Reconstructing Pigment Mixtures in Wu Guanzhong's *A Boat in the Night* by MA-XRF Spectral Unmixing and Probabilistic Pigment Mapping

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Introduction

Non-invasive Macro X-ray Fluorescence (MA-XRF) spectroscopy is commonly used to map elemental distributions in cultural heritage objects. However, identifying individual pigments can be a challenge because spectral signals often overlap, paint layers interfere with one another (multi-layer stratigraphy), and artists' painting practices introduce further complexity.

To reduce this bias, a hybrid framework was developed and tested on the analysis of **Wu Guanzhong**'s *A Boat in the Night*. MA - XRF elemental data maps and high-resolution visual imager were integrated as parallel data streams. Following spatial colour segmentation, localised elemental ratios were cross-referenced with an in-house pigment library.

A Bayesian optimisation solver then resolved multi-layer ambiguity by evaluating physical constraints, delivering an objective, probability-ranked list of candidate pigments per region to automate pigment deconvolution.

Wu and his Night Boat

Wu Guanzhong (1919–2010) is celebrated as one of the pioneers and a leading figure of modern Chinese art in the 20th century. Throughout his life, he pursed the convergence of East and West, bringing together the aesthetics of traditional Chinese ink and modern Western art in his work.

A Boat in the Night, an oil painting on wood board from the collection of the Hong Kong Museum of Art, was studied to identify the materials Wu used. This research helps reveal his approach to selecting pigments and his distinctive practice of mixing paints to achieve the bold, vibrant effects that define his work.

Wu Guanzhong (1919–2010)
A Boat in the Night , 1996
Oil on wood board
Collection of the Hong Kong Museum of Art
Donated by Mr Wu Guanzhong and his family

Data Acquisition

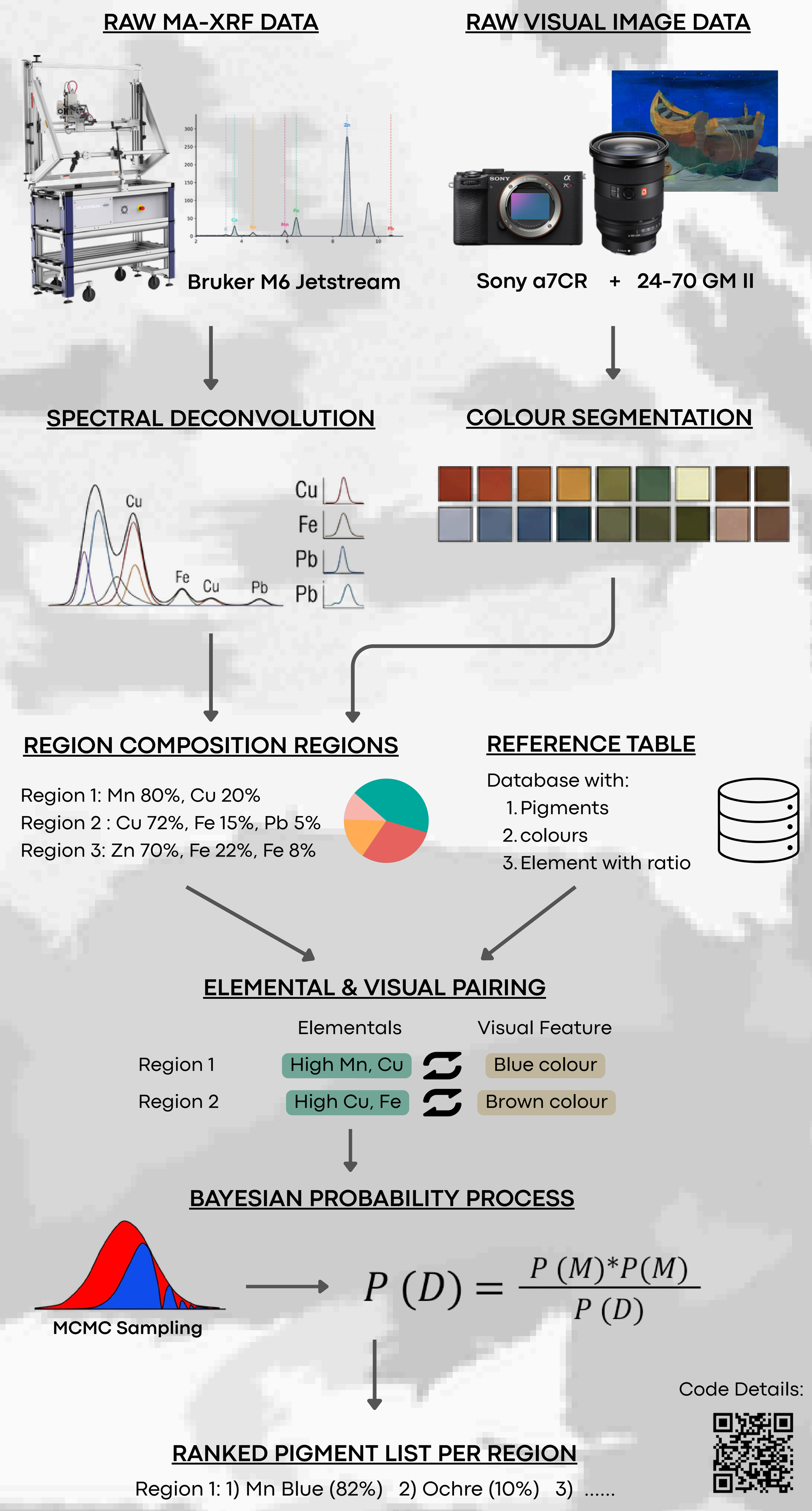
MA-XRF Mapping

- Equipment: Bruker M6 JETSTREAM (Rh X-ray tube)
- Parameters: 50 kV, 300 µA, 500 um steps, 5 ms/pixel
- Data: 3D spectral cube (X * Y * Energy)

Visual Imaging

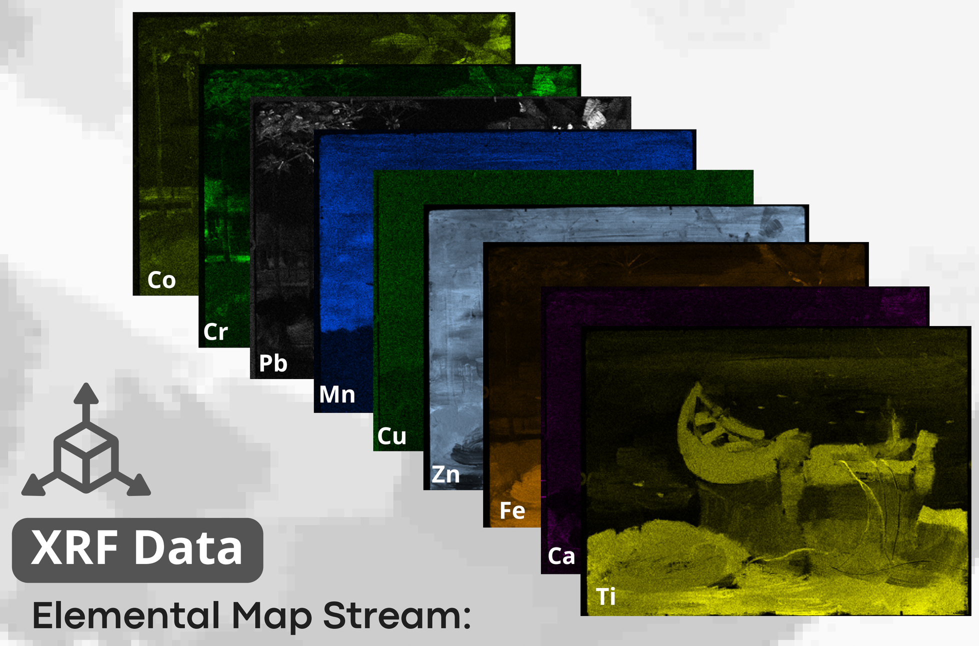
- Equipment: Sony a7CR (61 MP) + 24-70mm GM II lens (f/8)
- Setup: Cross-polarised 45° diffused LEDs (glare reduction)
- Data: sRGB JPEGs co-registered to MA-XRF grid

Logic Flow

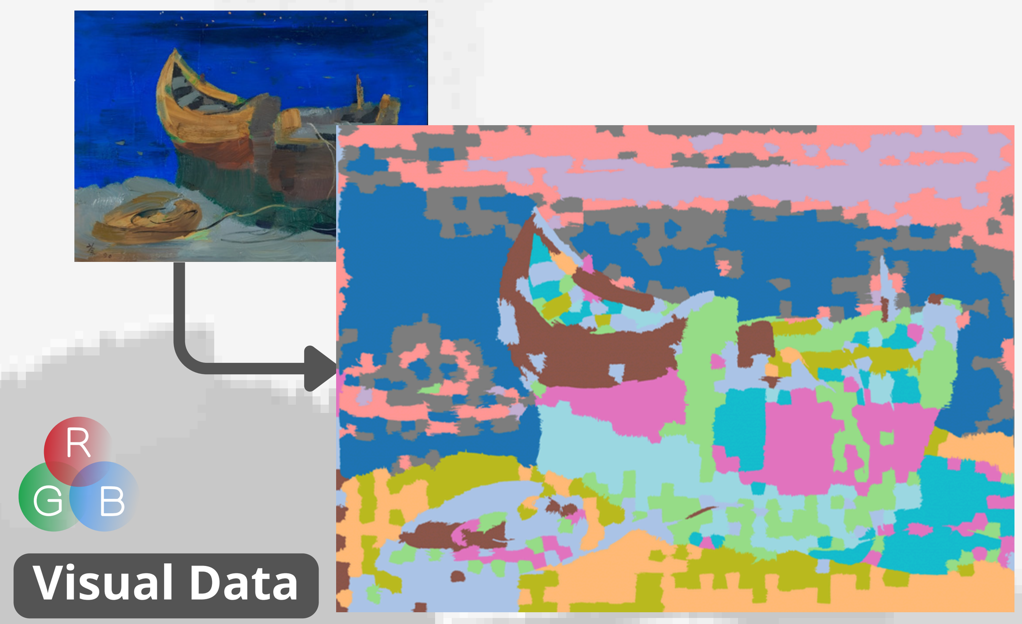


Milestone

Section I - Image Segmentation and Localised Rationing

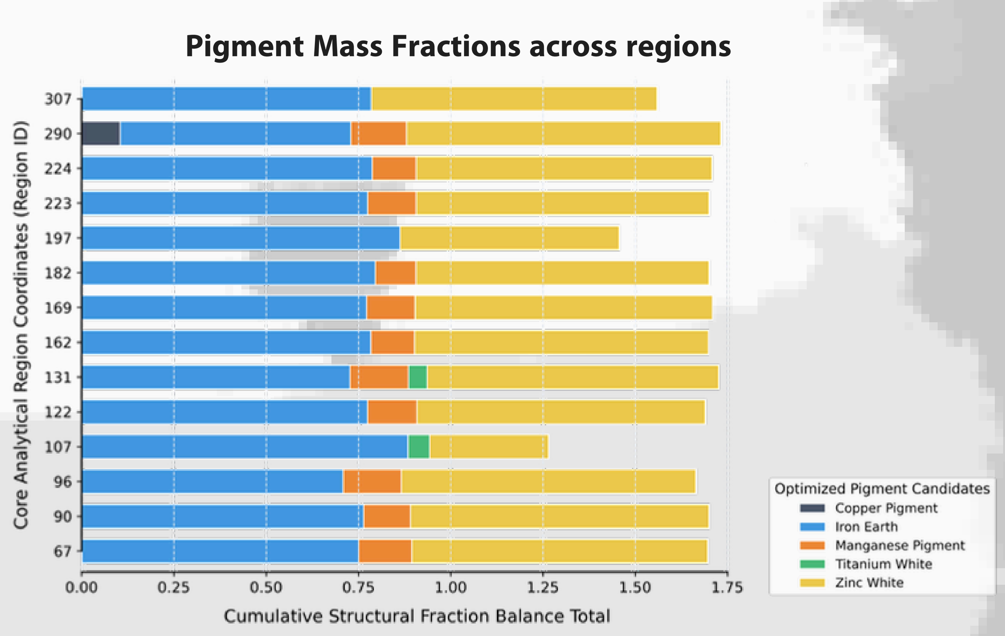


Elemental Map Stream:
Coordinated XRF intensity counts are ingested simultaneously as a co-registered spatial matrix by spectral deconvolution.



Colour Segmentation:
The visual image is segmented into distinct, colour-coherent regions using an RGB/CIELAB clustering algorithm.

Section II - Localised Rationing and The Reference Knowledge Base (The Matrix)

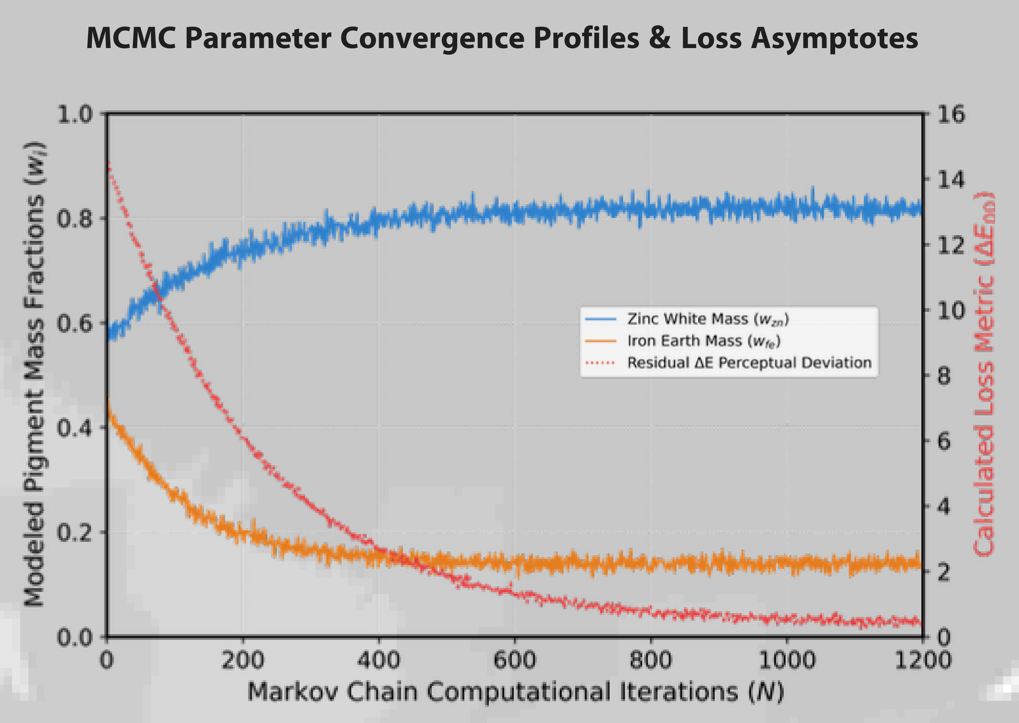


Stoichiometric Extraction:
For each segmented colour region, the averaged XRF signals are extracted. The system ties the averaged XRF data with visual data, calculates the relative ratio of each chemical elements present within that region.

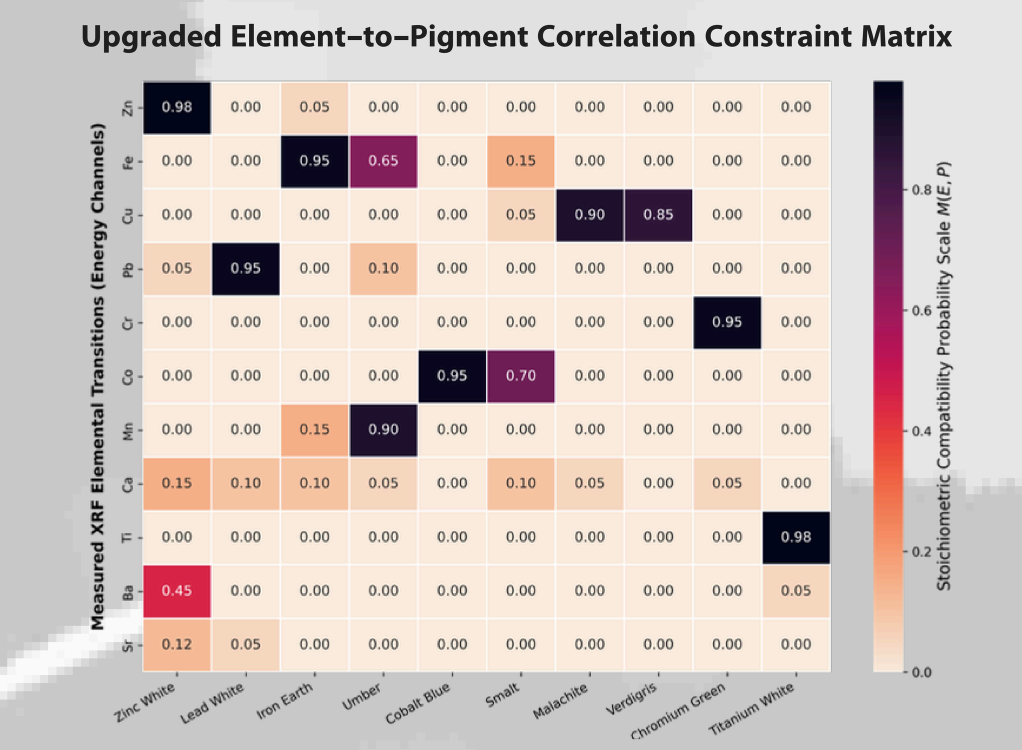
Pigment Library	Colour Role and RGB Threshold Targets	Stoichiometric Elemental Ratios (%)
Zinc White	Ground / High Brightness R > 220, G > 220, B > 220	85% Zn, 10% Ca, 5% Pb
Ochre / Umber	Brown / Dark Earth Tones R: 100-150, G: 50-100, B: 20-60	70% Fe, 15% Mn, 10% Ca, 5% Zn
Copper Pigments	Blue-Green / Cyan Tones R < 80, G: 120-180, B: 120-200	75% Cu, 15% Zn, 10% Ca
Cobalt Blue	Vibrant Blue R < 70, G < 100, B > 180	60% Co, 20% Zn, 15% Fe, 5% As
Chromium Pigments	Green R < 100, G > 140, B < 10	65% Cr, 20% Fe, 10% Zn, 5% Pb
Lead White	Warm Highlights / Dense Underlayers R > 200, G > 200, B > 190	90% Pb, 5% Zn, 5% Ca
Calcium Carbonate	Filler / Base Extender R: 200-230, G: 200-230, B: 200-230	80% Ca, 10% Fe, 10% Zn
Titanium White	Modern Bright White / Overpaints R > 240, G > 240, B > 240	85% Ti, 10% Zn, 5% Al

Reference Table: Establishes correlations between pigments, colour thresholds, and multi-elemental ratios (e.g., Ochre/Umber mapped to 70% Fe, 15% Mn, 10% Ca, 5% Zn) to serve as a ground-truth validation.

Section III - Bayesian Probability and Posterior Mapping



Bayesian Optimisation:
An MCMC random walk iteratively updates the pigment weight matrix. By comparing scanned XRF elemental ratios against the reference database, the system calculates the statistical likelihood of each pigment combination.



Probabilistic Pigment Mapping:
The system maps the matrix data onto a three-sided chart to calculate the probability of each pigment combination and provides an objective, statistically ranked list of pigments present in every region instead of a single guess.

Future Study

Expand Data Dimension: Integrate hyperspectral data to map vertical paint stratigraphy.
Database Scaling: Expand the reference matrix to include synthetic pigments and binders.
Validation: Benchmark solver accuracy limits on controlled mock-up canvases.

Summary & Discussion

The workflow successfully provides objective pigment probability, eliminating subjective ambiguity caused by multi-layer paint interference. It fuses high-resolution visual imagery with MA-XRF data via a Bayesian MCMC framework, ensuring robust integration of complementary datasets. Automated data processing delivers probability-ranked pigment profiles per region, enhancing reproducibility and diagnostic confidence. This streamlined approach bridges computational vigor with practical usability, advancing precision in pigment evaluation and supporting both research and conservation applications.

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HKMoA Hong Kong Museum of Art 香港藝術館
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Reference

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