SUPERRESOLUTION CONTOUR RECONSTRUCTION APPROACH TO A LINEAR THERMAL EXPANSION MEASUREMENT

F. M. Inochkin[a], S. K. Kruglov[b], I. G. Bronshtein[a], T. A. Kompan[c], S. V. Kondratiev[c], A. S. Korenev[c], N. F. Puhov[c]

[a]ITMO University, St. Petersburg, Russia
[b]Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russia
[c]D. I. Mendeleev Institute for Metrology, St. Petersburg, Russia

fedor.inochkin@gmail.com

Problem description (application)

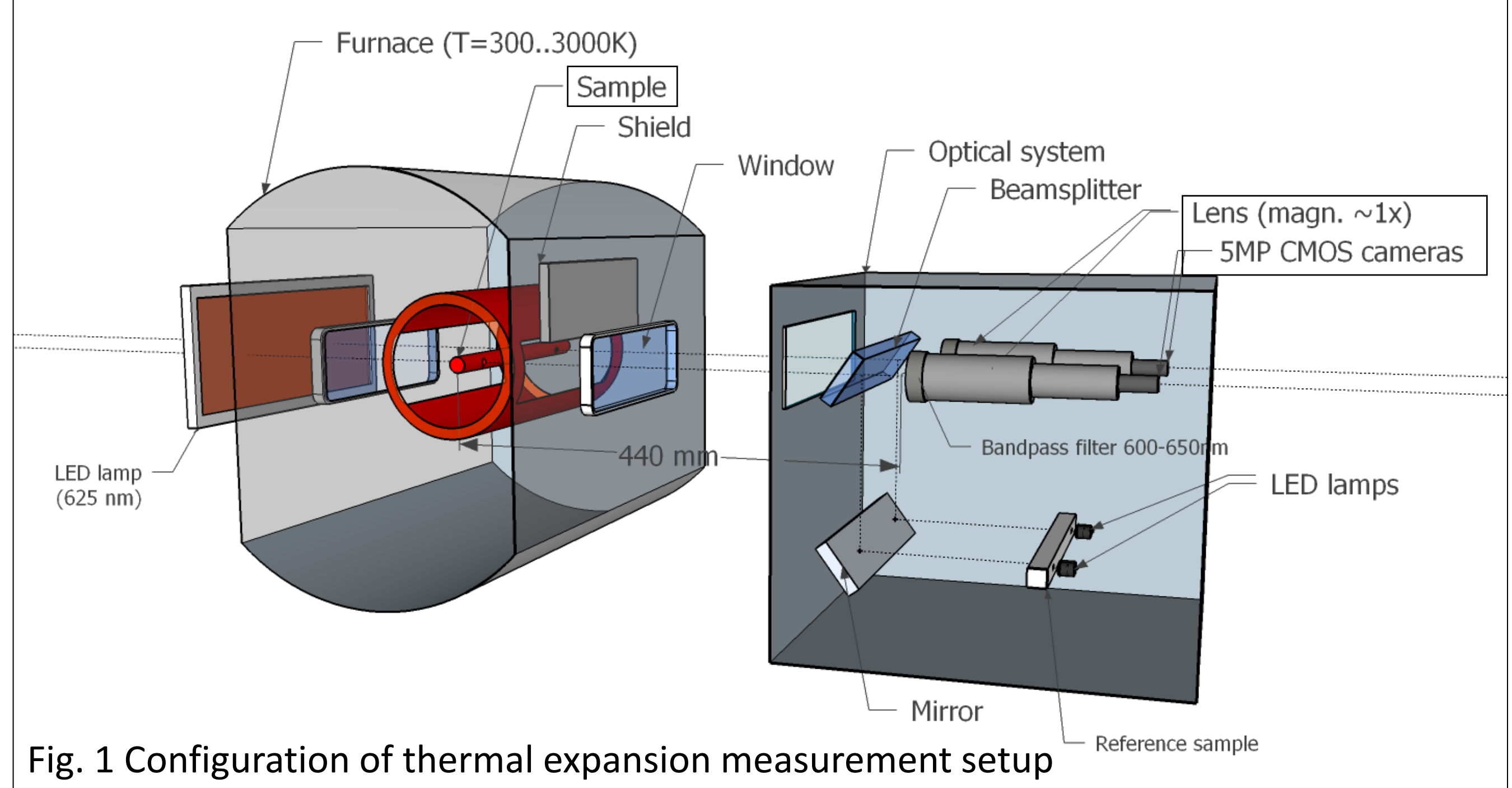


Fig. 1 Configuration of thermal expansion measurement setup
D. I. Mendeleev Institute for Metrology, St. Petersburg, Russia

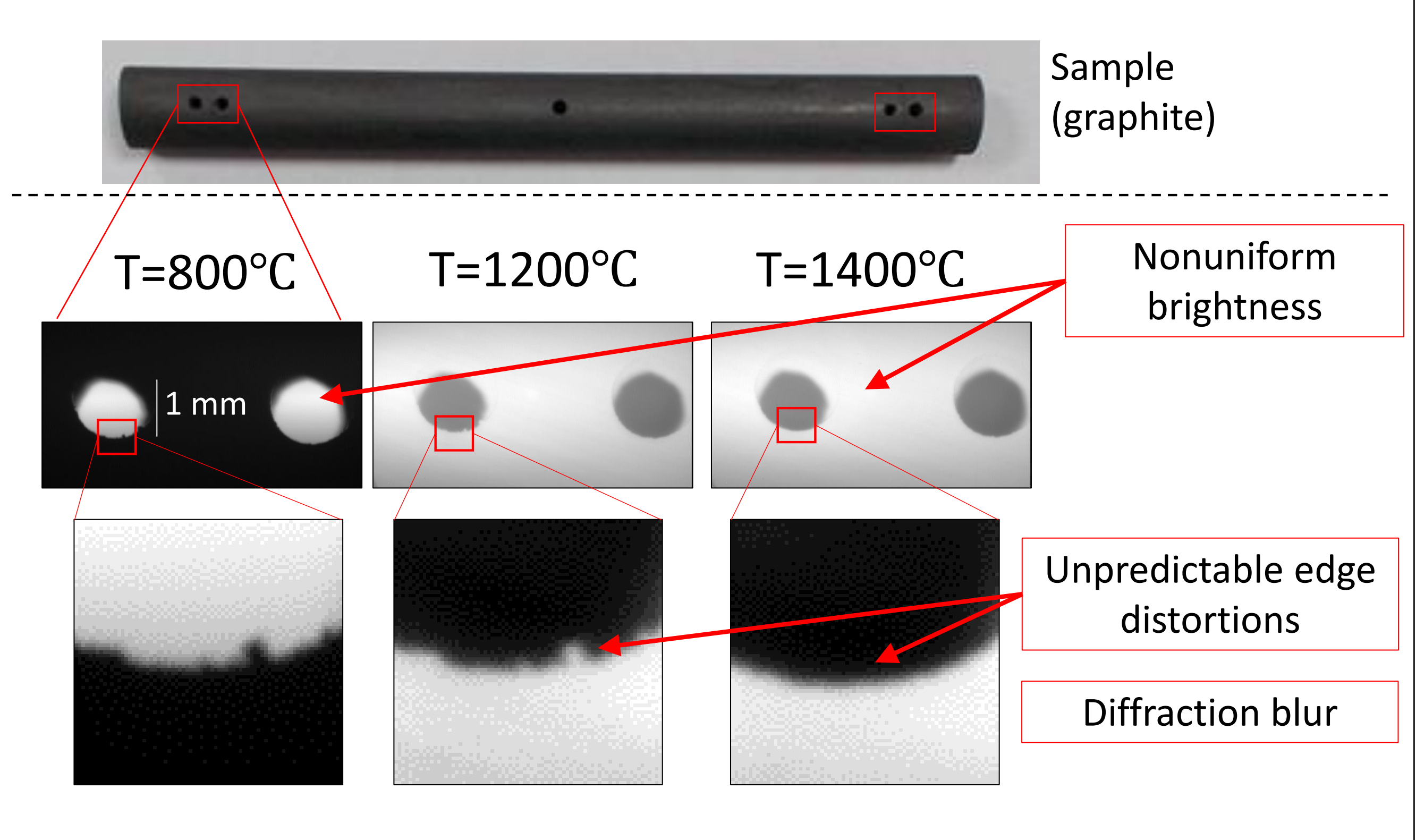


Fig. 2 Edge image processing challenges

Linear thermal expansion (LTE) parameters are widely used to describe thermomechanical properties of materials. Optical LTE measurement principle is based on the sample's edge image processing by computing the edge displacement from two or more images obtained at different temperatures. Generally being a well-known problem, which can also be solved by existing image processing techniques, in this application it is sufficiently complexified by the following factors:

1. Edges of a sample obtained at different temperatures may slightly differ due to unexpected **random edge distortions** along with the expected linear expansion of the edge.
2. Temperature range of the setup is up to 3000K. That requires long-distance microscopy (>400 mm object-to-lens distance), which leads to a limited optical resolution of integrated microscopes. Due to a phenomena known as **diffraction optical resolution limit**, small-sized features of the edge may not be resolved directly. For our system, spatial cutoff frequency is ≈60um^{-1}, while random edge distortions may be as small as 1..10 microns.
3. Image of sample and background surfaces have **nonuniform brightness**, which leads to **edge location error** for the majority of conventional edge estimation techniques.
4. **Subpixel processing** is required.
5. Setup is a part of the primary national standard for the LTE coefficient and requires high-accuracy and reliable measurements. **Non-reliable measurements must be detected** and excluded from further processing.

Results

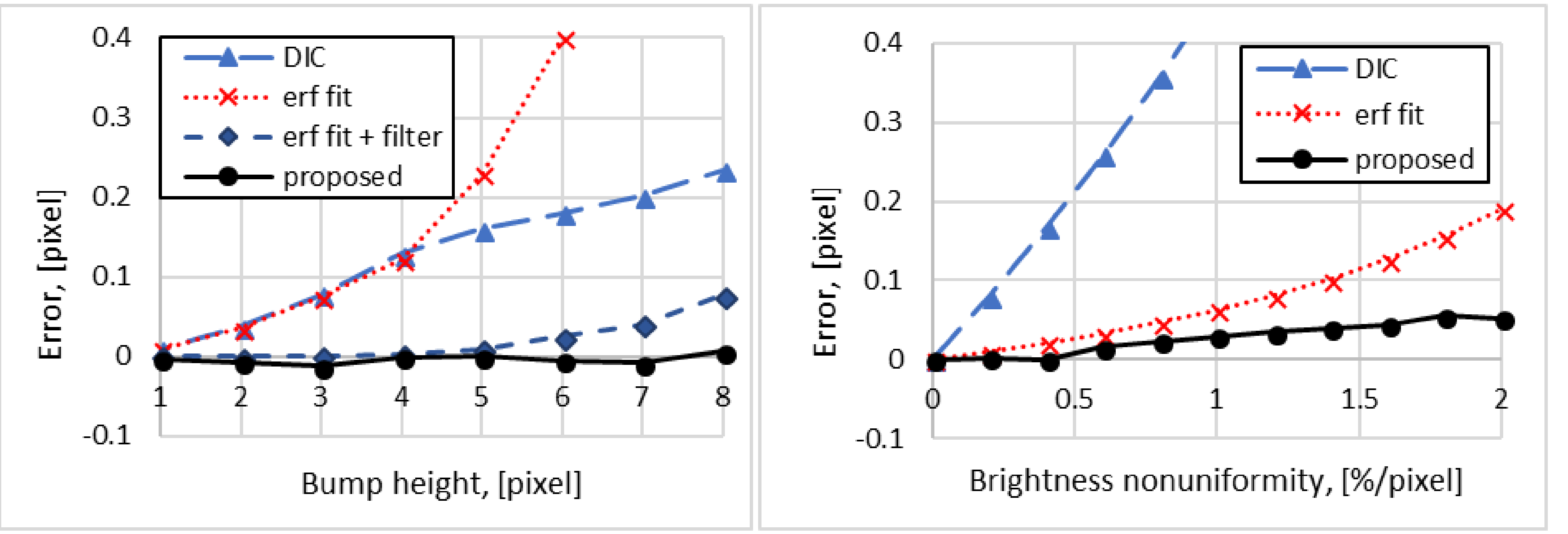


Fig. 5 Comparison of measurement error given by the proposed and conventional techniques

- Up to 5x less error for random edge distortions factor; up to 4x less error for the nonuniformity factor.
- **Two measurement reliability indicators are provided**: real-model images matching and contour-contour matching.

Comparison with digital image correlation (DIC) and conventional edge estimator based on *erf*-function fitting to the edge profile.

Superresolution contour reconstruction (method)

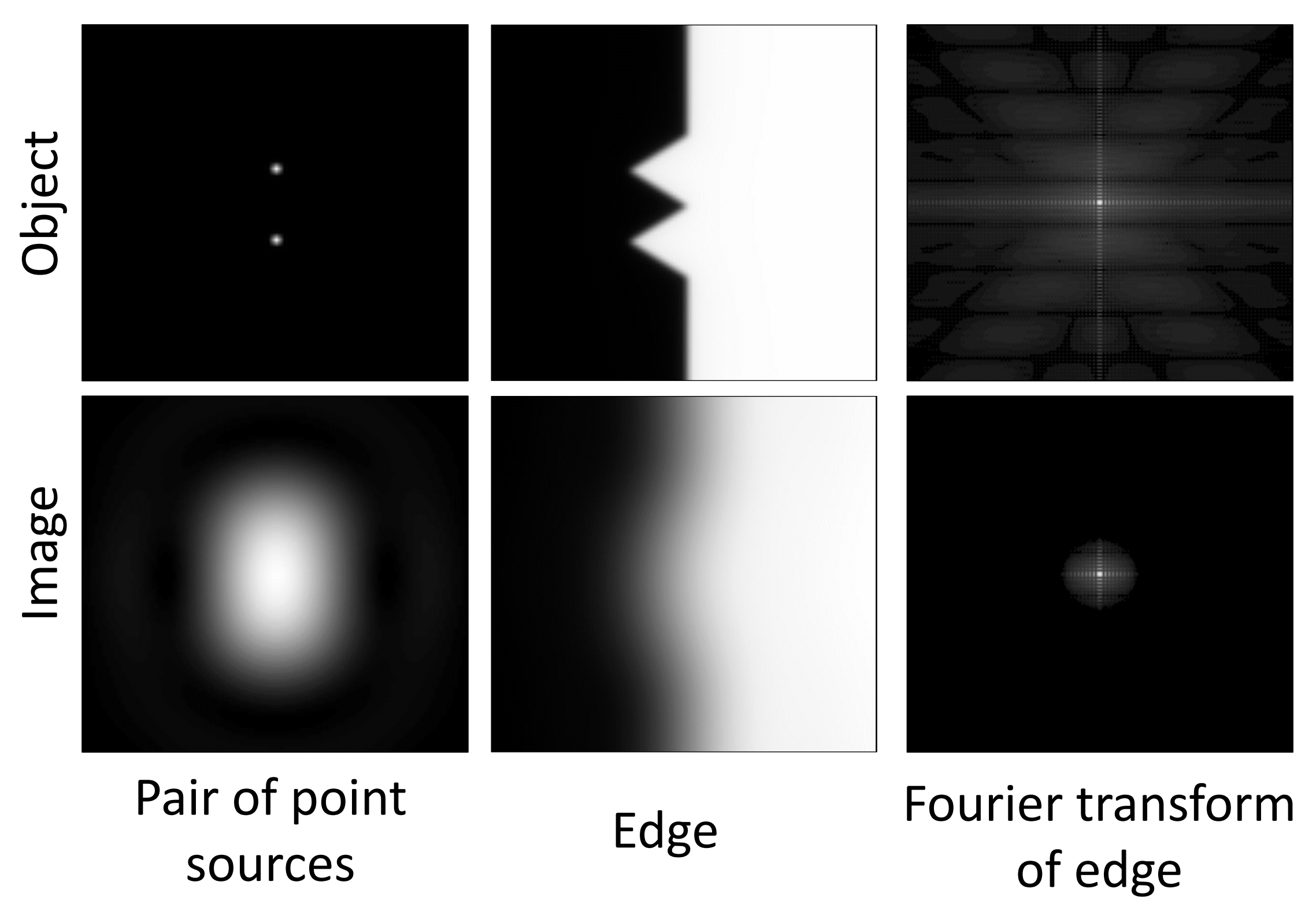


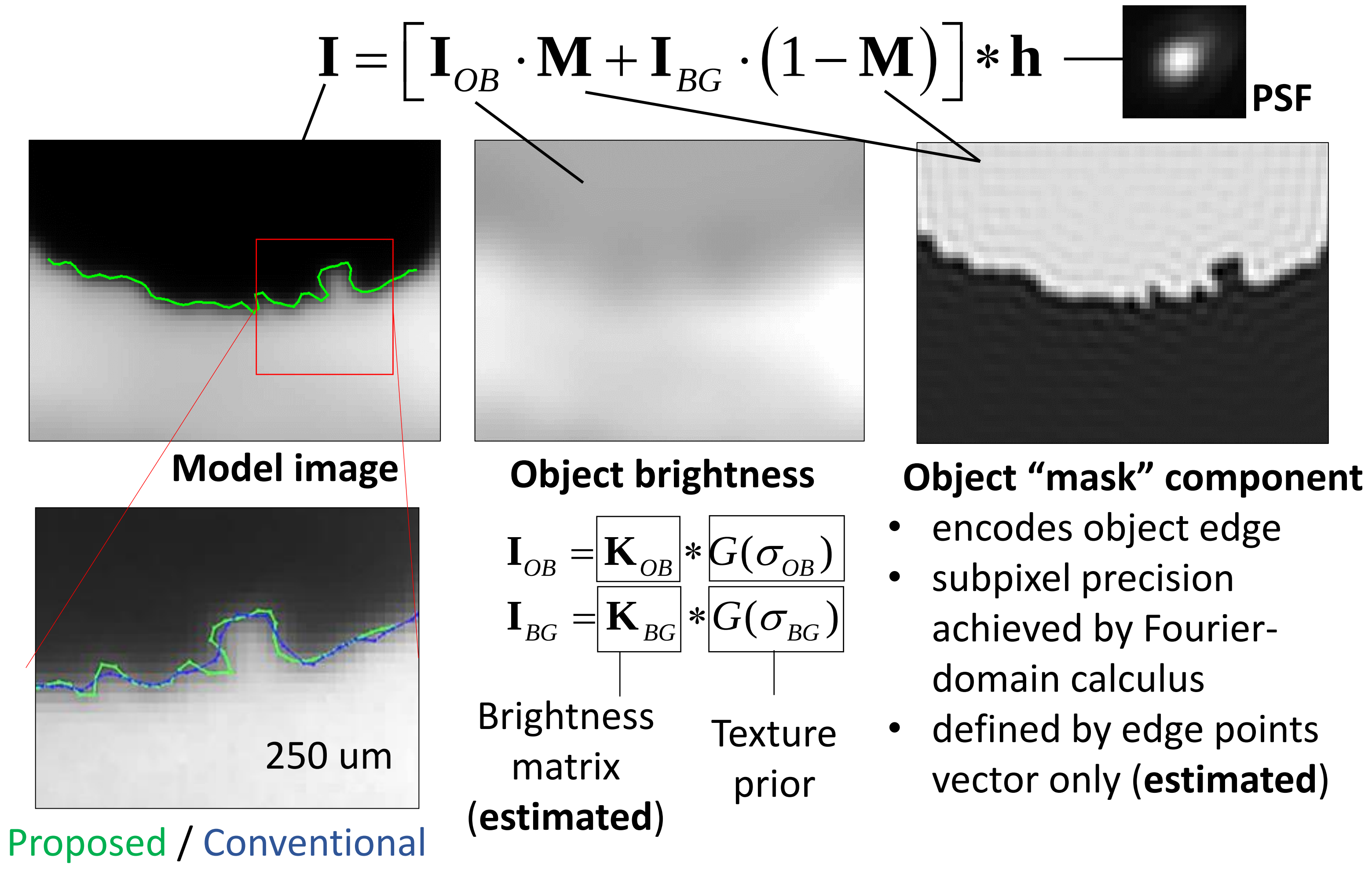
Fig. 3 Diffraction resolution limit impact on edge image

Diffraction blur (or diffraction resolution limit) leads to non-reversible image degradation by narrowing bandwidth of its Fourier transform. In case if Nyquist-Kotelnikov criterion is satisfied, image sampling does not limit the resolution of a system anymore. Accurate edge estimation involves an object de-blurring problem. Due to diffraction limit, it is an ill-posed problem (even without a noise) and requires prior information about the object.

Basic idea of the proposed solution is a reconstruction of object under explicit "edge prior". This is achieved by iterative approximation of an image, acquired by a camera, with the numerical model, parametrized by the point vector being estimated.

The proposed model contains image blur and brightness nonuniformity:

$$\mathbf{I} = \left[\mathbf{I}_{OB}\cdot\mathbf{M} + \mathbf{I}_{BG}\cdot\left(1-\mathbf{M}\right)\right] * \mathbf{h}$$



$$\mathbf{I}_{OB} = \mathbf{K}_{OB} * G(\sigma_{OB})$$
$$\mathbf{I}_{BG} = \mathbf{K}_{BG} * G(\sigma_{BG})$$

- encodes object edge
- subpixel precision achieved by Fourier-domain calculus
- defined by edge points vector only (**estimated**)

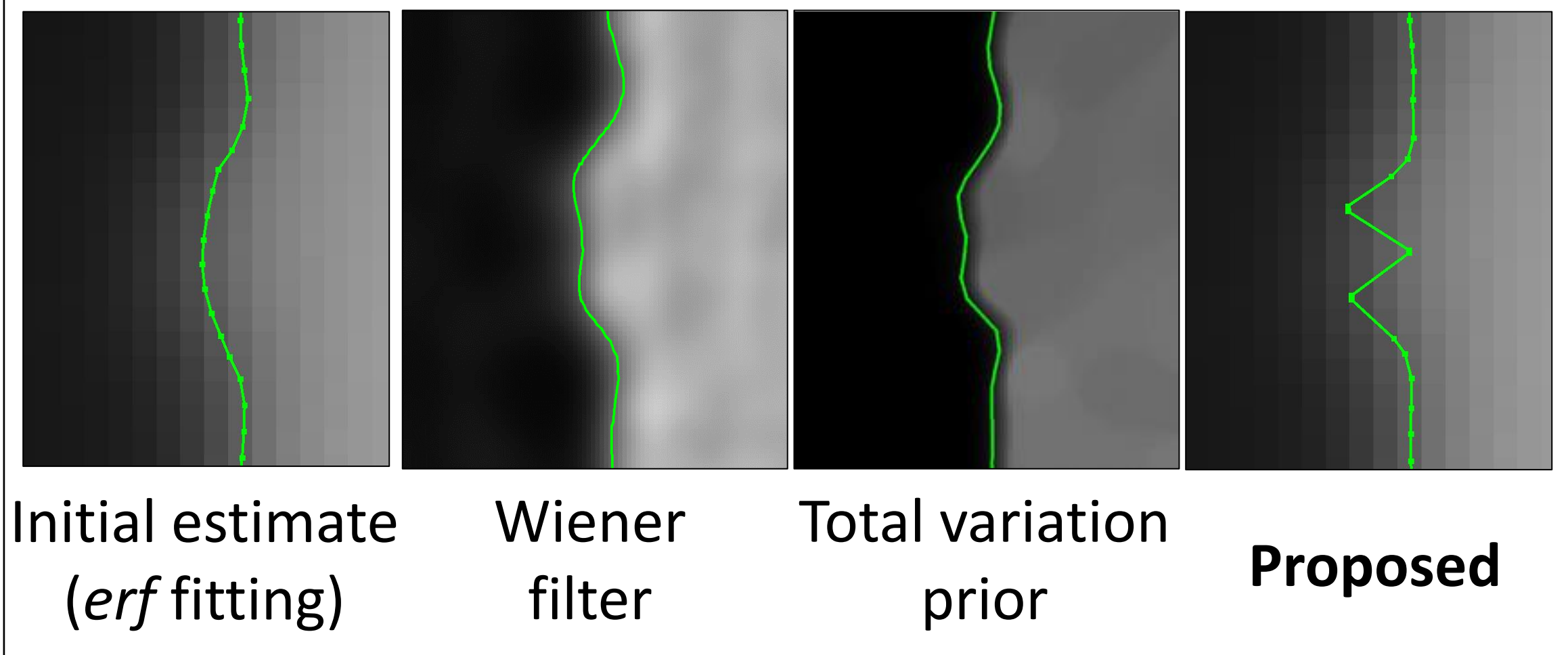
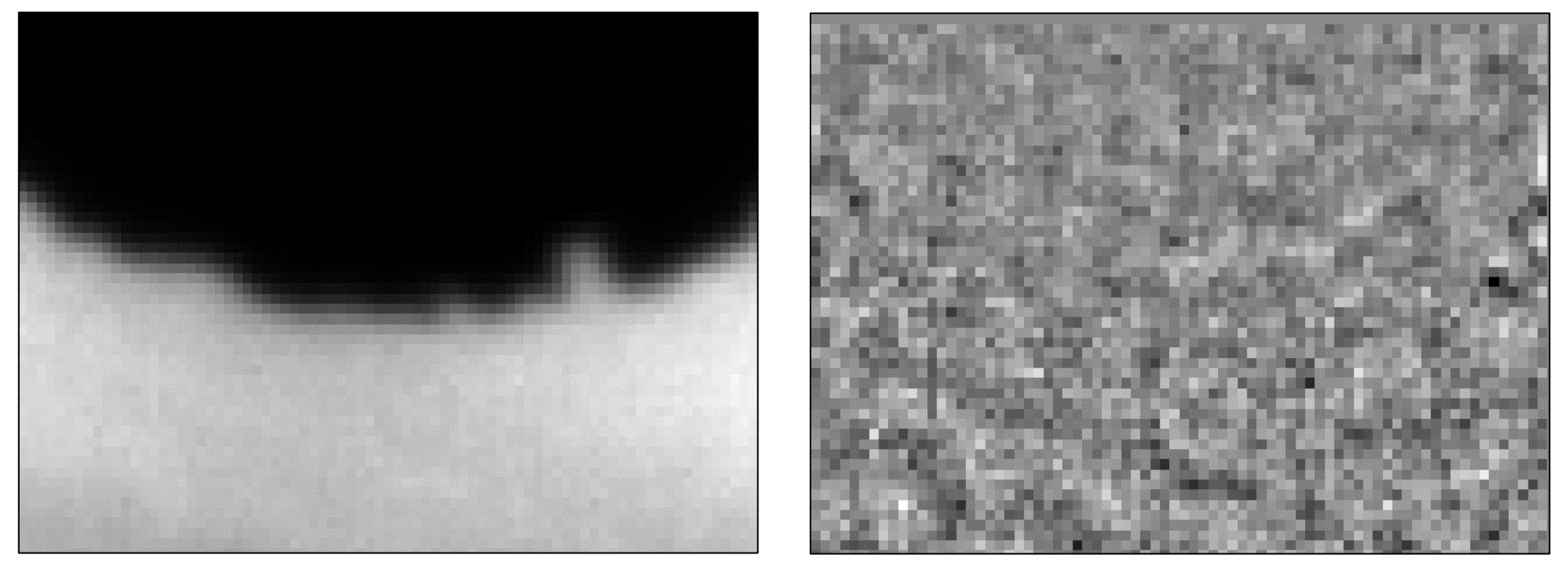
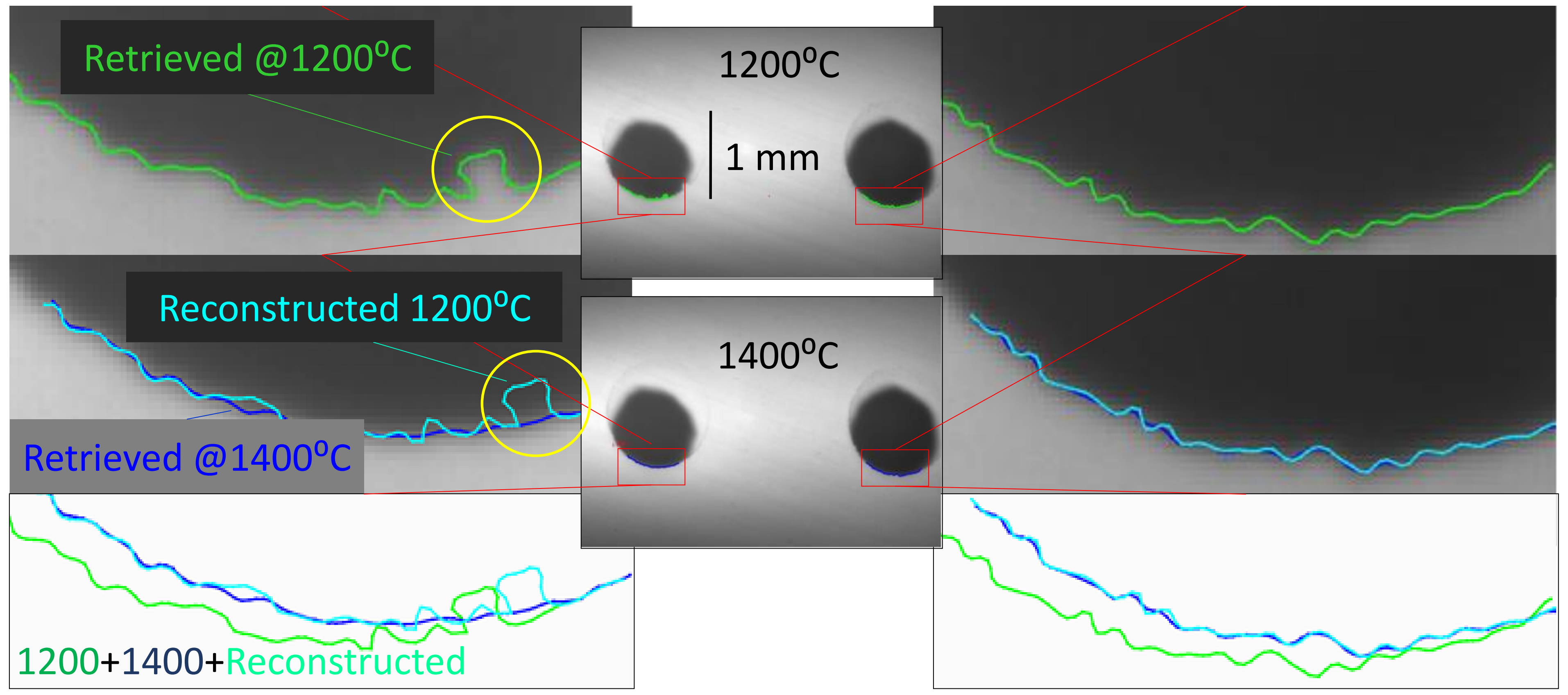


Fig. 4 Example of contour reconstruction results for non-resolvable edge features (real data)



1. **Blur compensation and subpixel precision.**
2. **Brightness nonuniformity compensation.**
3. **Measurement reliability estimate is provided.**

Thermal expansion measurement



- Expansion parameters are estimated trough the fitting of contour, measured for the first (reference) temperature, to the contour, measured for the second temperature via optimization-based technique according to a linear expansion model.
- Most outstanding points are excluded from contours by iterative 3σ-filtration.
- Resulting merit function value provides contour fitting reliability estimate.

Acknowledgement

The research is carried out in ITMO University under the financial support of Ministry of Education & Science of the Russian Federation.

ITMO UNIVERSITY