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Acquisition of a Sub-Micron Resolution X-Ray Computed Tomography System

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Principal Investigator: Landis, Eric N.
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Submitted By:
Landis, Eric - Principal Investigator
Title:
Acquisition of a Sub-Micron Resolution X-Ray Computed Tomography System

Project Participants

Senior Personnel

Name: Landis, Eric
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Khalil, Andre
Worked for more than 160 Hours: Yes
Contribution to Project:

Post-doc

Graduate Student

Name: Phillips, Megan
Worked for more than 160 Hours: Yes
Contribution to Project:
Person was one of two primary instrument operators. She performed calibrations, collected data, and in some cases provided data analysis.

Name: Ellis, Nathan
Worked for more than 160 Hours: Yes
Contribution to Project:
Person was one of three primary instrument operators. He performed calibrations, collected data, and in some cases provided data analysis.

Undergraduate Student

Name: Livingston, Clarissa
Worked for more than 160 Hours: Yes
Contribution to Project:
Person was one of three primary instrument operators. She performed calibrations, collected data, and in some cases provided data analysis.

Name: Ramsdell, Jonathan
Worked for more than 160 Hours: No
Contribution to Project:
Undergraduate research assistant.

Technician, Programmer

Other Participant

Research Experience for Undergraduates

Organizational Partners

Oregon State University
OSU faculty member was a significant user of the instrument.

Amherst College
Scheduled use of facilities.

Other Collaborators or Contacts

We have identified an initial slate of members in the Microtomography Users Grup (MTUG), which includes researchers both internal and external to the University of Maine. The internal members include Earth Sciences, Mechanical Engineering, Chemistry, and Physics. The external members include researchers from the Jackson Laboratory, and Amherst College.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)
Activities

Instrument Acquisition and Setup
The instrument purchased under this project is a Skyscan model 2011 Nanotomography from Skyscan of Belgium. The instrument was purchased through its US distributor, Microphotonics. The instrument was chosen for its unique (at the time) position of being the only commercially available sub-micron spatial resolution x-ray tomography unit. The unit is completely self-contained, with the exception of an external controlling computer. It was the first of its kind in the U.S.

As noted in the annual project report, the project got off to a slow start due to delays in the delivery of the instrument. The unit was installed at the University of Maine in late August of 2007, roughly eight months behind schedule. Clearly our initial project timeline was unrealistic, and that error will be apparent in this report. The x-ray unit was first energized in early September 2007.

Our initial tasks involved Training. In addition to the PI, five users took part in the initial training sessions provided by the vendor. As part of the management plan, subsequent users are trained by the PI or laboratory support personnel.

Unfortunately, for roughly the first eight months, we struggled to keep the unit fully operational. Problems ranged from computer interface issues and software stability to minor mechanical problems. The vendor was quite good about technical support, including several visits to the instrument, and upgrades of components. While each particular problem was typically rectified in due speed, each malfunction put us farther behind.

Regular Operation
Over the last eight months, the instrument has been running very well, and we may consider operation to be steady state. Initial usage and utilization was excellent, as users lined up to make scans and collect data. The last three months has seen usage drop somewhat as users (and prospective users) are re-evaluating project budgets. From June to October, instrument utilization was just over 50%. Here we define utilization as fraction

of a 40 hour work week that instrument was used for either collecting or processing data. (We should note that usage varied considerably depending on user. For example, out-of-town users often put in long hours such that utilization for the week can be as high as 200%.)

As established in our instrument management plan, all users are granted time with the instrument free of charge to collect data, and to evaluate instrument effectiveness for the particular problem. Users to date along with their applications are shown in Table 1. A number of additional users (Amherst College, Jackson Laboratory, Univ. of Toronto) have inquired about instrument usage, but have not yet scheduled time.

Image Processing
Since the funding of this project began, Khalil has set up a new image analysis and computational modeling lab at the University of Maine. The labÆs expertise and membership is growing rapidly, with activities including several applications in biomedicine and astrophysics.

The 2D WTMM method combines the rigorous mathematical concepts of wavelet theory with the analytical power of statistical physics to study complex signals. The formalism was adapted to perform a robust and objective segmentation of objects of interest from a noisy background, especially when compared to widely used intensity based techniques (Fig. 1). More recently, the WTMM segmentation method was generalized from 2D to 3D analysis (Fig. 2). This work is important because of the relatively low flux of the nanoCT instrument produces images with a high degree of background noise.

Even though these activities and findings concern applications of signal processing methods in the field of biomedicine (more particularly fluorescence microscopy), the development of the corresponding software is considered a great leap forward for applicability to X-ray images. Several algorithmic and computational approaches are now ready to quantitatively and rigorously characterize 3D images produced by the CT machine. References 3, 4, and 5 were published during the project period.

Findings: (See PDF version submitted by PI at the end of the report)

Each tomographic scan generates about a half a gigabyte of data between the raw projection images and the tomographic reconstructions. As such data analysis tends to be slow until it is known what 3D image processing routines are necessary, as well as the required parameters for those routines. Thus we only have some preliminary results to present here. Two sample experiments are presented here. The first is a focus on the 3D structure of the cell wall in spruce, while the second is on the internal structure of chitosan beads used as a potential tool for cleanup of sites contaminated with mercury and other trace metals.

Wood Cell Wall
Figure 3 shows a sample reconstructed slice of earlywood spruce. The image is significant because of its very high resolution (200 nm voxel size). Given the somewhat noisy nature of the low flux x-ray source, this translates into a spatial resolution of approximately 500 nm. In this work we are in the process of measuring a number of anatomical features: cell wall microfibrils, border pits, and ray crossings. In particular we are interested on the relationship between the submicron features to the hygro-mechanical properties at the macroscale. No journal publications have yet been prepared, but we plan to present the preliminary findings at the COST Meeting on Micro-Characterization Techniques in Wood Mechanics in Vienna in May 2009. Figures 4 and 5 illustrates the 3D nature of the data

through sectional images, and 3D renderings, respectively.

Chitosan Bead Analysis
Chitosan is a derivative of crustacean chitin that has been chemically modified to enhance its affinity for mercury and other trace metals. We are interested in the internal pore structure, including connectivity and accessibility of potential bonding sites. Figure 6 shows a cross sectional image of a 1 mm diameter chitosan bead. The figure illustrates the complexity of the internal structure as well as the importance of pore connectivity. Current work in progress will provide us with the basis for a numerical domain in which predictions of metal uptake can be made. Additional work in progress will test the models by measuring the locations of mercury sorption within the pore system.

Training and Development:

To date, four students are among those trained to operate the instrument. The experience provides these students both with specific tools for 3D image analysis, but it also provides them with a new way of looking at materials figuratively. Internal structure can be extremely complex if one looks closely enough.

Outreach Activities:

No formal outreach activities have been completed to date. We will participate in upcoming events organized by the UMaine College of Engineering, including 'Consider Engineering' for middle and high school students. We will have interactive displays of 3D data for students to work with.

Journal Publications

Books or Other One-time Publications

Web/Internet Site

Other Specific Products

Contributions

Contributions within Discipline:

As indicated in the Findings section, we set an unrealistic timeline for this project, and as such our contributions to date are limited. We anticipate that in the coming year, we will be able to demonstrate impacts in the following fields: wood science, pulp & paper, environmental engineering, cementitious nano-composites, and biological engineering.

Contributions to Other Disciplines:

Contributions to Human Resource Development:

Contributions to Resources for Research and Education:

Contributions Beyond Science and Engineering:

Categories for which nothing is reported:

Any Journal
Any Book
Any Web/Internet Site
Any Product
Contributions: To Any Other Disciplines
Contributions: To Any Human Resource Development
Contributions: To Any Resources for Research and Education
Contributions: To Any Beyond Science and Engineering

Findings

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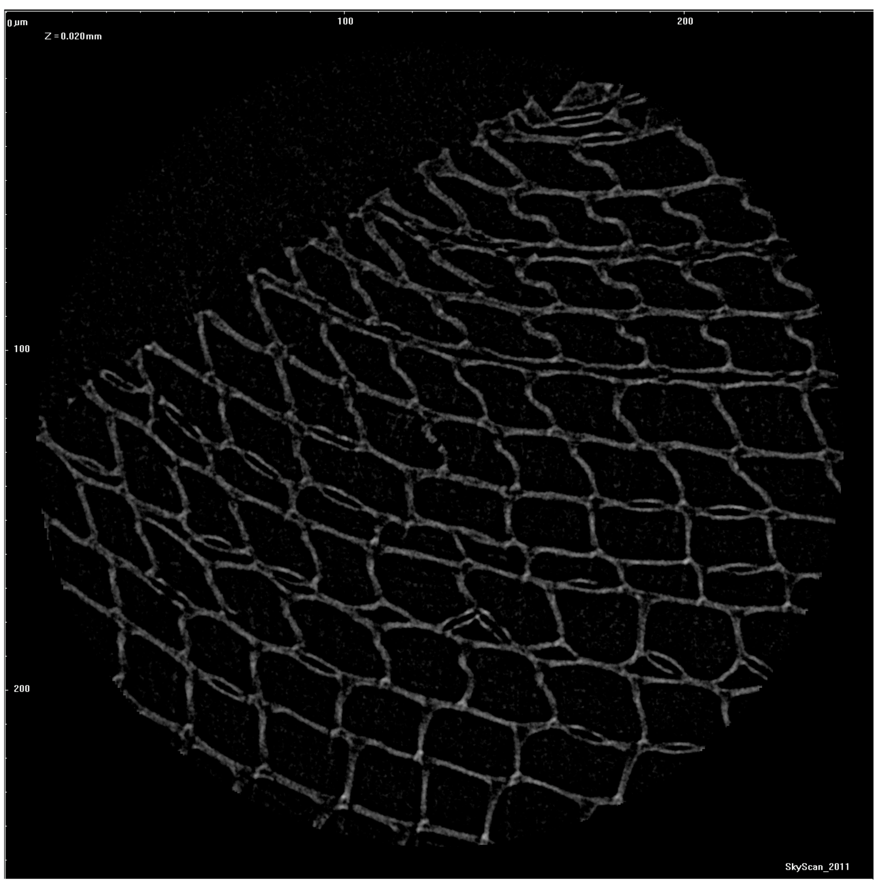

Figure 3. *Reconstructed slice of earlywood spruce. The 3D spatial resolution approaches 0.5 micron.*

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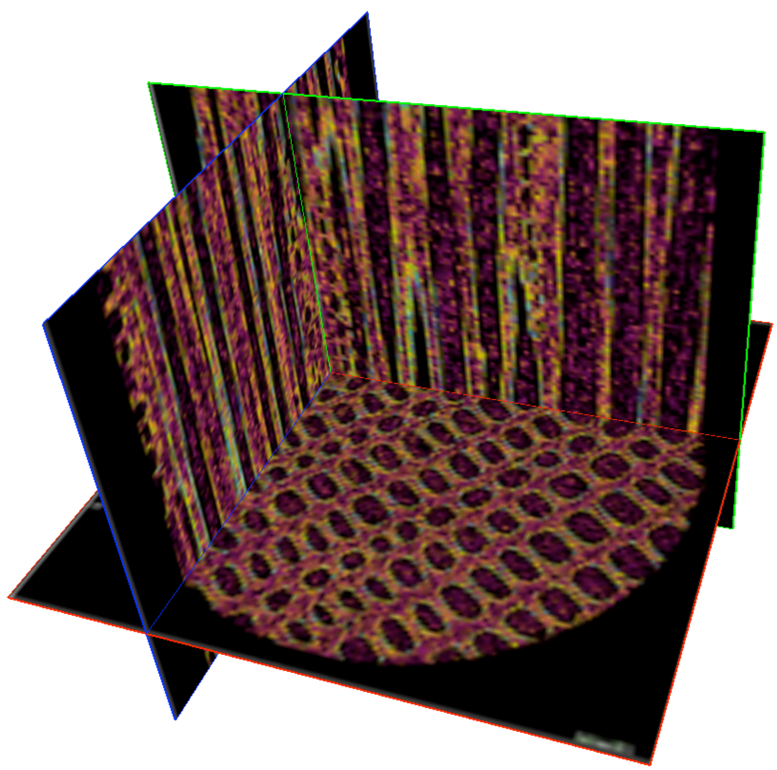

Figure 4. *3D sectional representations of a tomographic scan of latewood spruce at 1 micron spatial resolution. The bottom slice shows the transverse cellular structure, while the vertical slices illustrate the longitudinal dimensions of the cells.*

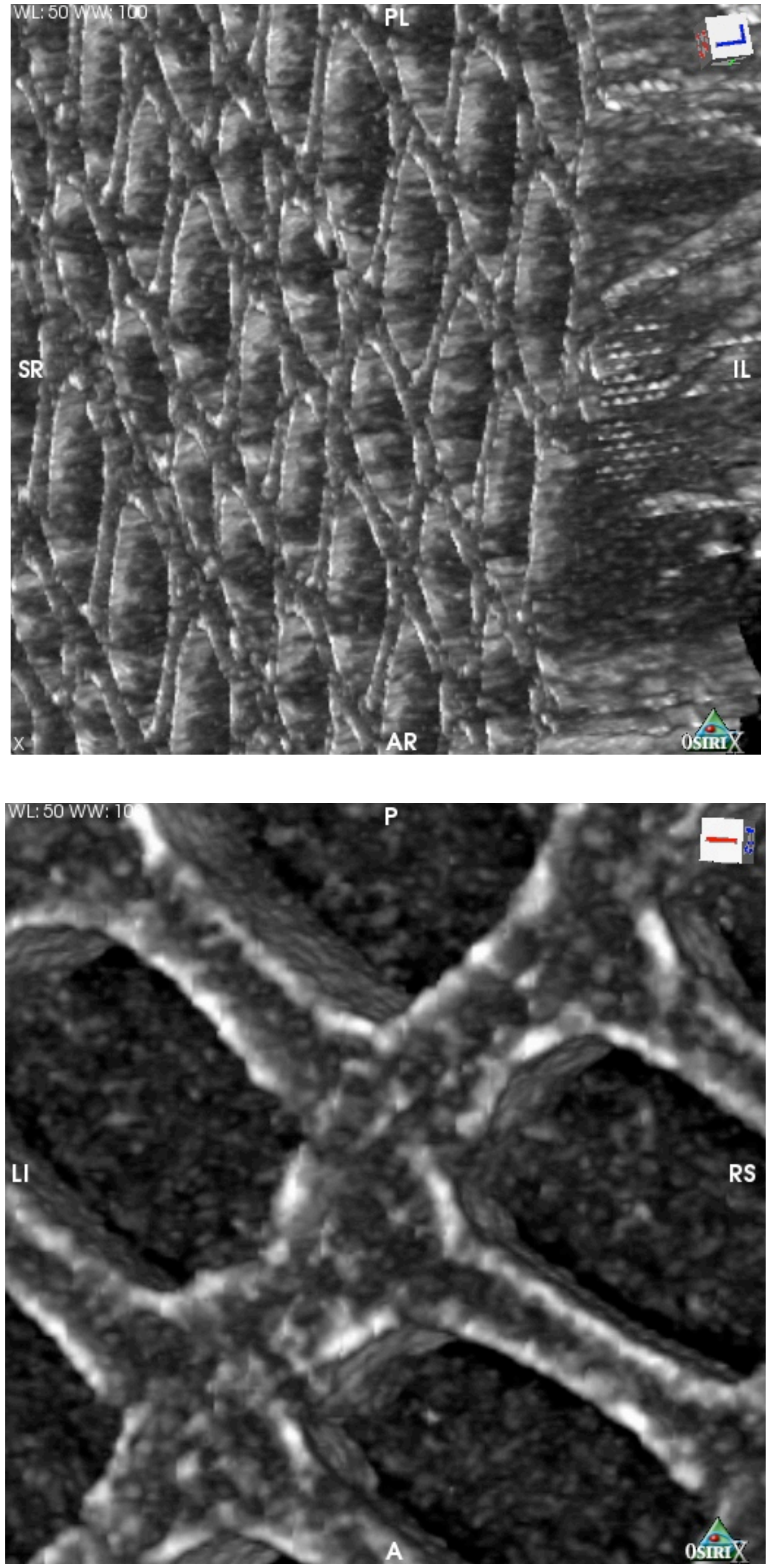

Figure 5. *3D renderings of tomographic data. The top image illustrates both the arrangement of the fibers, but also the structure of the cell wall, at the right hand side. The bottom image illustrates the spatial variation in cell wall density, as the brighter regions correspond to more absorptive material.*

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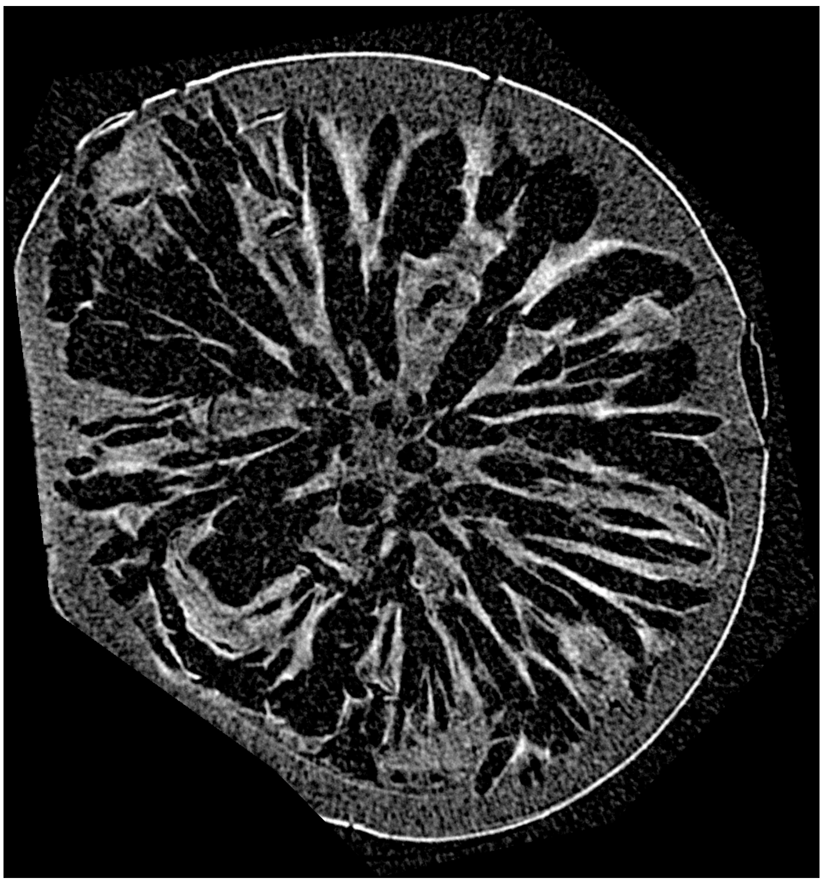

Figure 6. *Tomographic cross sectional slice of chitosan bead. Variations in pixel intensity correspond to x-ray absorption, and can thus be correlated with regions of low nano-porosity. Connectivity analysis of pore network can be used to determine pathways through the complex structure.*

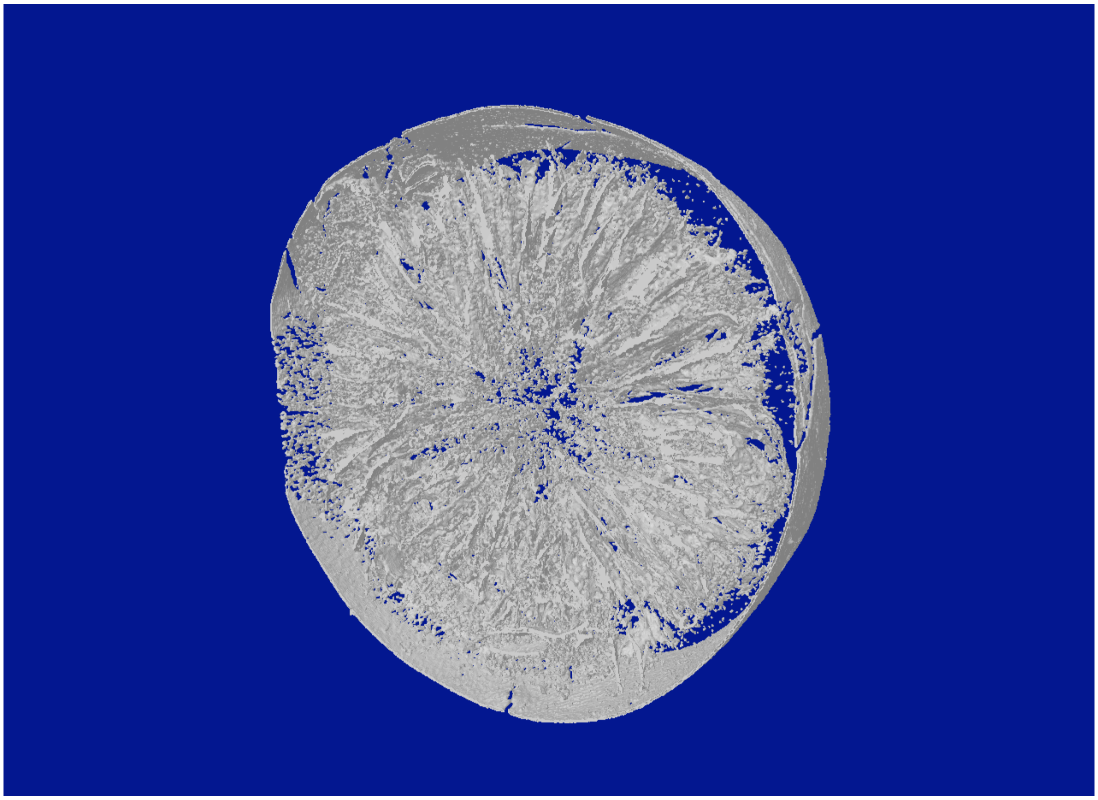

Figure 7. *3D rendering of solid phases of chitosan beads. Such data can be used to formulate a computational domain for flow simulations.*

Table 1. List of Instrument Users

User (PI)	Institution	Application
Megan Phillips (Landis)	UMaine	Cement fracture surfaces
Nathan Ellis (Landis)	UMaine	Capillary pore connectivity in portland cement concrete
Fadi El Chiti (Lopez Anido)	UMaine	Kevlar fiber weave bundles and interface porosity
Clarissa Livingston (Goodell & Landis)	UMaine	Wood cell wall measurements and intercellular connectivity
Jon Ramsdell (Amirbahman)	UMaine	Internal structure of citosen beads
Jon Kenerson (Lindyberg)	UMaine	Spatial distribution of carbon fiber
Lech Muszynski	Oregon State	Phase distribution in wood plastic composite formulations
Lech Muszynski	Oregon State	Aerogel structure
Lin Lin (Peterson)	UMaine	Metal foams
Kevin Trainor (MacRae)	UMaine	Locations of arsenic uptake by citosen beads
Earl Weller	Weidmann Electrical Technology	Micropores in electronic packing materials

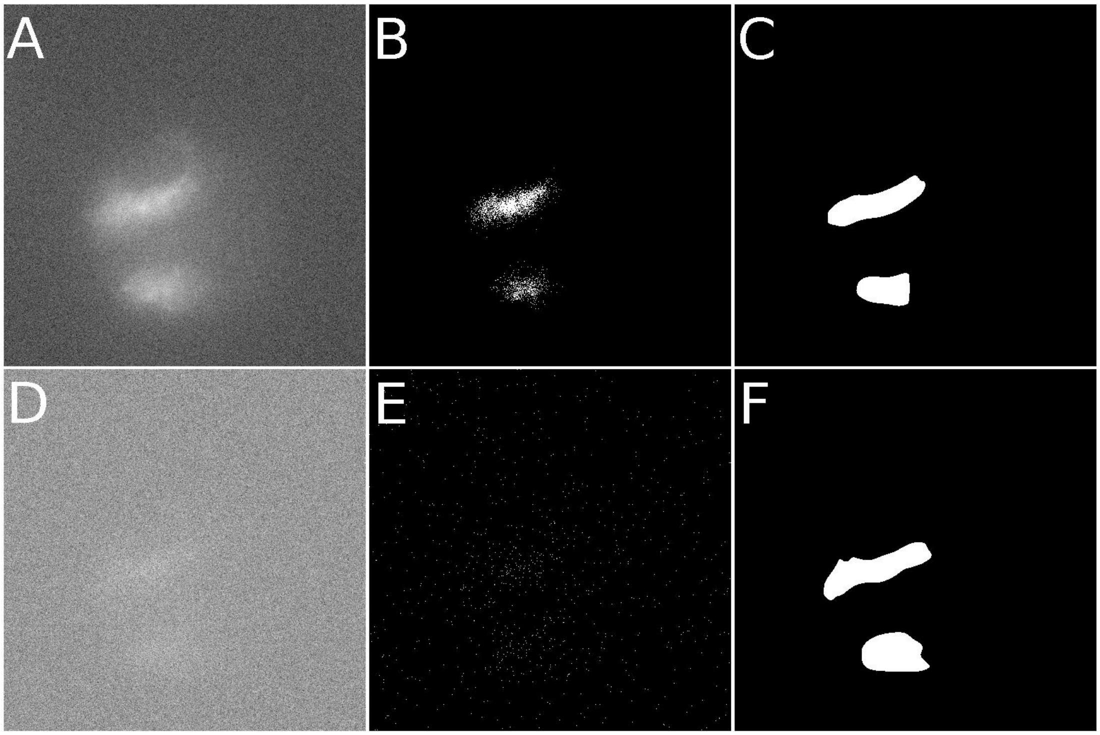

Figure 1. **Objective determination of chromosome territory boundary**. Comparison between traditional automated intensity thresholding vs. **WTMM segmentation**. When images of mouse chromosomes have a non-optimal signal-to-noise ratio **(A)**, intensity thresholding **(B)** fails to adequately define a precise boundary while the WTMM method succeeds **(C)**. When further decreasing the signal-to-noise ratio **(D)**, intensity thresholding is rendered inapplicable **(E)** while the WTMM method creates nearly unchanged results **(F)**.

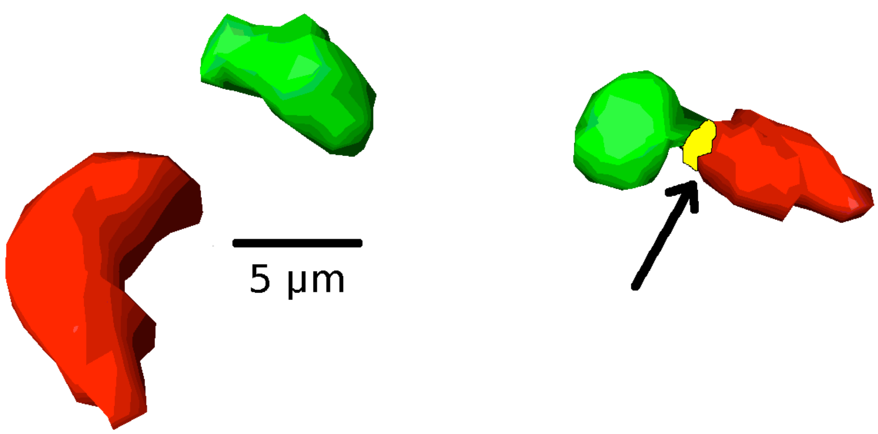

Figure 2. 3D segmentation of mouse chromosome territories 12 (red) and 15 (green) via the WTMM method (confocal data). A critically important zone of interaction is highlighted in yellow (arrow).