Multispectral and Computational Imaging Methods for Documentation of a 19th Century British Landscape Painting

Taylor Bennett Intern-Digital Diagnostic Specialist, Kept Art Restoration

Ken Boydston President, MegaVision, Inc.

William A. Christens-Barry Principal Scientist, Equipoise Imaging, LLC

INTRODUCTION

A 19th century British painting depicting the Giudecca Canal and the Santa Maria della Salute Basilica in Venice was documented using a combination of digital and computational imaging techniques: multispectral imaging, Reflectance Transformation Imaging (RTI), and photogrammetry. These methods were chosen with consideration for the long-term preservation and reuse of the data using well-documented and open-source standards. Rapid developments of computational photography methods and improvements in digital imaging equipment have made these techniques highly portable and applicable to cultural heritage *in situ*, outside of an institutional research setting. These methods provide a detailed digital record documenting the condition of the painting and providing a basis for further analysis and scholarship regarding the artist's technique and use of materials.

OBJECTIVES

The objectives for applying these digital and computational imaging techniques are as follows:

- Document current condition after conservation treatment (cleaning)
- Build an integrated, comprehensive, high-resolution data set using non-contact, non-invasive techniques
- Provide a reliable baseline model for digital collaboration and open-access scholarship
- Allow intercomparison studies of the artist's palette, brush-strokes, technique, and materials
- Aid in the selection of areas for further testing and analysis using complementary methods
- Allow detailed correlation of further analytical tests and imaging data with spectral, spatial/geometric, and textural features
- Examine for changes in composition and areas of damage, and to distinguish original pigments from later retouching

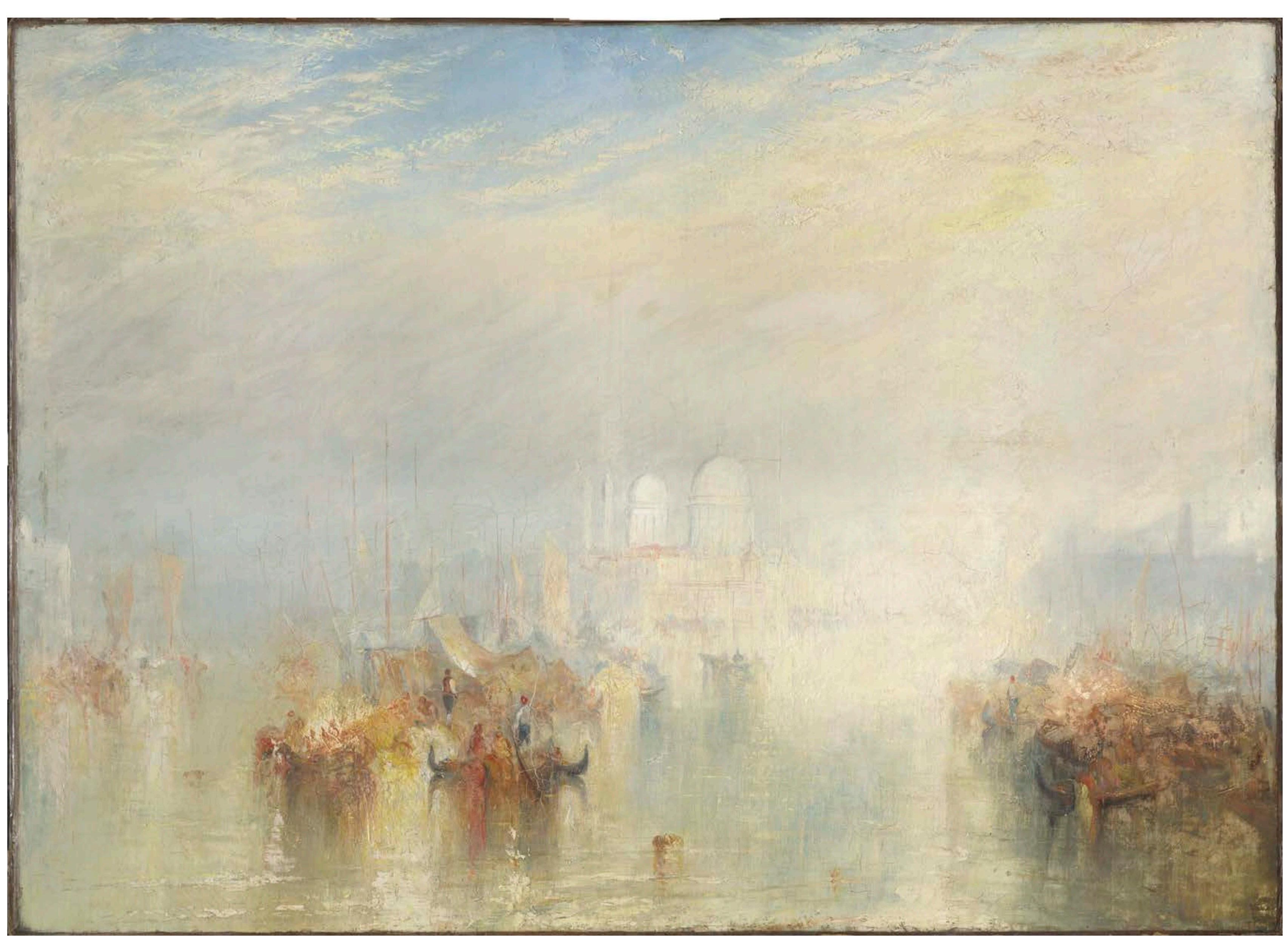
METHODS

Three categories of data were generated:

Textural: 2-½D normal vectors—a detailed, per-pixel mathematical map of the surface texture using Reflectance Transformation Imaging (RTI)

Spatial/Geometric: 3D point cloud, polygonal mesh, and orthophotographs using photogrammetry

Multispectral: 12 reflected wavebands, including ultraviolet (UV), 6 visible, and 5 infrared (IR); UV- and blue-induced visible fluorescence



Giudecca Canal and Santa Maria della Salute, Venice (920 x 1,270 millimeters [mm] or 36 inches x 50 inches)

DOCUMENTATION

This project uses a variety of well-documented and open-source software to allow dissemination and reuse of the data for open-access collaborative research and scientific evaluation.

Reflectance Transformation Imaging (RTI) uses open-source RTIBuilder and RTIViewer software developed by Cultural Heritage Imaging (CHI). All of the image processing steps are recorded in an XML file using the RTIBuilder software, which becomes part of the Digital Lab Notebook for the project (http://culturalheritageimaging.org/Technologies/Digital_Lab_Notebook/).

Dense-range photogrammetry is a well-documented technique for terrain mapping that has been adapted with wide applications for studying cultural heritage. Photogrammetric processing was performed using Agisoft Photoscan™ proprietary software (http://www.agisoft.ru/products/photoscan/professional/), which keeps log files of all the processing steps.

The multispectral digital imaging methods were developed for the Archimedes Palimpsest Project (archimedespalimpsest.org) and other cultural heritage projects, such as David Livingstone's Journals and the Walseemuller, Carta Marina, and Rossi Maps.

COMPUTATIONAL IMAGING

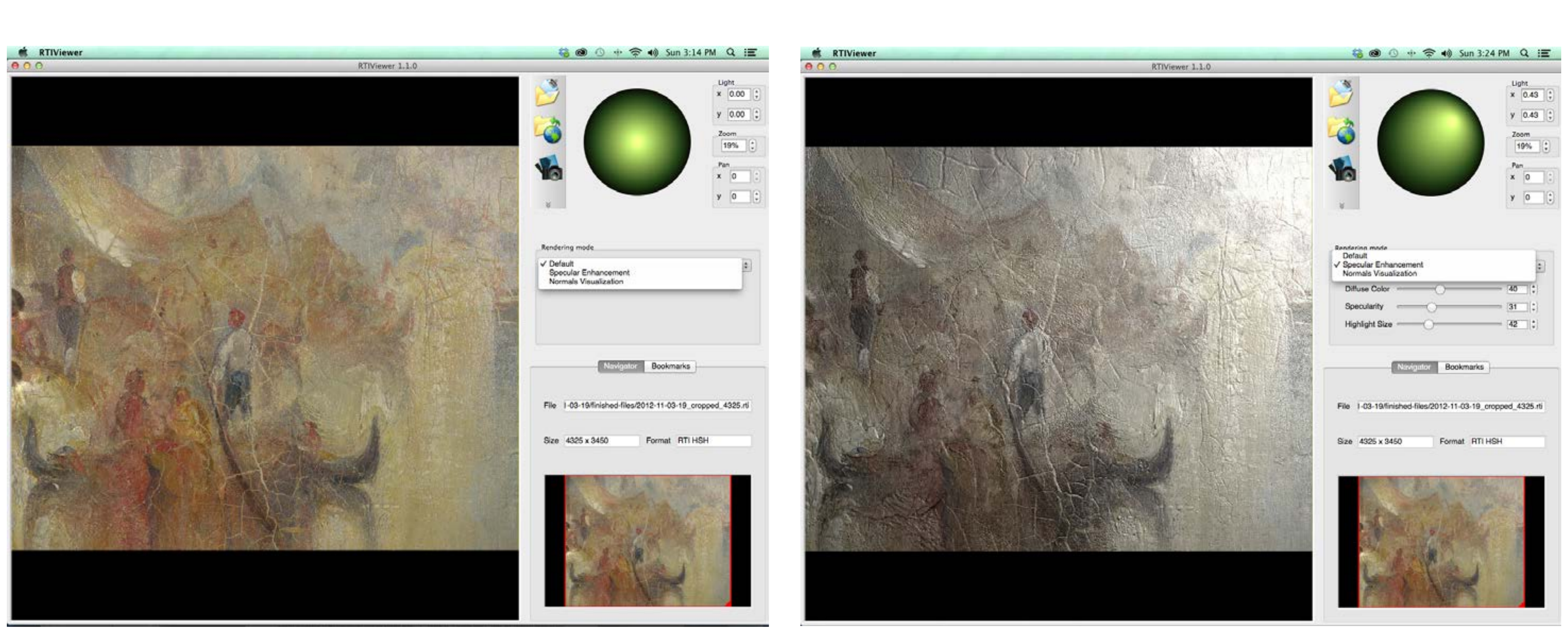


FIGURE 2. Normal and interactive relighting of detail and application of specular enhancement algorithm using RTIViewer. Specular enhancement with relighting removes color, revealing the texture of impasto, craquelure, and brushstrokes.

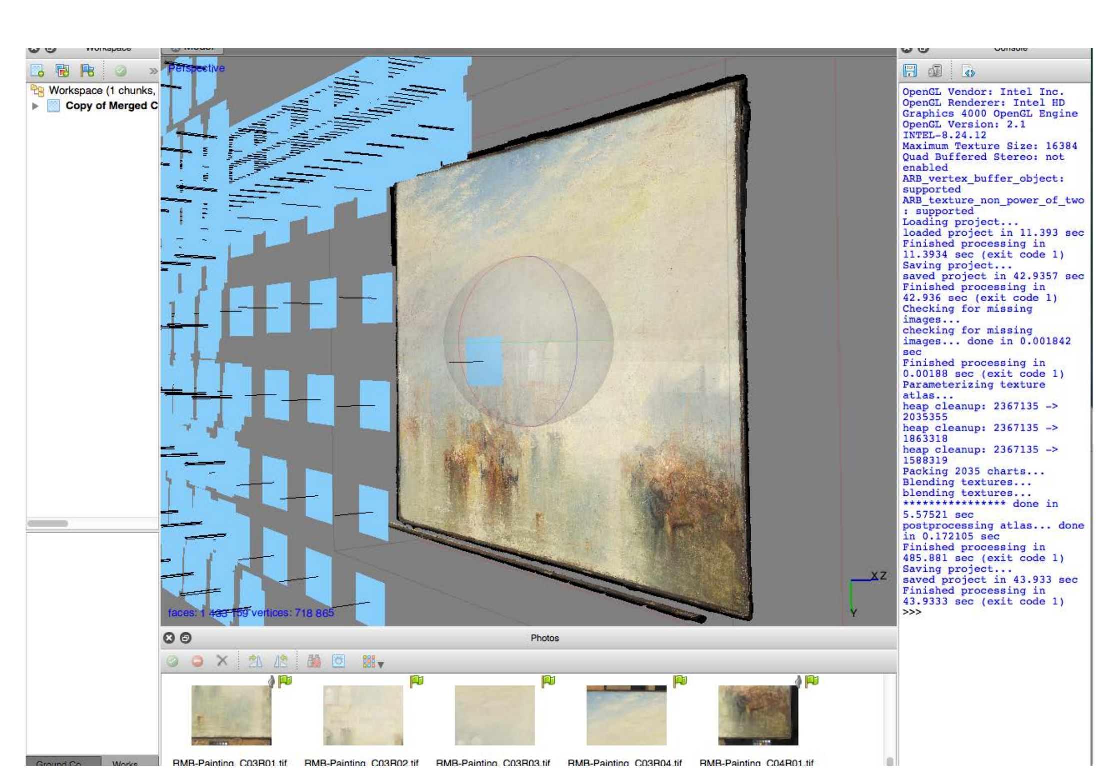


FIGURE 3: 3D model of painting showing camera positions (blue rectangles) used to generate the model.

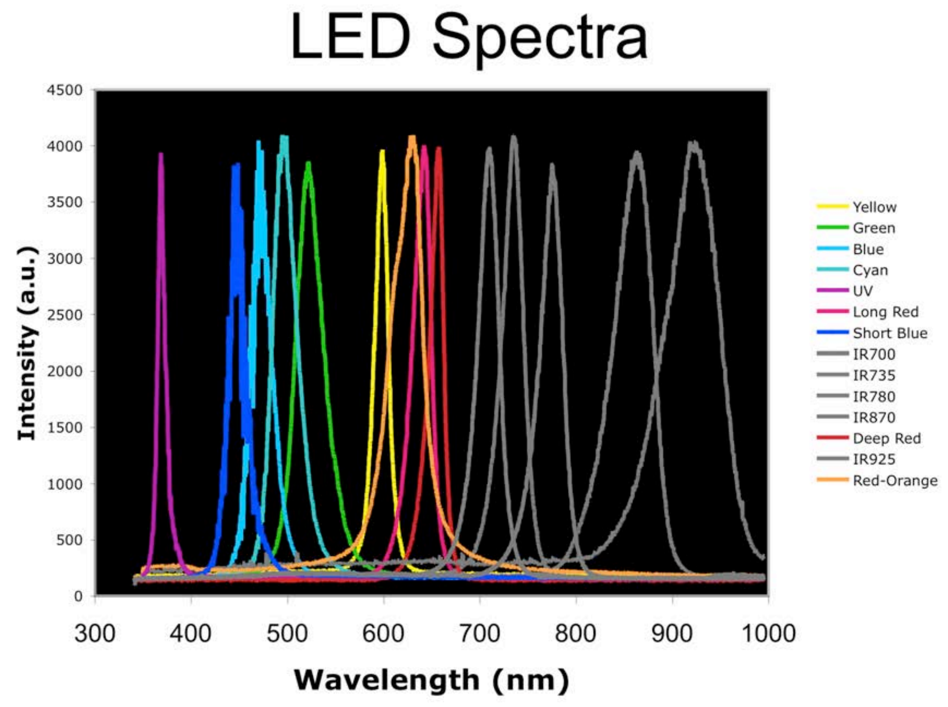
Reflectance Transformation Imaging (RTI): Detailed surface textural information was captured using RTI, a relatively new computational imaging technique introduced in 2001 by Tom Malzbender, Dan Gelb, and Hans Wolters of HP Laboratories, and developed further by Cultural Heritage Imaging (CHI). RTI calculates the direction of the normal vector (perpendicular to the surface) at every pixel of an image. An RTI derives surface reflectance properties and normal vectors from a sequence of images captured with a stationary camera and varying light positions. The resulting 2-½D mathematical map of the object's surface texture allows the conservator or researcher to interactively change the position of the light source ("relighting") from their computer monitor and to apply algorithms to enhance surface details (e.g., brush strokes, craquelure, impasto, and areas of damage) at very high resolution. RTIs can also be used to monitor conservation treatments and changes in the object's surface over time. RTIs can be transmitted electronically and viewed remotely by researchers without direct access to the painting.

Photogrammetry: 3D spatial geometric data were gathered using photogrammetry, a type of computational imaging that was originally developed for terrain mapping. Photogrammetry produces a 3D point cloud and polygonal mesh similar to laser scanning but can be done relatively inexpensively using any digital camera capable of capturing high quality images. Dense-range photogrammetry derives the 3D coordinates (x, y, and z) of points on the surface of an object by triangulation of the same points in overlapping digital images taken from different camera positions. The points in the resulting point cloud can then be connected by polygons to generate a 3D model (or "mesh") of the surface of the object. An advantage of photogrammetry compared to laser scanning is the ability to simultaneously capture 3D geometry with color, which can be used to texture the model with color or multispectral images. This allows high-resolution mosaic images to be stitched together and exported as unified, orthorectified, high-resolution images. Photogrammetry also provides a common 3D spatial framework to integrate textural, geometric, spectral, and other analytical data.

MULTISPECTRAL IMAGING

Multispectral imaging measures the reflectance and fluorescence properties of the pigments using different wavelengths of light within the ultraviolet (UV), visible, and near-infrared (IR) spectrum.

Multispectral imaging was performed using a MegaVision™ E7 digital back with a monochrome 50-megapixel sensor, an apochromatic, parfocal lens, and a multispectral lighting system with two panels each containing 12 light-emitting diodes (LEDs), with one LED for each waveband. Controlling the wavelength of the light source using narrow-waveband LEDs reduces the amount of potentially damaging light on the painting's surface and allows reflectance images to be captured without using filters, which would degrade optical quality. Filters are used only for UV- and blue-induced fluorescence images to isolate the reflected and induced fluorescence wavebands of interest.



The monochrome sensor does not have a red-green-blue (RGB) Bayer filter array that is common on many consumer cameras, allowing the reflectance and fluorescence properties of the painting's surface to be accurately measured at very high resolution and eliminating the demosaicing and interpolation algorithms required for imaging with RGB color sensors. Therefore, every pixel in the multispectral image cube can be precisely registered (i.e., aligned) and compared across several wavebands. The multispectral images of the painting were captured in a mosaic of four rows and four columns of 50 megapixels each. The mosaic tiles were orthorectified to remove any lens distortion and stitched together using photogrammetry software. The resulting stitched images contain over 325 million pixels, with each pixel measuring an area of approximately 3,600 μ^2 (square microns) or 3.6×10^{-3} mm^2 or 5.6×10^{-6} $inches^2$ of the painting's surface.

Infrared Reflectance (940 nm)

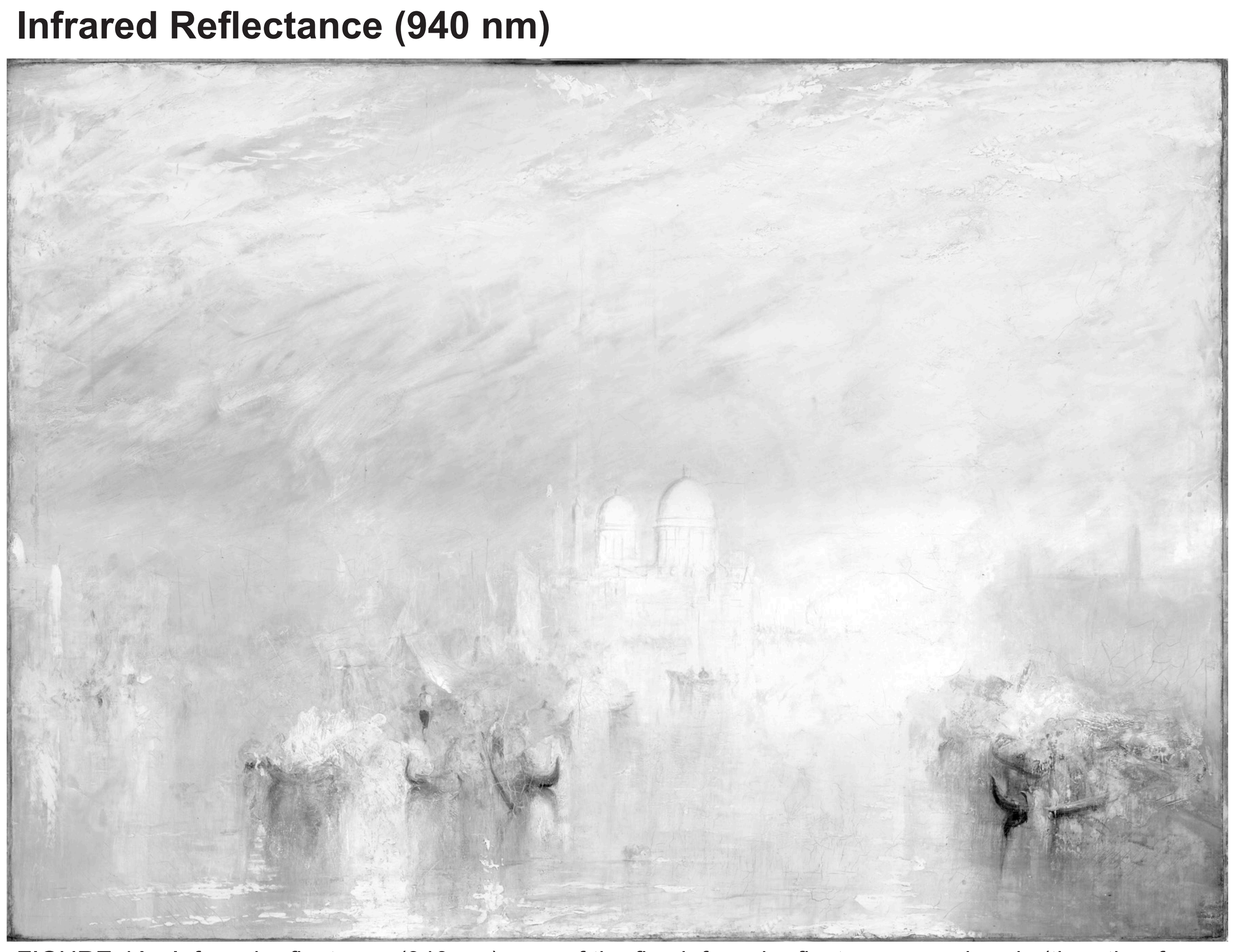


FIGURE 4A: Infrared reflectance (940 nm), one of the five infrared reflectance wavebands (the other four infrared wavebands are centered at 700, 735, 780, and 870 nm; *cf.* Figure 4B).

Infrared Reflectance (700 nm)

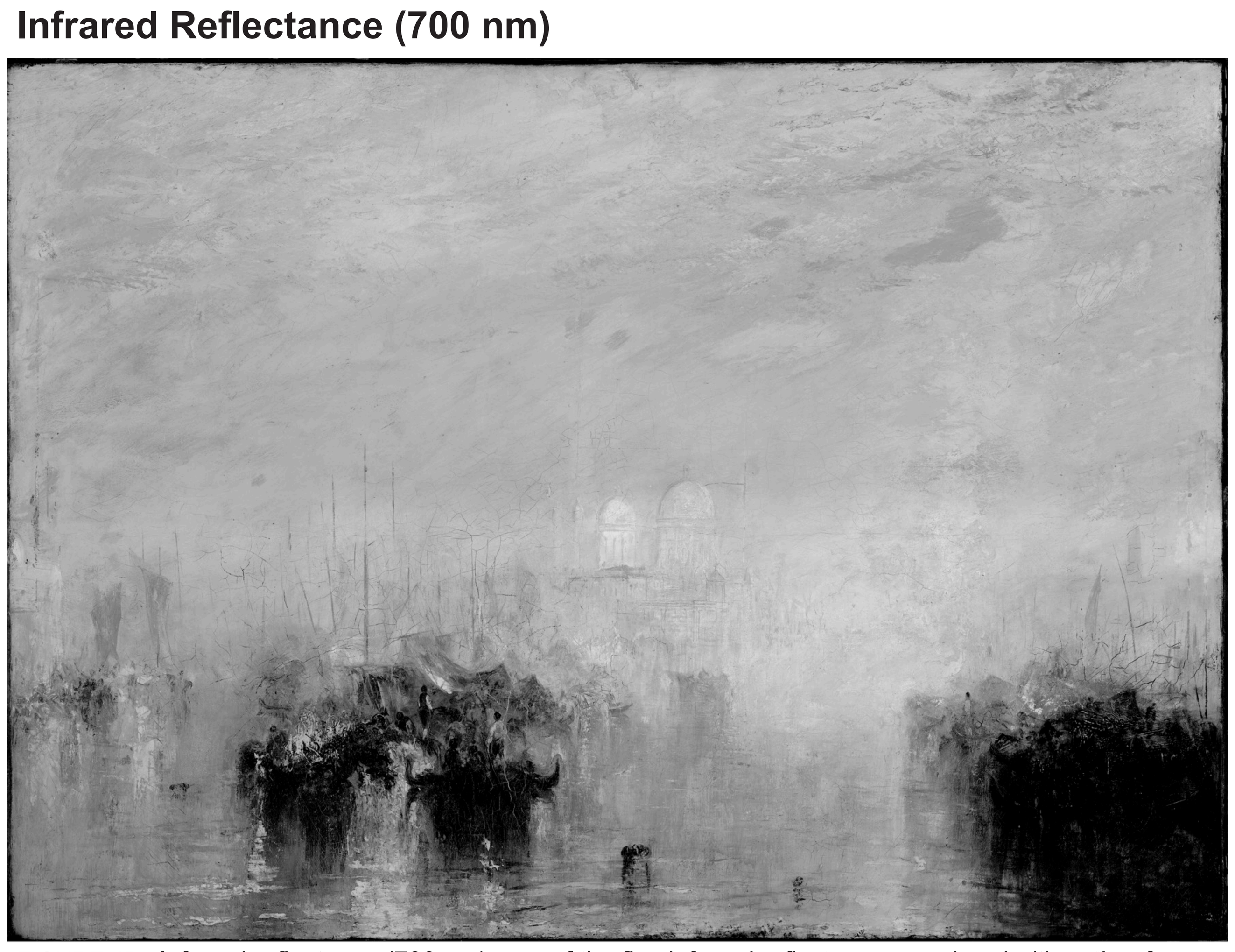


FIGURE 4B: Infrared reflectance (700 nm), one of the five infrared reflectance wavebands (the other four infrared wavebands are centered at 735, 780, 870, and 940 nm).

UV Reflectance (365 nm)

FIGURE 4C: UV reflectance (365 nm). Dark patches in sky indicate retouching, possibly with titanium white, a pigment introduced in the 1920s.

False-Color Infrared (FCIR)

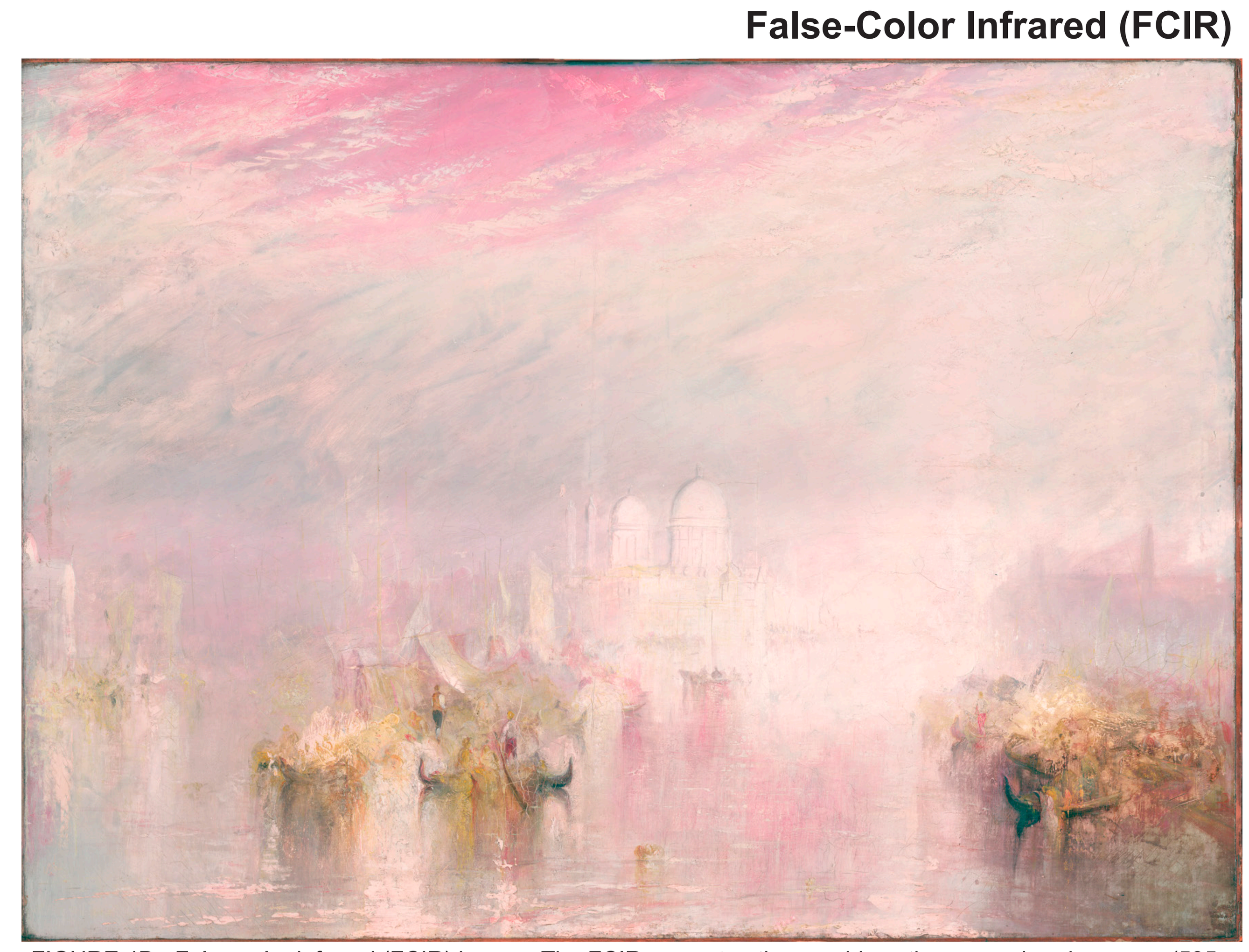


FIGURE 4D: False-color infrared (FCIR) image. The FCIR reconstruction combines three wavebands: green (535 nm) replaces the blue channel; red (625 nm) replaces the green channel; and infrared (940 nm) replaces the red channel. FCIR imaging can help identify and show the spatial distribution of some pigments such as ultramarine (shaded red in this FCIR).

Blue-Induced Visible Fluorescence

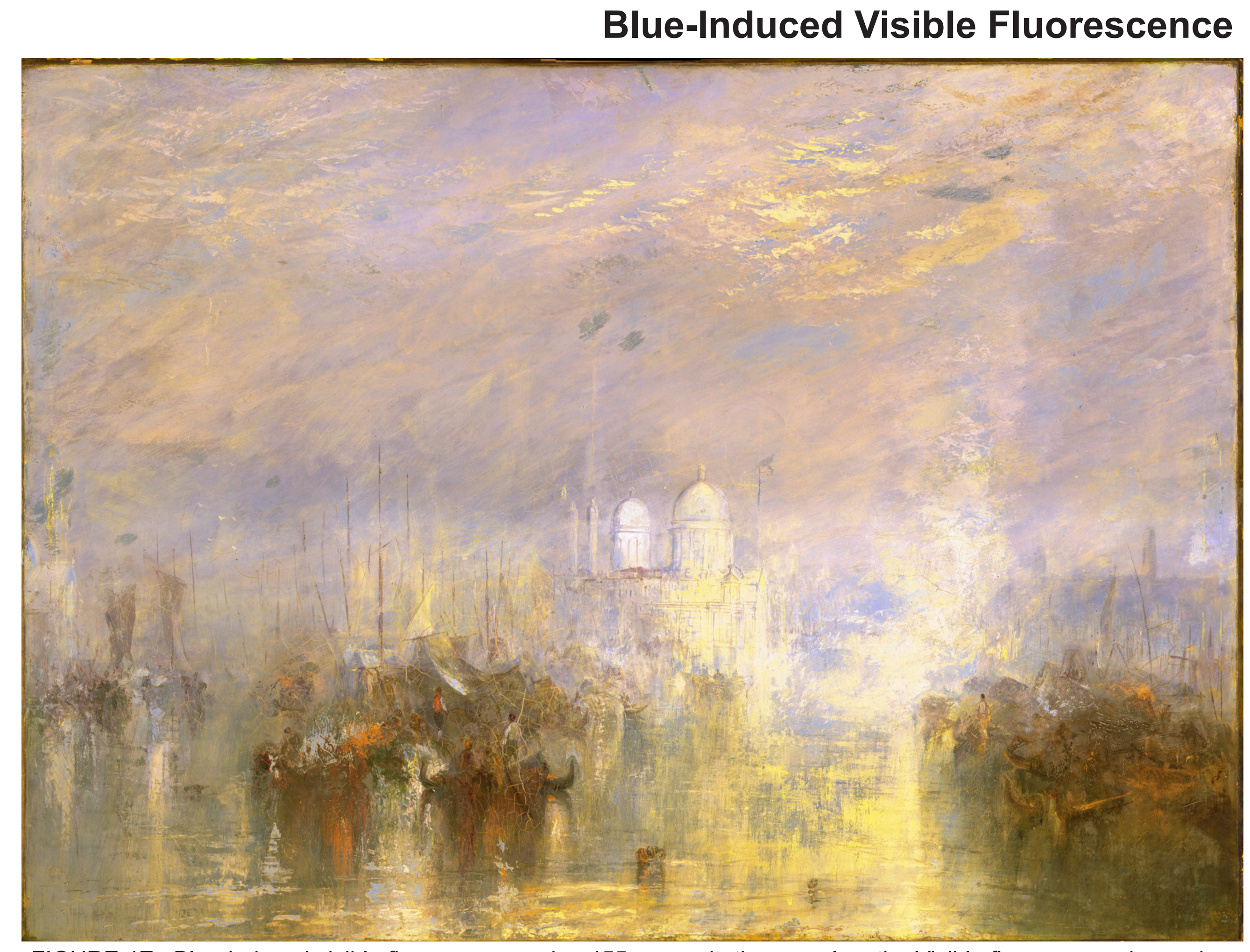


FIGURE 4E: Blue-induced visible fluorescence using 455 nm excitation wavelength. Visible fluorescence image is reconstructed from three wavebands using red, green, and blue bandpass filters on the lens (Wratten #25, #58, and #47 filters, respectively)

UV-Induced Visible Fluorescence

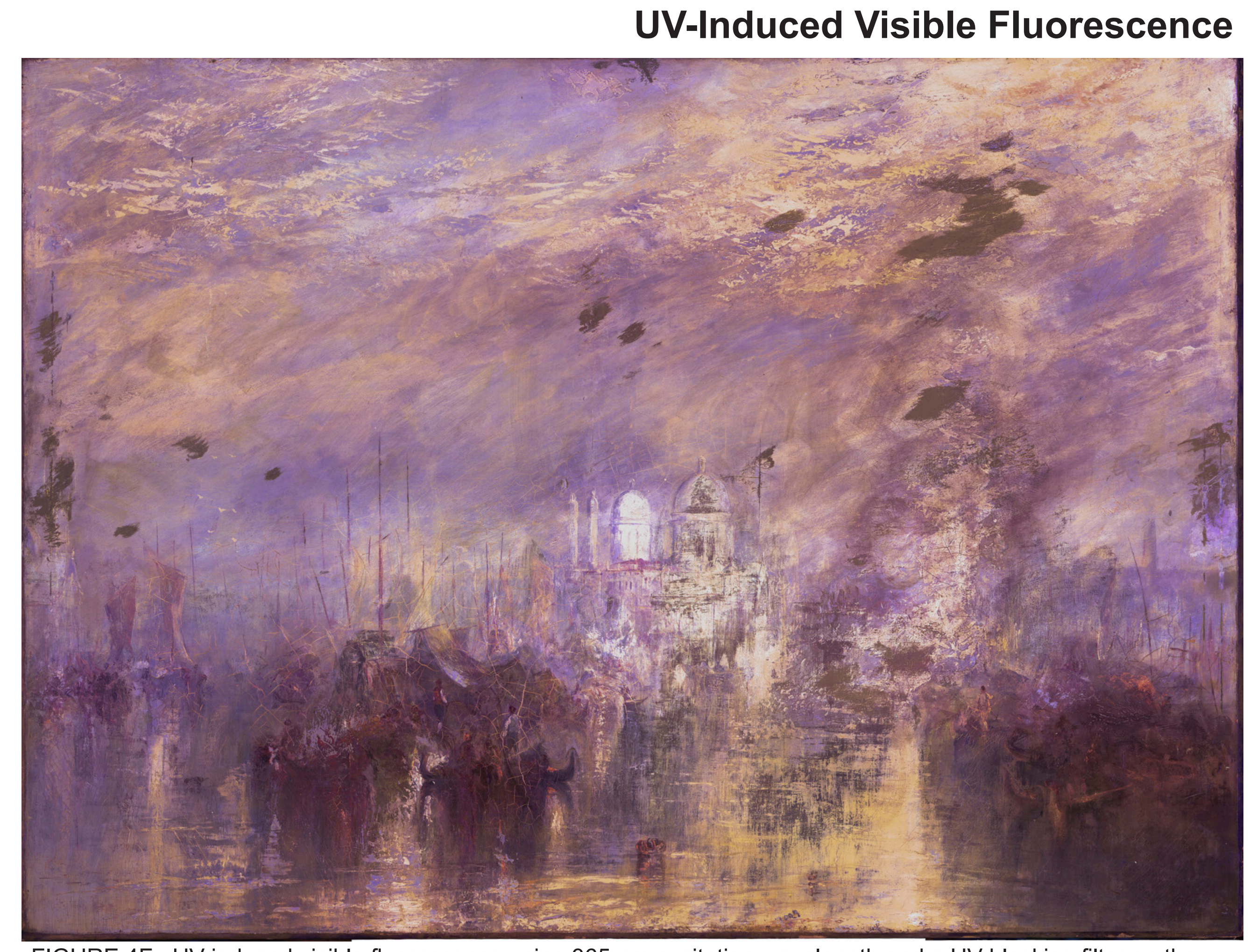


FIGURE 4F: UV-induced visible fluorescence using 365 nm excitation wavelength and a UV blocking filter on the lens to block reflected UV. Visible fluorescence image is reconstructed from three wavebands using red, green, and blue bandpass filters on the lens (Wratten #25, #58, and #47 filters, respectively)

FUTURE WORK

Future studies are anticipated to include integrating the normal maps generated from RTIs with the photogrammetry to make a more accurate 3D model showing surface texture. This could allow analysis of craquelure patterns and features of the artist's technique, such as brush-stroke patterns. Principal Components Analysis (PCA) of the various pigments can be used to identify areas of past retouching and distinguish original pigments from overpainted areas. PCA also can be used to compare the palette of this painting with other known works, which may help to identify the probable artist. Planning is underway to create a project database and publish the complete data sets on-line to allow collaborative, open-access scholarship.

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