Interior Tomography

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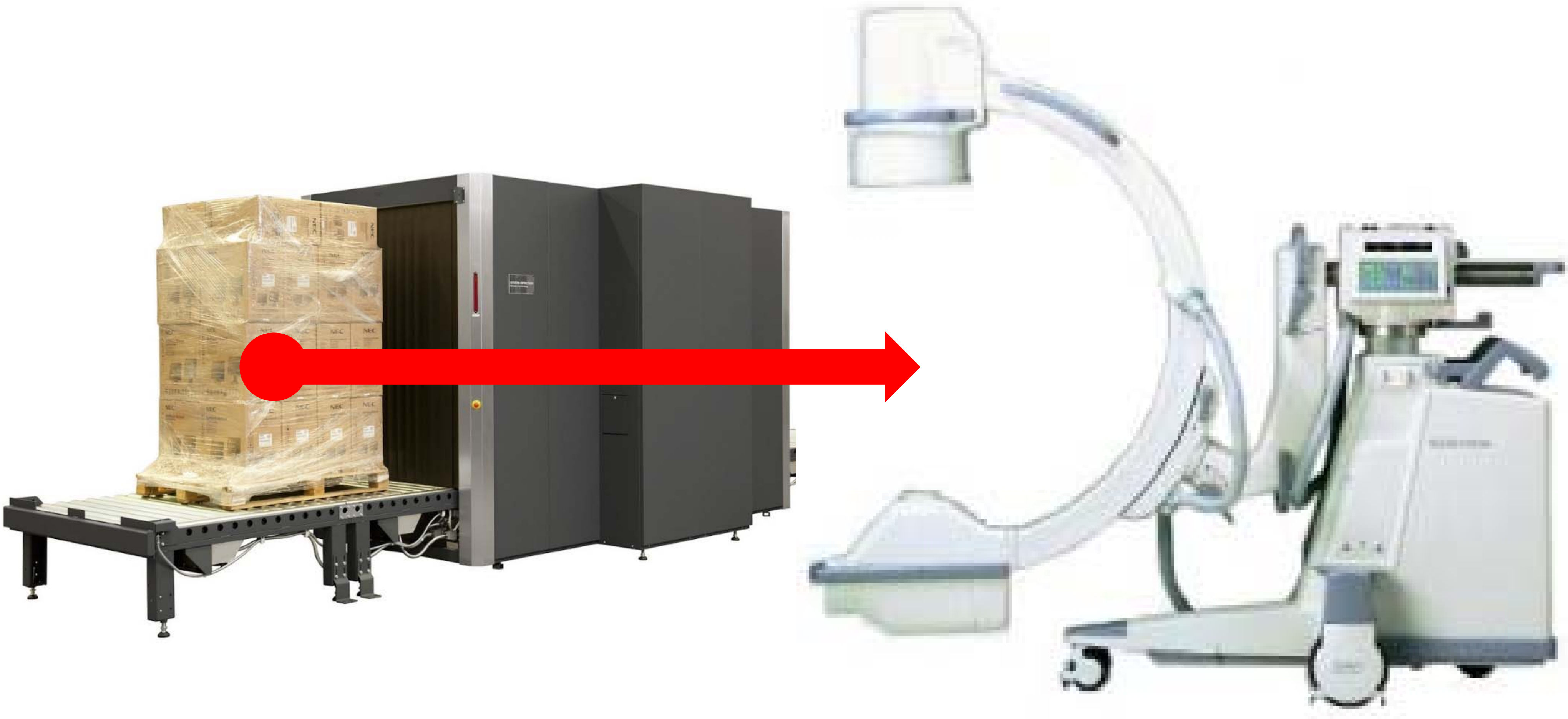
May 7, 2014

Detailed Look?

Automatic Workflow!



...ntly

...tiny are expected to

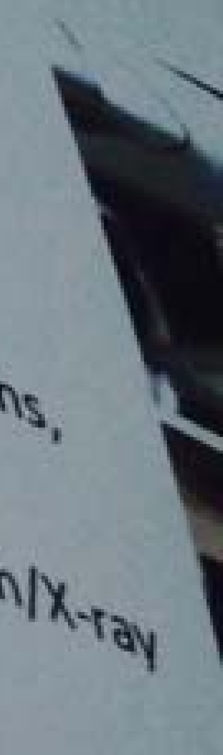
...potential threats – explosives, weapons,

..., prohibited materials, etc

CSIRO and Nuctech have developed a fast-neutron/X-ray scanner to address the problem

Major challenges

- Scanner - footprint, speed, reliability
- Imaging – small objects in large cargo
- People – effective process



Interior Tomography

IOP PUBLISHING PHYSICS IN MEDICINE AND BIOLOGY

Phys. Med. Biol. **58** (2013) R161–R186 doi:10.1088/0031-9155/58/16/R161

TOPICAL REVIEW

The meaning of interior tomography

Ge Wang[1] **and Hengyong Yu**[2,3]

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Received 30 August 2012, in final form 4 April 2013
Published 2 August 2013

Spiral/Helical Fan-beam CT

Computed tomography scanning with simultaneous patient translation

Carl R. Crawford and Kevin F. King
GE Medical Systems, Milwaukee, Wisconsin 53201

(Received 27 November 1989; accepted for publication 14 March 1990)

This paper deals with methods of reducing the total time required to acquire the projection data for a set of contiguous computed tomography (CT) images. Normally during the acquisition of a set of slices, the patient is held stationary during data collection and translated to the next axial location during an interscan delay. We demonstrate using computer simulations and scans of volunteers on a modified scanner how acceptable image quality is achieved if the patient translation time is overlapped with data acquisition. If the concurrent patient translation is ignored, structured artifacts significantly degrade resulting reconstructions. We present a number of weighting schemes for use with the conventional convolution/backprojection algorithm to reduce the structured artifacts through the use of projection modulation using the data from individual and multiple slices. We compare the methods with respect to structured artifacts, noise, resolution and to patient motion. Review of preliminary results by a panel of radiologists indicates that the residual image degradation is tolerable for selected applications when it is critical to acquire more slices in a patient breathing cycle than is possible with conventional scanning.

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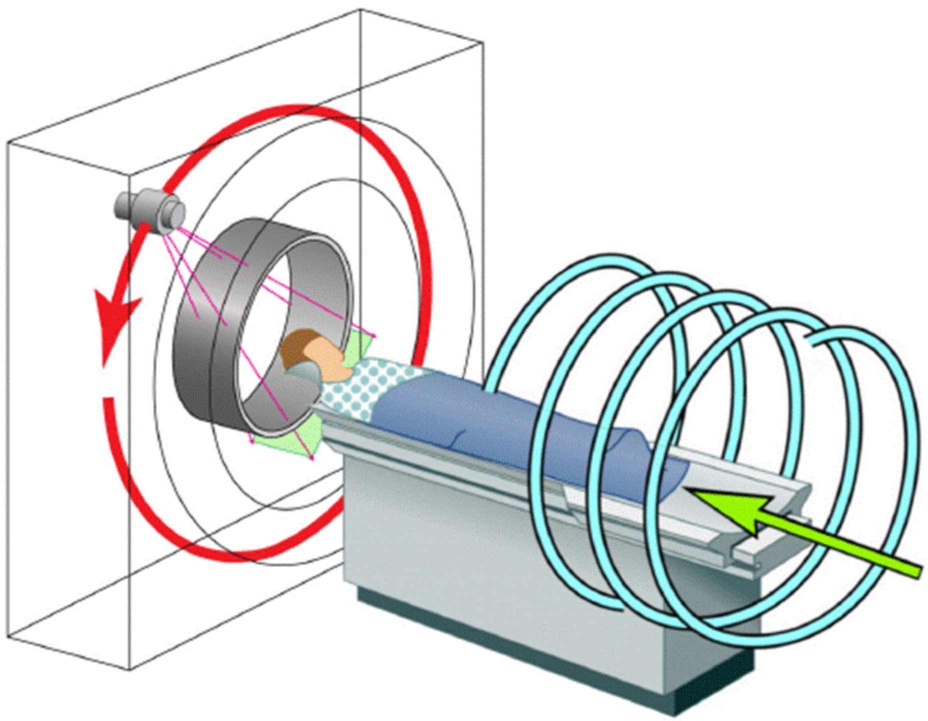
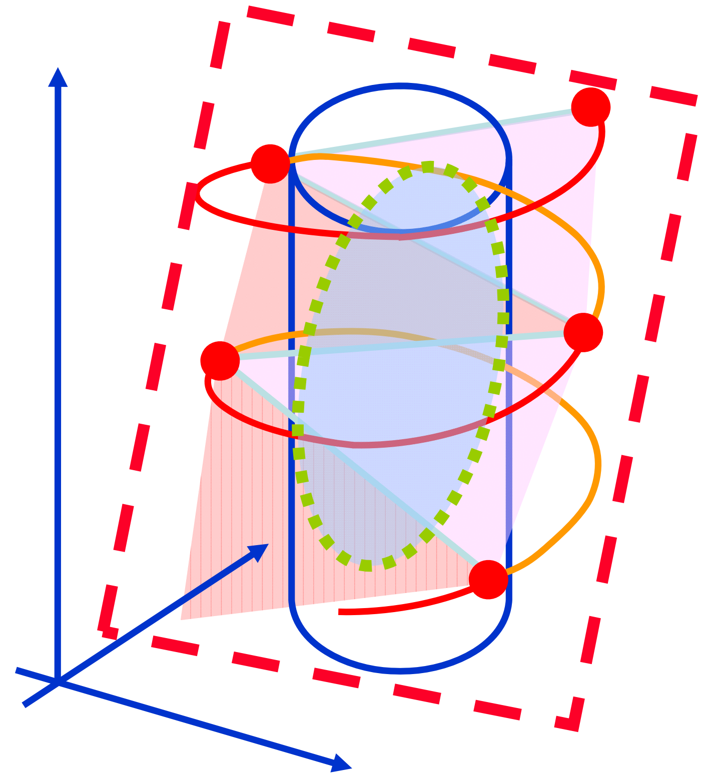
Spiral/Helical Multi-slice/Cone-beam CT





Wang, G, Lin, TH, Cheng PC, Shinozaki DM, Kim HG: Scanning cone-beam reconstruction algorithms for x-ray microtomography. Proc. SPIE 1556:99-112, July 1991

Wang G, Lin TH, Cheng PC, Shinozaki DM: A general cone-beam reconstruction algorithm. IEEE Trans. on Med. Imaging 12:486-496, 1993

Citation Counts

To solve the long-object problem, a first level of improvement with respect to the 2D FBP algorithms was obtained by backprojecting the data in 3D, along the actual measurement rays. The prototype of this approach is the algorithm of Wang et al.

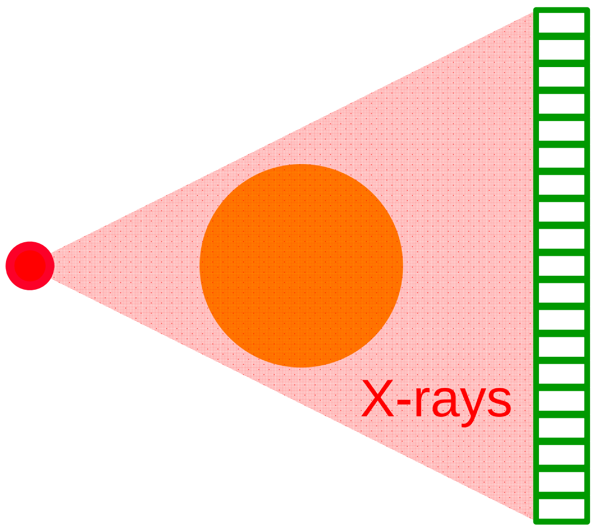
Defrise, Noo, Kudo: A solution to the long-object problem in helical cone-beam tomography. Phys. Med. Biol. 45:623-643, 2000

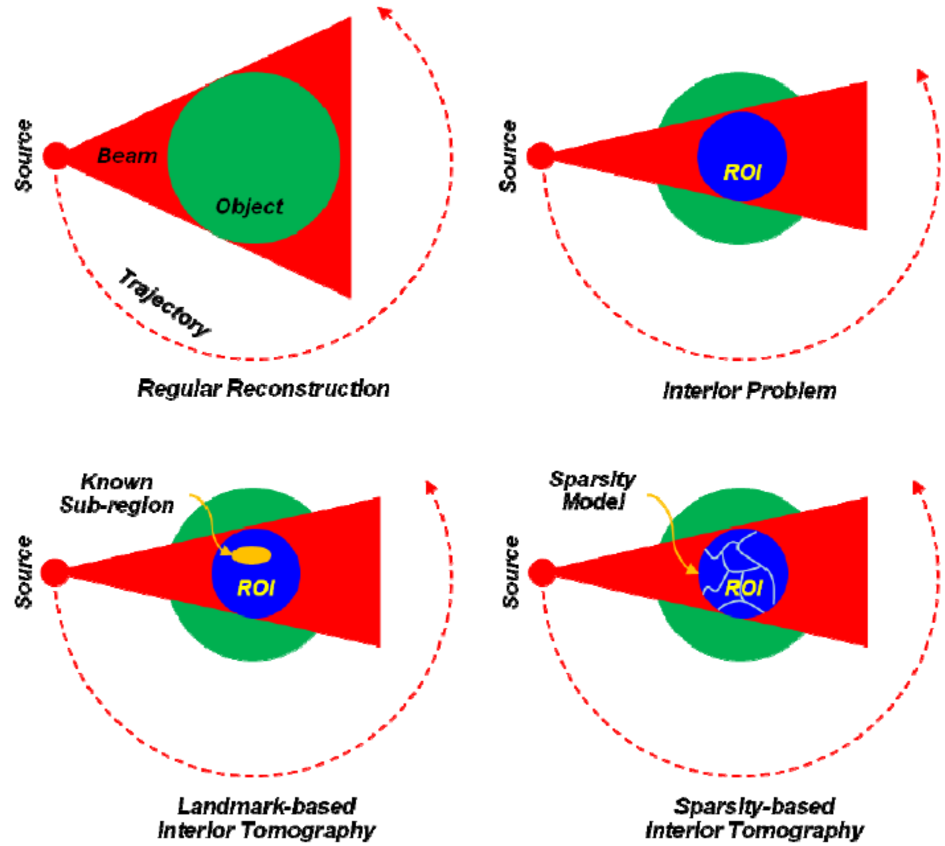
Many advances in CB reconstruction have been made recently thanks to the quest for an attractive reconstruction method in helical CB tomography.

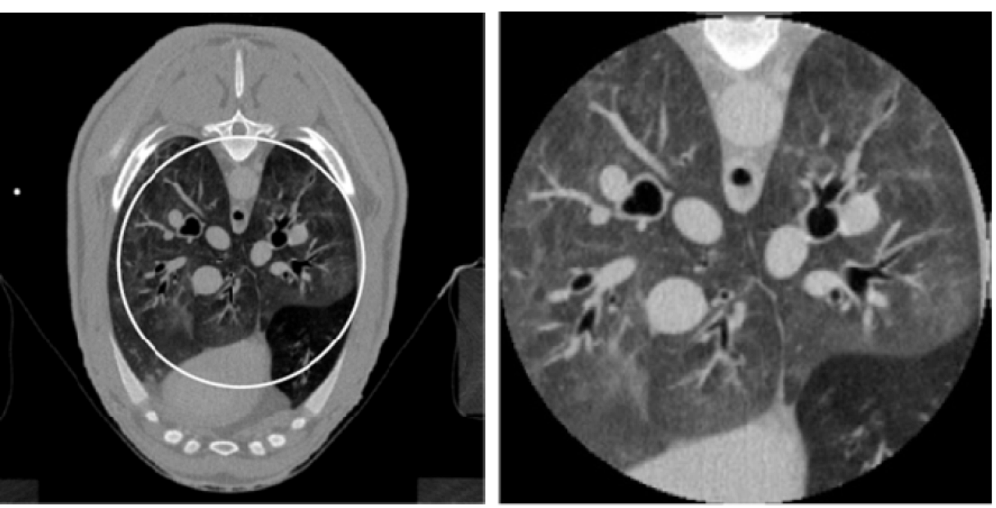
Pack, Noo, Clackdoyle: Cone-beam reconstruction using the backprojection of locally filtered projections. IEEE Trans. Medical Imaging 24:1-16, 2005

100M Multi-slice/Cone-beam CT Scans Annually

Interior Tomography



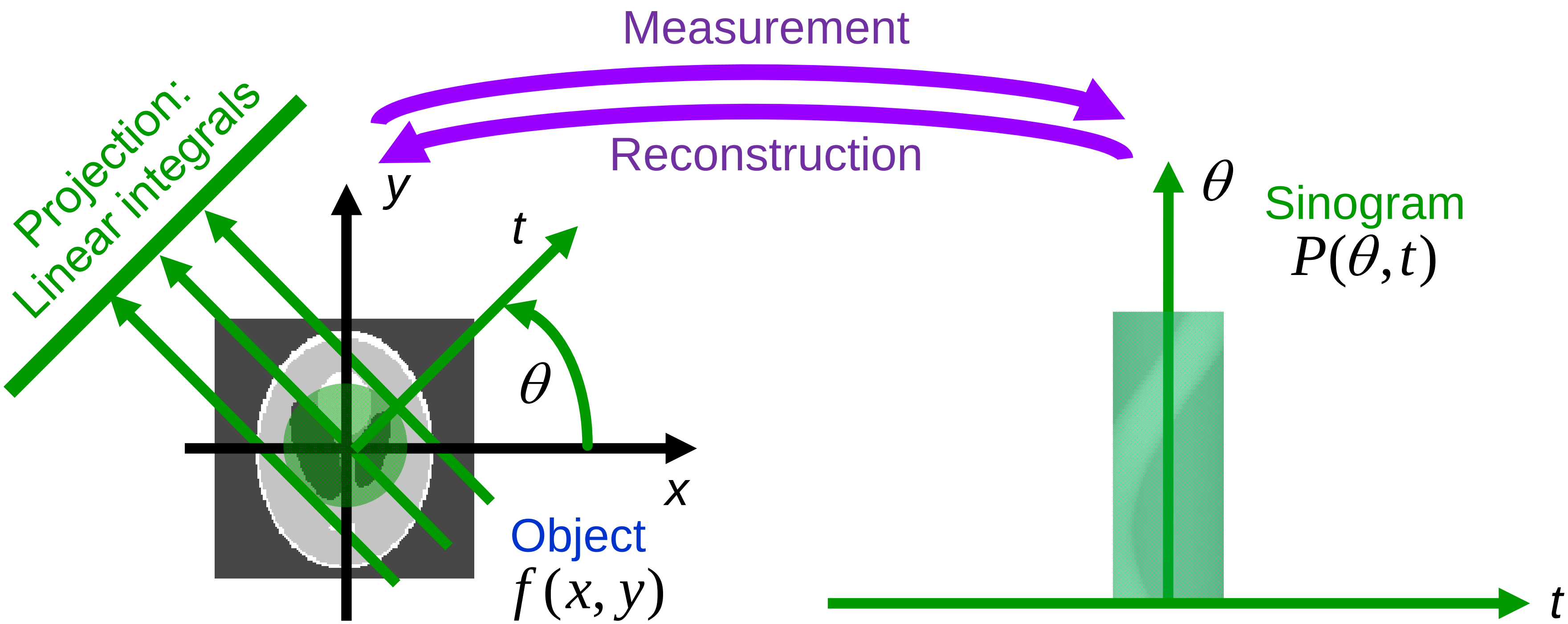




Left: The conventional FBP reconstruction from a complete dataset of a sheep chest CT scan (the white circle identifies our selected ROI).
Right: Our TV-minimization-based interior reconstruction from truncated projections associated with x-rays only through the ROI. The sheep scan was done by Dr. Eric Hoffman, University of Iowa, Iowa City, USA

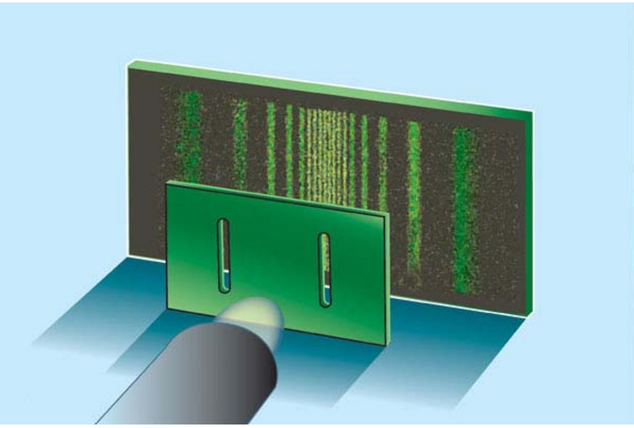
Wang G, Yu HY: Can interior tomography outperform lambda tomography? Proc. Natl. Acad. Sci. USA, 2010. 107(22): p. E92-3

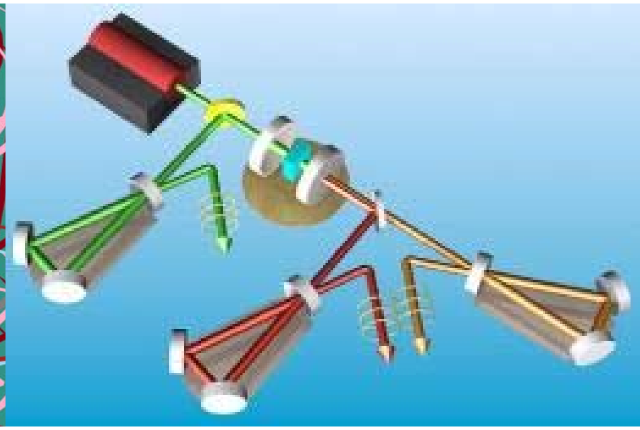
Less Is Deeper
– Break through Tomographic Entanglement



Ye YB, Yu HY, Wei YC, Wang G: General local reconstruction approach based on truncated Hilbert transform; International Journal of Biomedical Imaging, ID63634, 2007

Yu HY, Wang G: Compressive sensing based interior tomography. PMB 54:2791-2805, 2009





Inverse Problems **28** (2012) 000000 (28pp) UNCORRECTED PROOF

Stability of the interior problem for polynomial region of interest

E Katsevich[1], **A Katsevich**[2] **and G Wang**[3]

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[2] Department of Mathematics, University of Central Florida, Orlando, FL 32816-1364, USA
[3] Biomedical Imaging Division, VT-WFU School of Biomedical Engineering and Sciences, Virginia Tech, Blacksburg, VA 24061, USA

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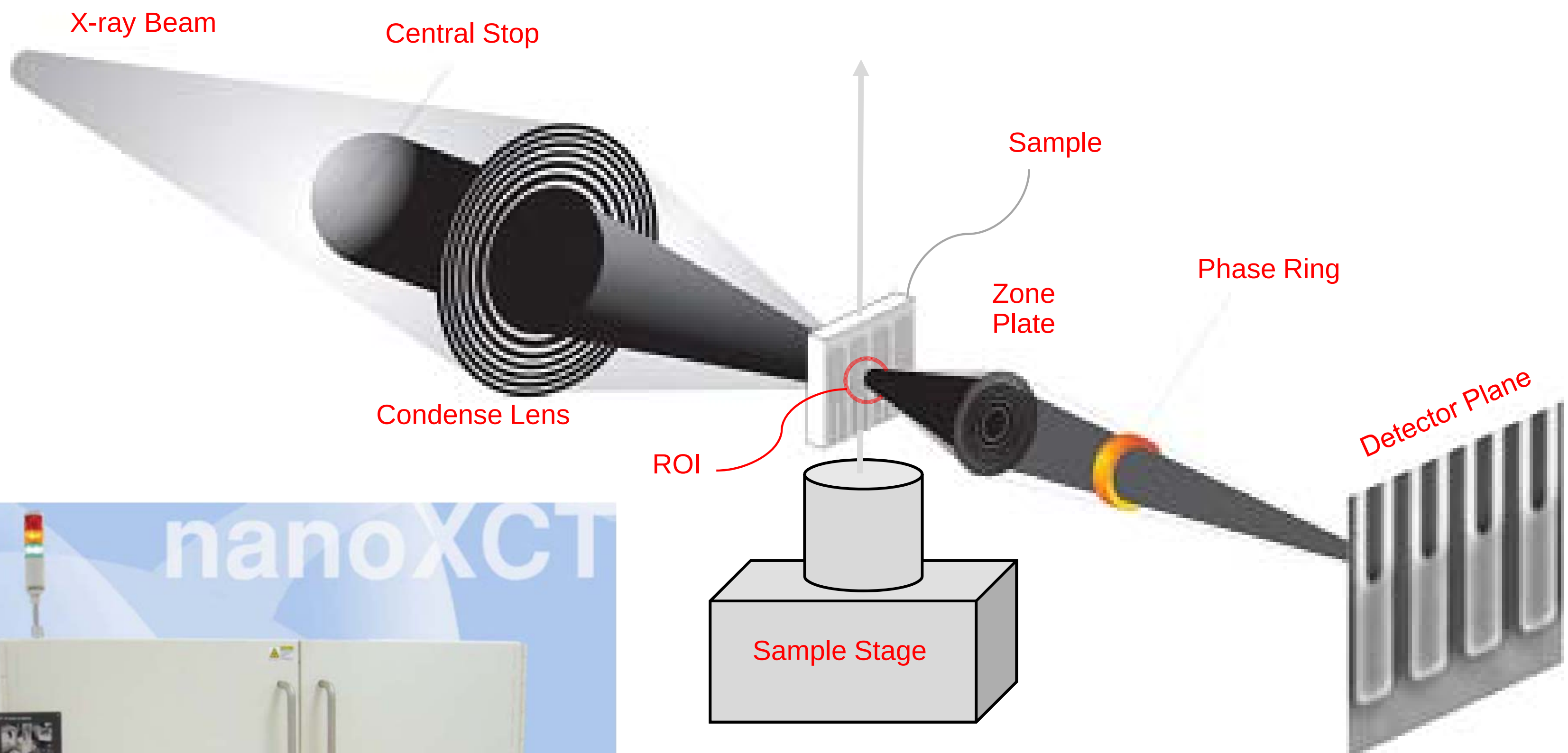
Received 14 September 2011, in final form 20 April 2012
Published DD MMM 2012
Online at stacks.iop.org/IP/28/000000

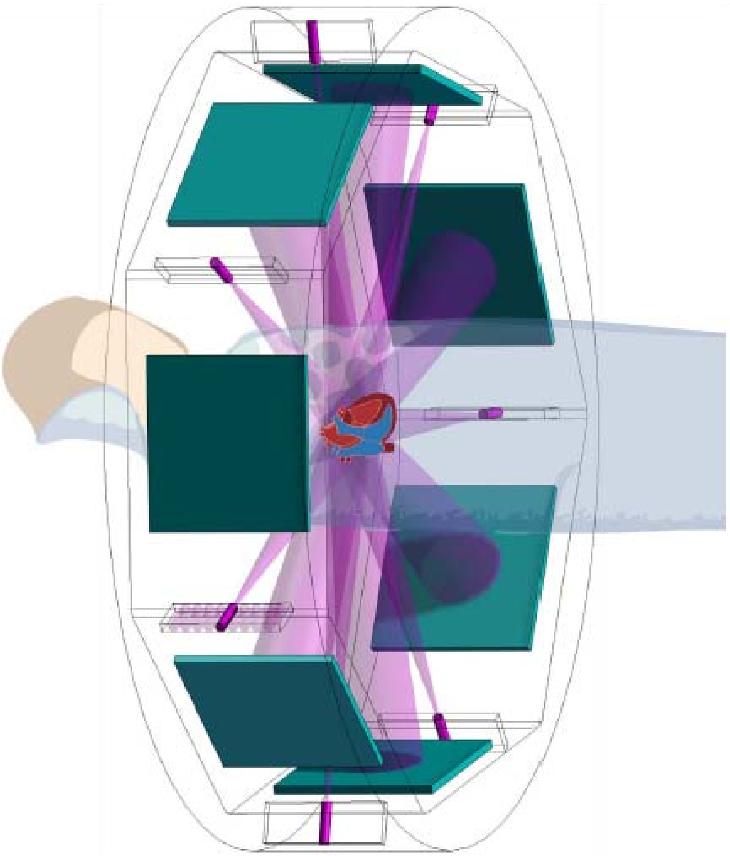
Abstract

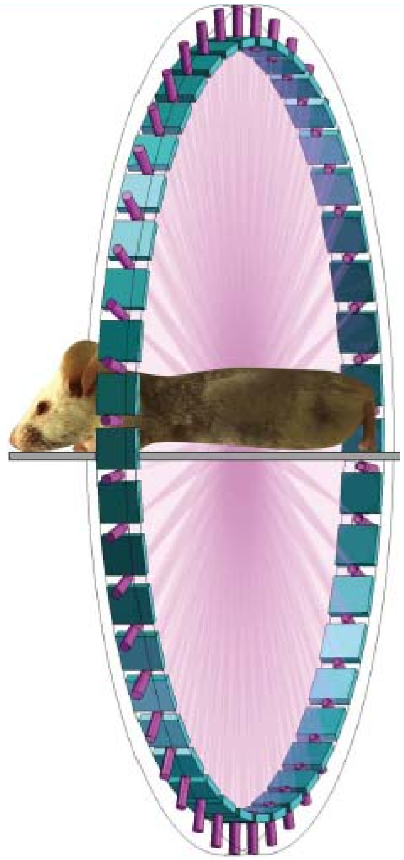
In many practical applications, it is desirable to solve the interior problem of tomography without requiring knowledge of the attenuation function f_a on an open set within the region of interest (ROI). It was proved recently that the interior problem has a unique solution if f_a is assumed to be piecewise polynomial on the ROI. In this paper, we tackle the related question of stability. It is well known that lambda tomography allows one to stably recover the locations and values of the jumps of f_a inside the ROI from only the local data. Hence, we consider here only the case of a polynomial, rather than piecewise polynomial, f_a on the ROI. Assuming that the degree of the polynomial is known, along with some other fairly mild assumptions on f_a, we prove a stability estimate for the interior problem. Additionally, we prove the following general uniqueness result. If there is an open set U on which f_a is the restriction of a real-analytic function, then f_a is uniquely determined by only the line integrals through U. It turns out that two known uniqueness theorems are corollaries of this result.

Less = Larger
– Interior Nano-CT



Less = Faster
– Multi-source Interior (Stationary) CT





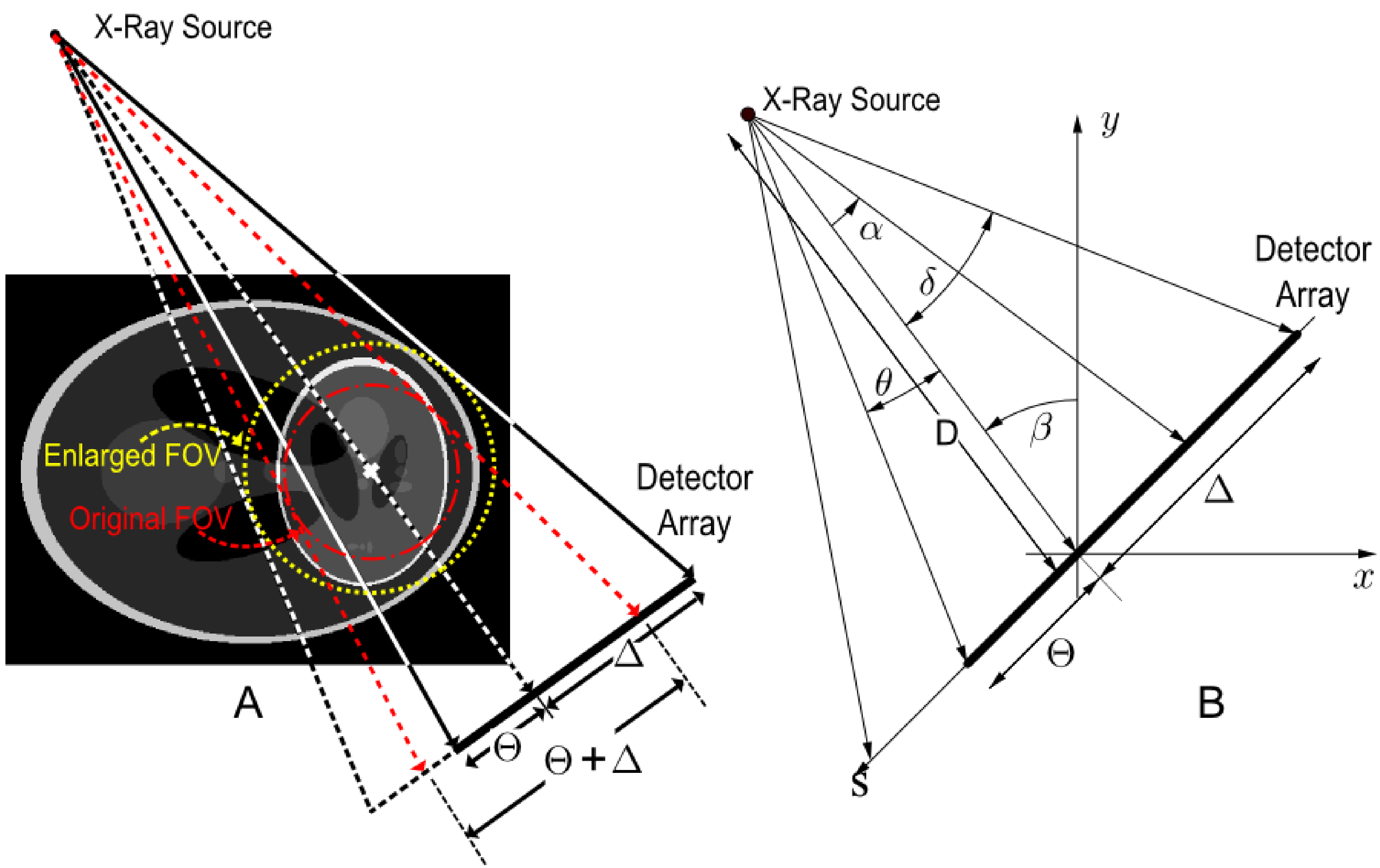
Less =
Deeper understanding
Larger object
Less radiation dose
Finer image resolution
Wider dynamic range
… …
***Faster* imaging speed**

Wang G, Yu HY, Ye YB: A scheme for multi-source interior tomography. Med. Phys. 36:3575-3581, 2009

Wang G: The meaning of interior tomography. Proc. of ICASSP, 5764-5767, 2011

Ritman EL, Kinsey JH, Robb RA, Gilbert BK, Harris LD, Wood EH: Three-dimensional image of the heart, lungs, and circulatory. Science 210:273-280, 1980

Interior Tomography with Offset Detector



Shamar KS, Gong H, Ghasemalizadeh O, Yu HY, Wang G, Cao GH: Interior micro-CT with an offset detector. To appear in Med. Phys., 2014

Phantom Examples

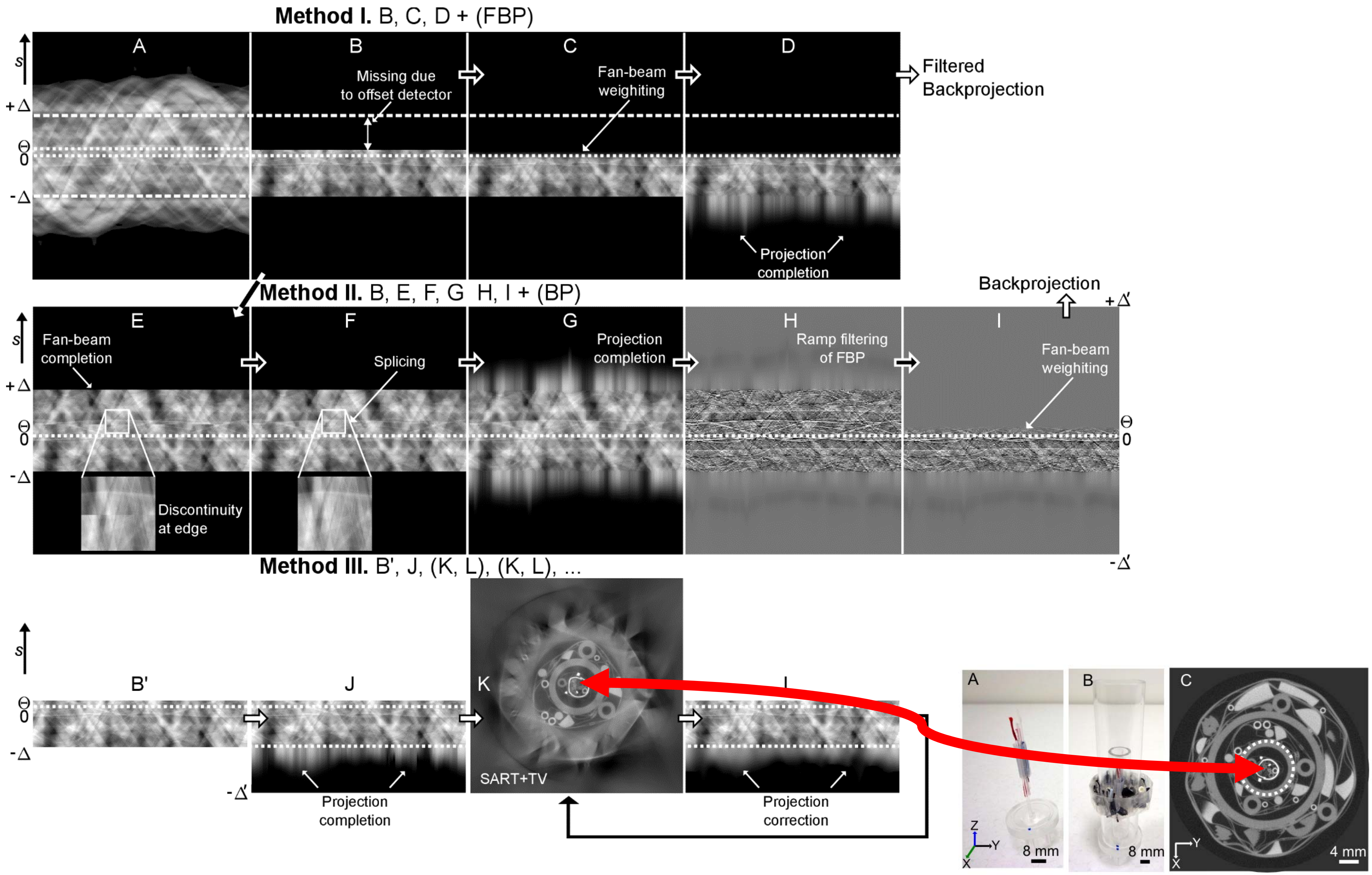
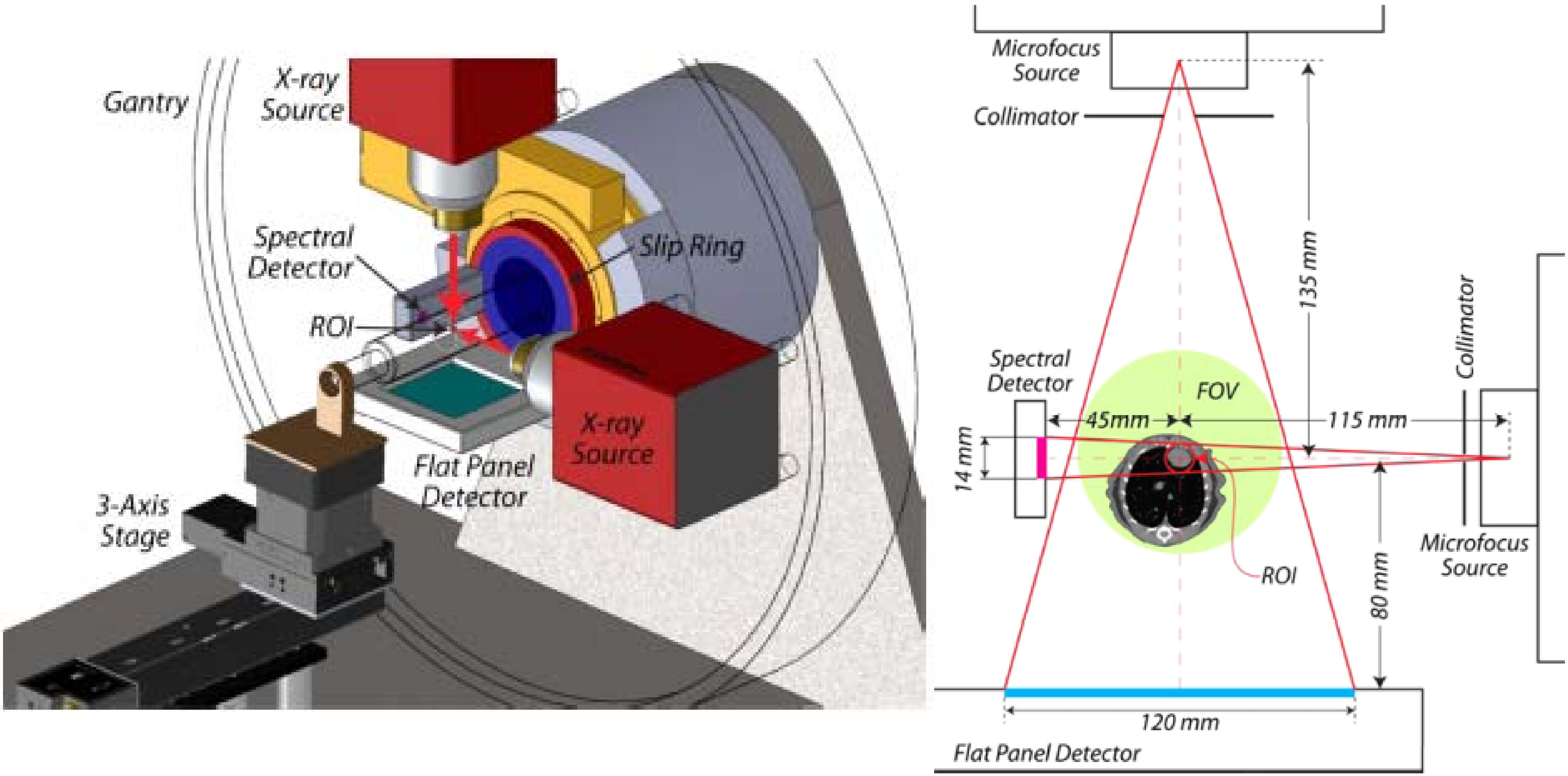


Image Reconstruction for Hybrid True-Color Micro-CT

Qiong Xu, Hengyong Yu*, *Senior Member, IEEE*, James Bennett, Peng He, Rafidah Zainon, Robert Doesburg, Alex Opie, Mike Walsh, Haiou Shen, Anthony Butler, Phillip Butler, Xuanqin Mou, and Ge Wang*, *Fellow, IEEE*



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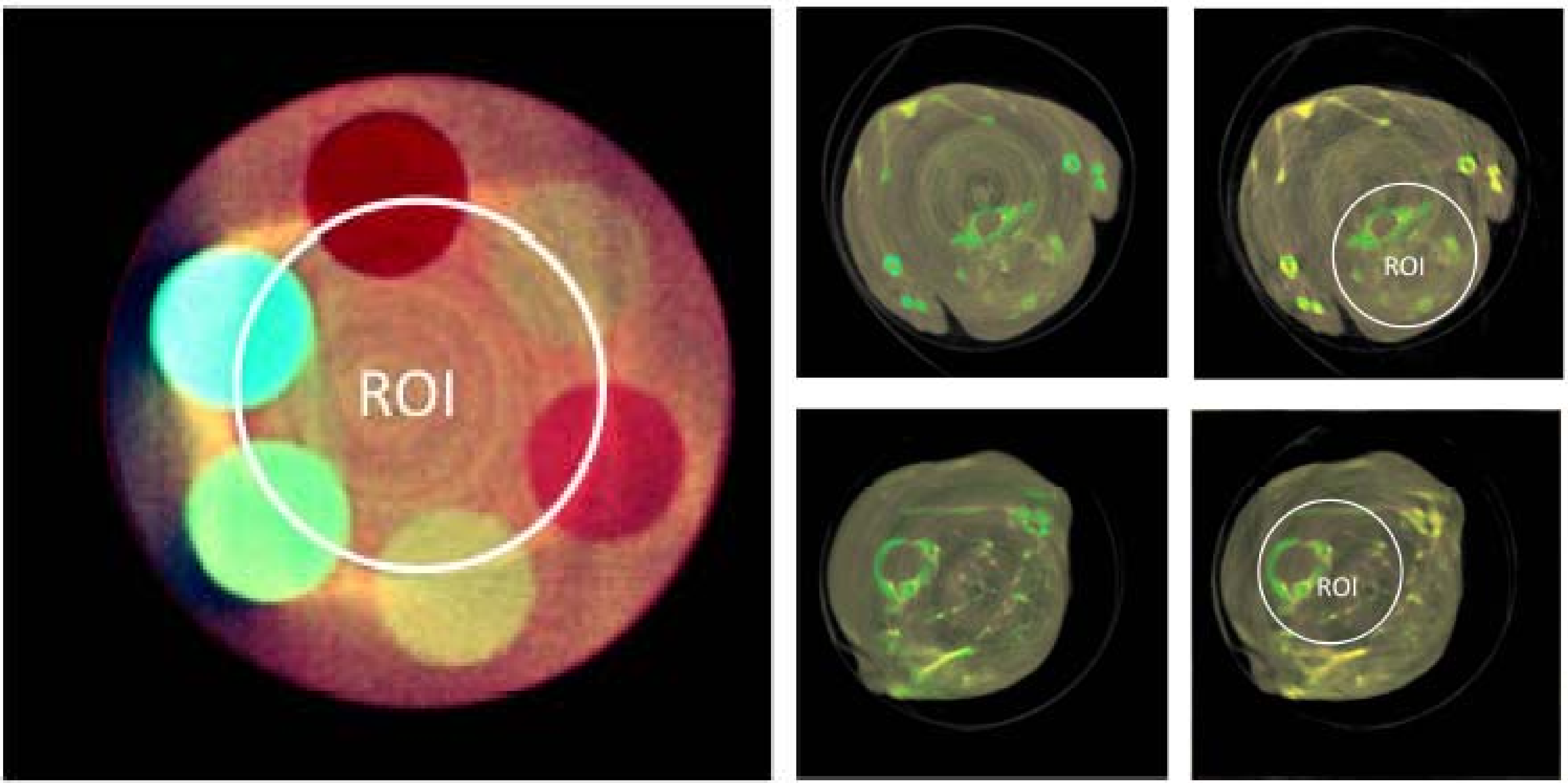
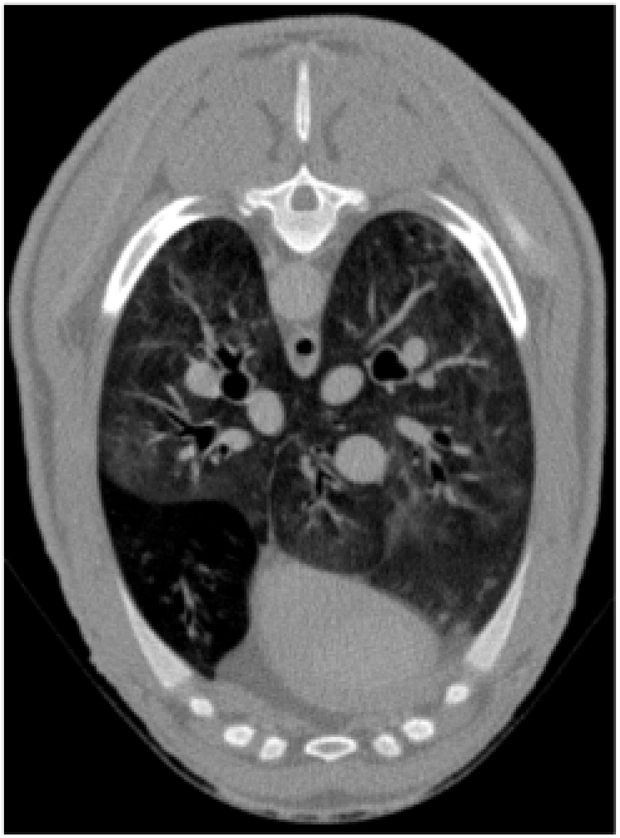
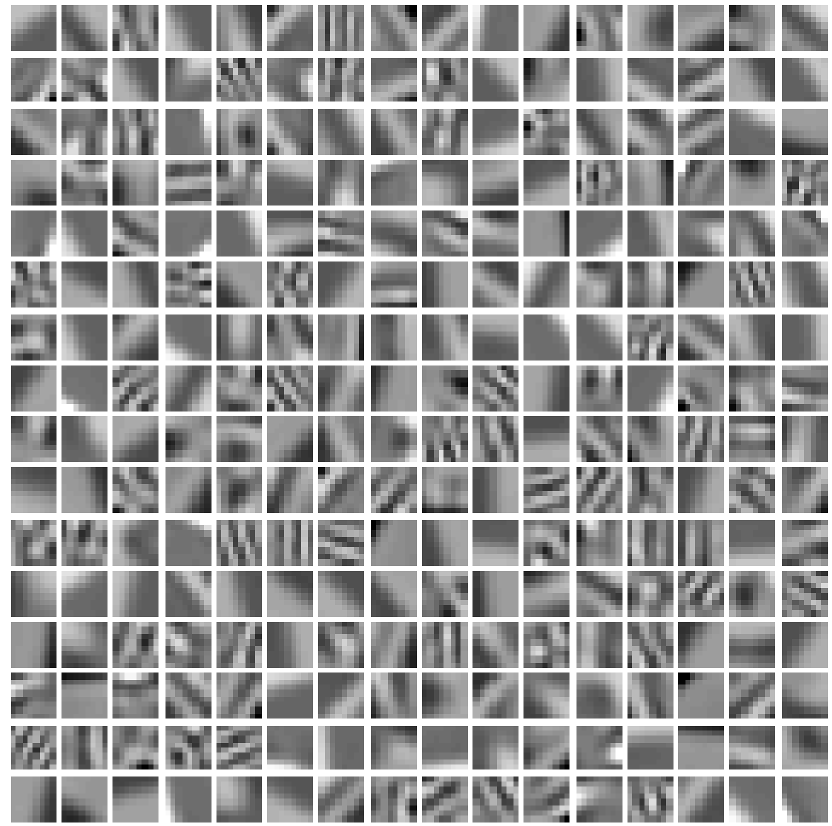


Features Extracted as Patches



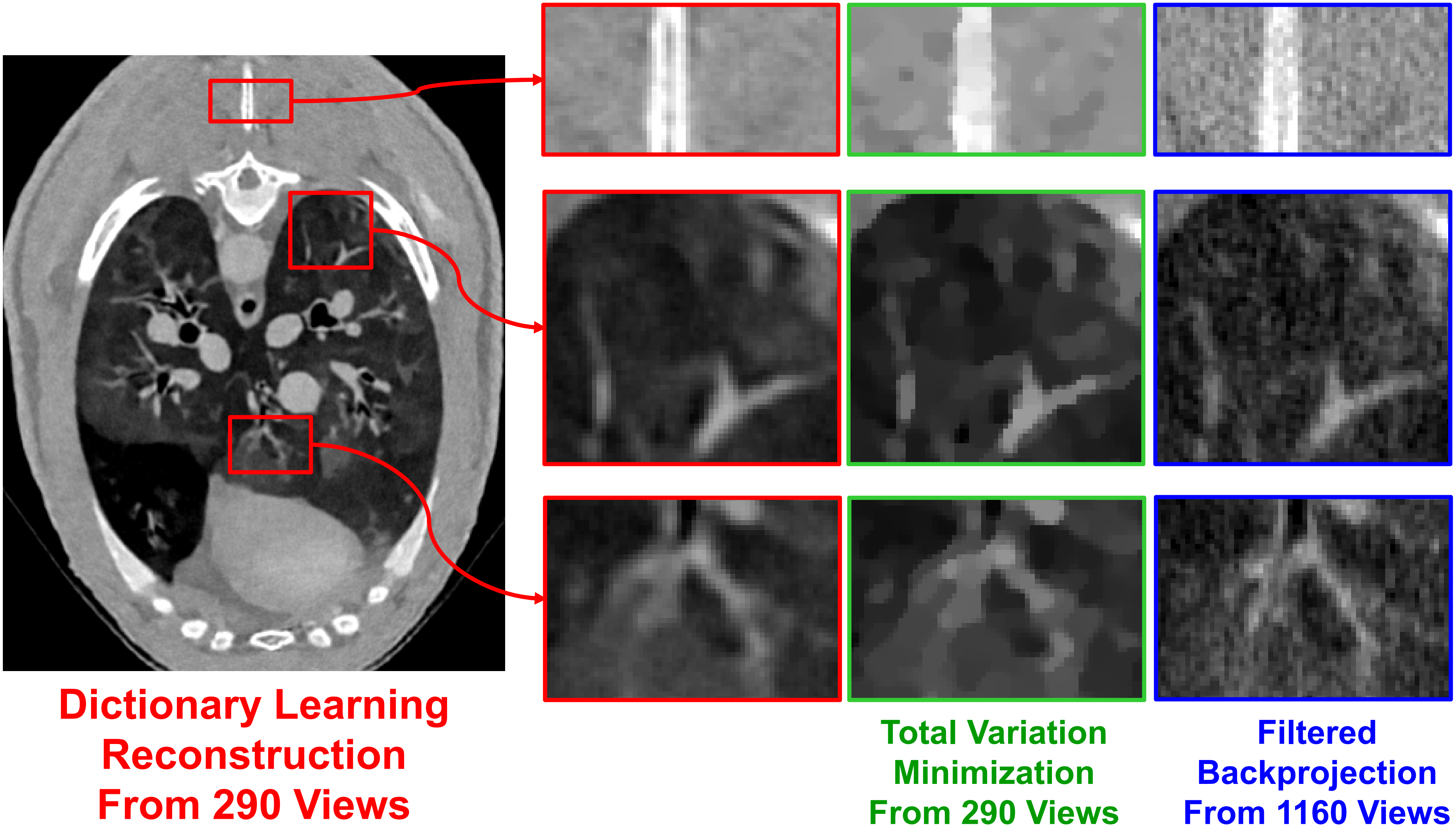
A CT image for training



Dictionary of 256 patches

Xu Q, Yu HY, Mou XQ, Zhang L, Wang G, Low-dose x-ray CT reconstruction via dictionary learning. IEEE Transactions on Medical Imaging 31:1682-1697, 2012

Dictionary-based Imaging



Xu Q, Yu HY, Mou XQ, Zhang L, Wang G, Low-dose x-ray CT reconstruction via dictionary learning. IEEE Transactions on Medical Imaging 31:1682-1697, 2012

PRISM: Prior Rank, Intensity & Sparsity Model

We model X as the sum of two matrices X_L and X_S

$$X = X_L + X_S$$

and enforce the following regularization

$$R(X_L, X_S) = \lambda_* \| T_L(X_L) \|_* + \lambda_1 \| T_S(X_S) \|_1 + \lambda_t \| X \|$$

By our **PRISM**, we have

$$(X_L, X_S) = \underset{(X_L, X_S)}{\arg\min} \| A(X_L + X_S) - Y \|^2 + R(X_L, X_S)$$

Remark: $\|\cdot\|_*$ is the nuclear norm for the rank regularization on X_L; $\|\cdot\|_1$ is the L_1 norm for the sparsity regularization on X_S; $\|\cdot\|$ is a regularizing norm on the total image X

Gao H, Cai JF, Shen Z, Zhao H: Robust principle component analysis based four-dimensional computed tomography. Phys. Med. Biol. 56:3181–98, 2011

Gao H, Yu HY, Osher S, Wang G: Multi-energy CT based on a Prior Rank, Intensity and Sparsity Model (PRISM). Inverse Problems 27:115012 (22pp), 2011

Generalized Interior Imaging Principle

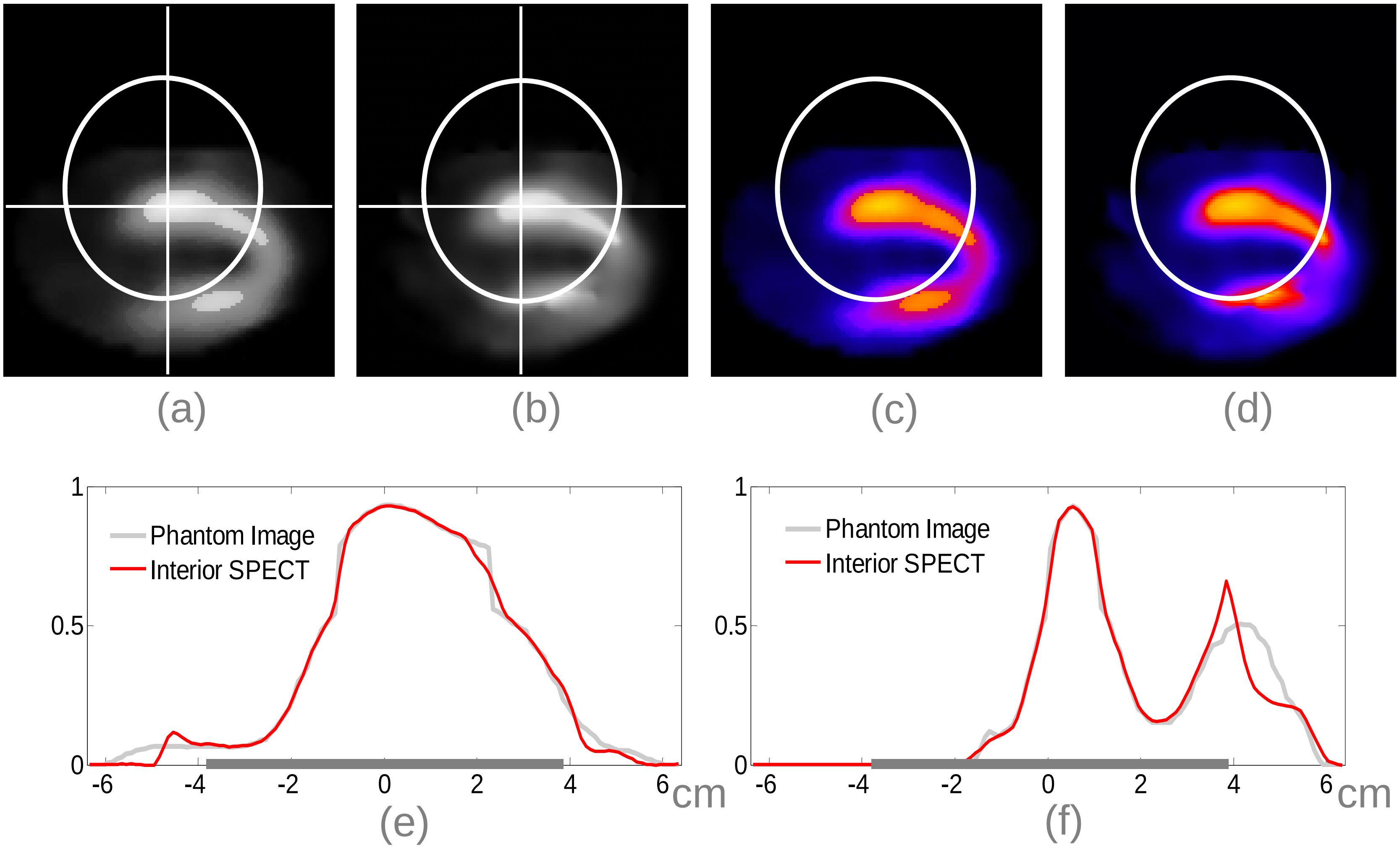
Version 1: Localized tomographic reconstruction needs and only needs local data.

Version 2: Tomographic characterization can be performed with the least amount of information.

Version 3: Tomographic imaging of an interior region of interest (ROI) can be in principle exactly and stably performed from a subset *I* of a dataset *G* where *G* contains indirectly measured data sufficient for theoretically exact and stable reconstruction over the whole support of an object, and *I* contains and only contains those indirectly measured data that directly involve the ROI.

Wang G, HY Yu: The meaning of interior tomography. Phys. Med. Biol. 58:R161–R186, 2013; also the PMB Editor's Choice on http://medicalphysicsweb.org, 08/05/13

Interior SPECT



Yu HY, Yang JS, Jiang M, Wang G: Interior SPECT- Exact and stable ROI reconstruction from uniformly attenuated local projections. Communications in Numerical Methods in Engineering DOI:10/1002/cnm.1206, 18 pages, 2008

Yang JS, Yu HY, Jiang M, Wang G: High order total variation minimization for interior tomography. Inverse Problems 26:1-29, 2010

Yang JS, Yu HY, Jiang M, Wang G: High order total variation minimization for interior SPECT. Inverse Problems. Accepted pending minor revisions

Interior φCT

BRUKER

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PREVIOUS Project 2 of 3 NEXT

DESCRIPTION | DETAILS | RESULTS | HISTORY | SUBPROJECTS | SIMILAR PROJECTS | NEARBY PROJECTS BETA | LINKS | NEWS AND MORE

Project Number: 1R01EB016977-01A1

Title: GRATING-BASED X-RAY PHASE-CONTRAST TOMOGRAPHY METHODS

Contact PI / Project Leader: WANG, GE

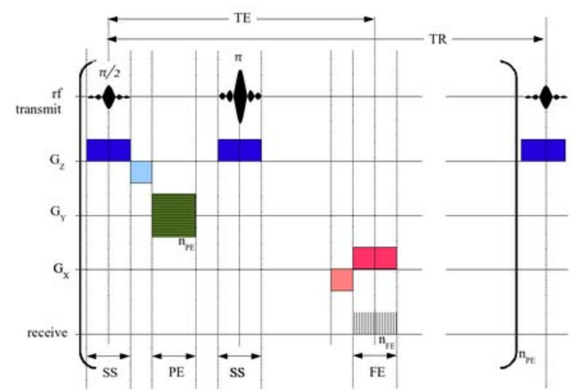
Awardee Organization: RENSSELAER POLYTECHNIC INSTITUTE

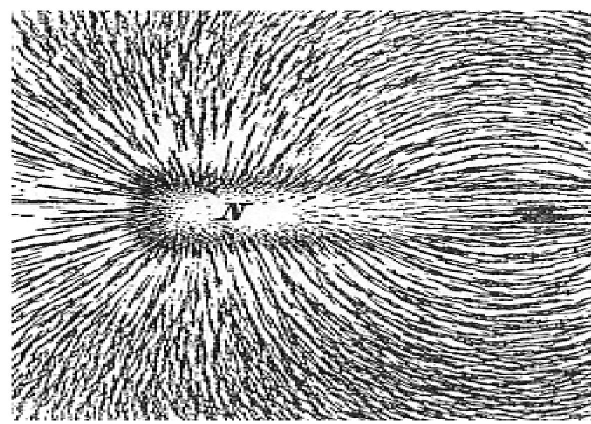
Abstract Text:

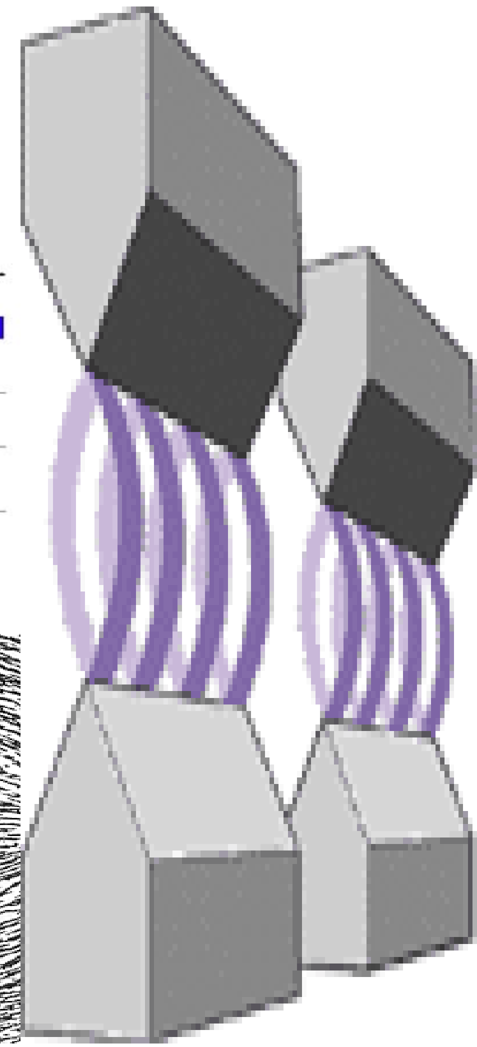
DESCRIPTION (provided by applicant): Biological soft tissue consists mainly of light elements, and its composition is nearly uniform with little density variation. Traditional attenuation-based x-ray imaging cannot provide sufficient contrast for this type of materials. The cross-section of x-ray phase shift is three orders of magnitude greater than that of x-ray attenuation in soft tissue over the diagnostic energy range. Hence, x-ray phase-contrast imaging is sensitive to subtle features especially micro-structures of soft tissue and offers superior contrast for analyses of various normal and diseased conditions. X-ray phase-contrast imaging approaches face challenges in biomedical applications. Analyzer-based phase- contrast imaging requires monochromatic x-rays and high-precision crystals, being limited to the synchrotron radiation facility. Propagation-based imaging suffers from a low photon flux of a micro-focus x-ray tube. Grating-based phase-contrast imaging is a recent breakthrough. However, two main obstacles for this paradigm shift are (1) the large-area gratings of small periods and high aspects and (2) the long time needed for data acquisition. Technically, it is rather difficult to make large gratings especially when x-ray energy is high. Theoretically, it is extremely complicated to model the propagation of x-rays through large gratings from a point x-ray source. In this project, we will establish two enabling innovations that are (1) interior phase contrast tomography for accurate region of interest (ROI) reconstruction and (2) few-view phase-contrast reconstruction without phase-stepping for accelerated data acquisition and minimized radiation dose. The synergistic combination of these innovations will define a new frontier of x-ray phase-contrast tomography. Although the conventional wisdom is that grating-based phase-contrast tomography must use sufficiently large gratings to cover an object and capture projections completely, our main innovative thinking is to target theoretically exact reconstruction over an ROI from

Interior MRI

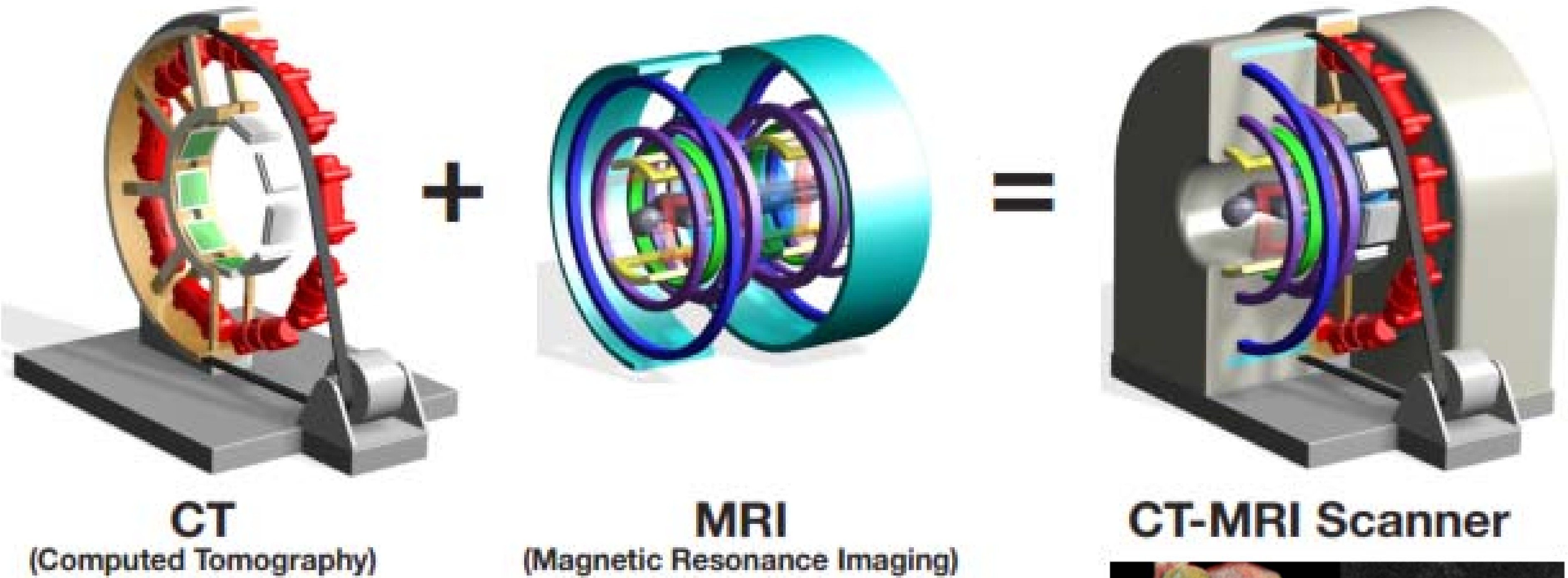
- **Localized Magnetic Field**
- **Focused RF Excitation**
- **Truly Interior Algorithms**

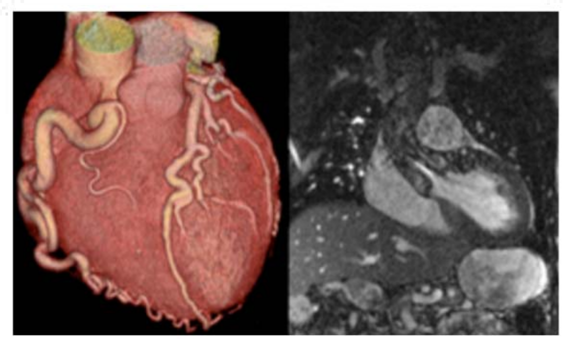






A Combined CT-MRI Scanner




CT Angiography MRI Perfusion

Ge Wang, PhD
Professor of Biomedical Engineering
http://www.rpi-bic.org
wangg6@rpi.edu

This image of human liver tumor exhibits information only Available in real-time with This combined system