speaker: **Gen Nakamura** (Hokkaido University)
Title: *Time resolved diffusive optical tomography*
Abstract: As an application of the dynamical probe method for detecting unknown inclusions in heat conductors, we provide some reconstruction scheme for time resolved diffusive optical tomography

Speaker: **Sarah Patch** (University of Wisconsin-Milwaukee)
Title: *Thermoacoustic Tomography — Contrast Mechanism over Large Fields of View*
Abstract: Thermoacoustic tomography is a hybrid imaging technique combining electromagnetic (EM) excitation (similar to MRI) with ultrasound receivers. Ideal EM excitation pulses are homogeneous in space and impulsive in time. Just as in MRI, the patient tissue itself wreaks havoc with mathematically elegant 0th order imaging equations. The hard realities of signal excitation in practice will be discussed along with more physical models of thermoacoustic signal excitation.

Speaker: **Kui Ren** (University of Texas at Austin)
Title: *Numerical investigation of a nonlinear inverse source problem for the Boltzmann-Poisson system*
Abstract: We investigate numerically an inverse source problem related to the Boltzmann-Poisson system of equations for transport of electrons in semiconductor devices. The objective of the (ill-posed) inverse problem is to recover the doping profile of a device, presented as source function in the mathematical model, from its current-voltage characteristics. To reduce the degree of ill-posedness of the inverse problem, we proposed to parameterize the unknown doping profile function to limit the number of unknowns in the inverse problem. We showed by numerical examples that the reconstruction of a few low moments of the doping profile is possible when relatively accurate measurements are available. We also compare reconstructions from the Boltzmann-Poisson model to those from the classical drift-diffusion-Poisson model, assuming that measurements are generated with the former model. We show that the two type of reconstructions can be significantly different in certain regimes. This is a joint work with Yingda Cheng and Irene Gambaat UT Austin.

Speaker: **Mikko Salo** (University of Helsinki)
Title: *Attenuated geodesic ray transform on simple surfaces*
Abstract: We prove that the attenuated geodesic ray transform for functions is invertible on simple 2D manifolds, with arbitrary attenuation coefficient. We prove a similar result for 1-forms. The proof uses complex analysis and involves a geometric version of ideas of Arbuzov-Bukhgeim-Kazantsev, Novikov, and Boman-Strömberg in the Euclidean case.

This is a joint work with Gunther Uhlmann (University of Washington).

Speaker: **Otmar Scherzer** (University Vienna and the Radon Institute)
Title: *Photoacoustic tomography taking into account attenuation*
Abstract: Photoacoustic Imaging is a promising new modality for non destructive evaluation. In this work we review models that take into account attenuation, and investigate their causality property. In the second part of the talk we present some photoacoustic tomographic imaging which takes into account attenuation. Thereby we use an attenuation law, which is documented in the physical literature for oil. In this case the equation describing wave propagation has a fractional derivative inside. This equation has to be “inverted for imaging. joint work with R. Kowar.

Speaker: **Alexandru Tamasan** (University of Central Florida)
Title: *Gauge equivalence in inverse stationary transport*
Abstract: In the case of anisotropic attenuation there is non-uniqueness in the inverse problem of stationary transport: gauge equivalent pairs of coefficients yield the same albedo operator. I will explain the gauge equivalence and show that equivalent classes can be stably determined by the albedo operator. This is joint work with Plamen Stefanov and Stephen McDowall.

Speaker: **Tanja Tarvainen** (University of Eastern Finland)
Title: *Approximation error approach for compensating for modelling errors in diffuse optical tomography*
Abstract: Image reconstruction in diffuse optical tomography (DOT) is a non-linear ill-posed inverse problem. Thus, it tolerates measurement and modelling errors poorly. The modelling errors arise, for example, from using approximate forward models which are unable to describe the measurements with adequate accuracy. Furthermore, model reduction by using too coarse discretization in the solution of the forward problem can cause errors to the solution.

In DOT the most typical approach is to use the diffusion approximation (DA) to the radiative transport equation (RTE) as forward model. The DA is basically a special case of the first order spherical harmonics approximation to the RTE, and thus it has some limitations. Firstly, the medium is assumed to be scattering dominated, and secondly light propagation can not be modelled accurately close to the collimated light sources and boundaries.

Recently, a Bayesian approach for the treatment of modelling errors has been proposed (Kaipio and Somersalo 2005 *Statistical and Computational Inverse Problems*). In the Bayesian framework, all variables are modelled as random variables. In the approximation error approach, also the computational model inaccuracy is represented as a random variable and the statistical properties of the modelling errors are computed before the reconstructions.

In this work, we consider utilising the approximation error approach for compensating for modelling errors between the RTE and the DA. Further, different density discretizations of the forward solution are investigated.

Speaker: **Lihong V. Wang** (Washington University in St. Louis)
Title: *Photoacoustic Tomography: Breaking through the Optical Diffusion Limit*
Abstract: We develop photoacoustic imaging technologies for in vivo early-cancer detection and functional imaging by physically combining non-ionizing electromagnetic and ultrasonic waves. Unlike ionizing x-ray radiation, non-ionizing electromagnetic waves, such as optical and radio waves, pose no health hazard and, at the same time, reveal new contrast mechanisms. Unfortunately, electromagnetic waves in the non-ionizing spectral region do not penetrate biological tissue in straight paths as x-rays do. Consequently, high-resolution tomography based on non-ionizing electromagnetic waves alone, as demonstrated by confocal microscopy and two-photon microscopy as well as optical coherence tomography, is limited to superficial imaging within about one optical transport mean free path ($\sim$ 1 mm in the skin) of the surface of biological tissue. Ultrasonic imaging, on the contrary, provides good image resolution but has strong speckle artifacts as well as poor contrast in early-stage tumors. We have developed ultrasound-mediated imaging modalities by combining electromagnetic and ultrasonic waves synergistically to overcome the above limitations. The hybrid modalities provide relatively deep penetration at high ultrasonic resolution and yield speckle-free images with high electromagnetic contrast. In photoacoustic computed tomography, a pulsed broad laser beam illuminates the biological tissue to generate a small but rapid temperature rise, which leads to emission of ultrasonic waves due to thermoelastic expansion. The short-wavelength pulsed ultrasonic waves are then detected by unfocused ultrasonic transducers. High-resolution tomographic images of optical contrast are then formed through image reconstruction. Endogenous optical contrast can be used to quantify the concentration of total hemoglobin, the oxygen saturation of hemoglobin, and the concentration of melanin. Melanoma and other tumors have been imaged in vivo in small animals. Exogenous optical contrast can be used to provide molecular imaging and reporter gene imaging. In photoacoustic microscopy, a pulsed laser beam is focused into the biological tissue to generate ultrasonic waves. The ultrasonic waves are then detected with a focused ultrasonic transducer to form a depth resolved 1D image directly. Raster scanning yields 3D high-resolution tomographic images. Super-depths beyond the optical diffusion limit have been reached with high spatial resolution. Thermoacoustic tomography is similar to photoacoustic tomography except that low-energy microwave pulses, instead of laser pulses, are used. Although long-wavelength microwaves diffract rapidly, the short-wavelength microwave-induced ultrasonic waves provide high spatial resolution, which breaks through the microwave diffraction limit. Microwave contrast measures the concentrations of water and ions.

Speaker: **Roger Zemp** (University of Alberta)
Title: *Multiple Illumination Photoacoustic Tomography*
Abstract: While photoacoustic methods offer significant promise for high-resolution optical-contrast imaging, quantification has thus far proved challenging. In this paper, a non-iterative reconstruction technique for producing quantitative photoacoustic images of both absorption and scattering perturbations is introduced for the case when the optical properties of the turbid background are known and when multiple optical illumination locations are used. Through theoretical developments and computational examples it is demonstrated that multiple optical source photoacoustic imaging can alleviate ill-posedness due to absorption-scattering non-uniqueness, and produce quantitative high-resolution and high-accuracy reconstructions of both absorption and scattering perturbations robust to spatially-varying Grueneisen coefficients.

Speaker: **Hongkai Zhao** (UC Irvine)
Title: *Radiative transport equation based optical imaging*
Abstract: I will discuss a fast forward solver for radiative transport equation (RTE), the most accurate model for in vivo photon migration which is crucial for optical and molecular imaging. Our algorithm is based on a novel multigrid method in both physical and angular space that can effectively deal with different regimes of transport. Then I will introduce a few a multi-level optical imaging algorithms that can achieve high resolution.

Speaker: **Ting Zhou** (University of Washington)
Title: *Reconstructing electromagnetic obstacles by the enclosure method*
Abstract: We show that one can determine Perfectly Magnetic Conductor obstacles, Perfectly Electric Conductor obstacles and obstacles satisfying impedance boundary condition, embedded in a known electromagnetic medium, by making electromagnetic measurements at the boundary of the medium. The boundary measurements are encoded in the impedance map that sends the tangential component of the electric field to the tangential component of the magnetic field. We do this by probing the medium with complex geometrical optics solutions to the corresponding Maxwell's equations and extend the enclosure method to this case. Moreover, using complex spherical waves, constructed by the inversion transformation with respect to a sphere, the enclosure method can recover some non-convex part of the obstacle.