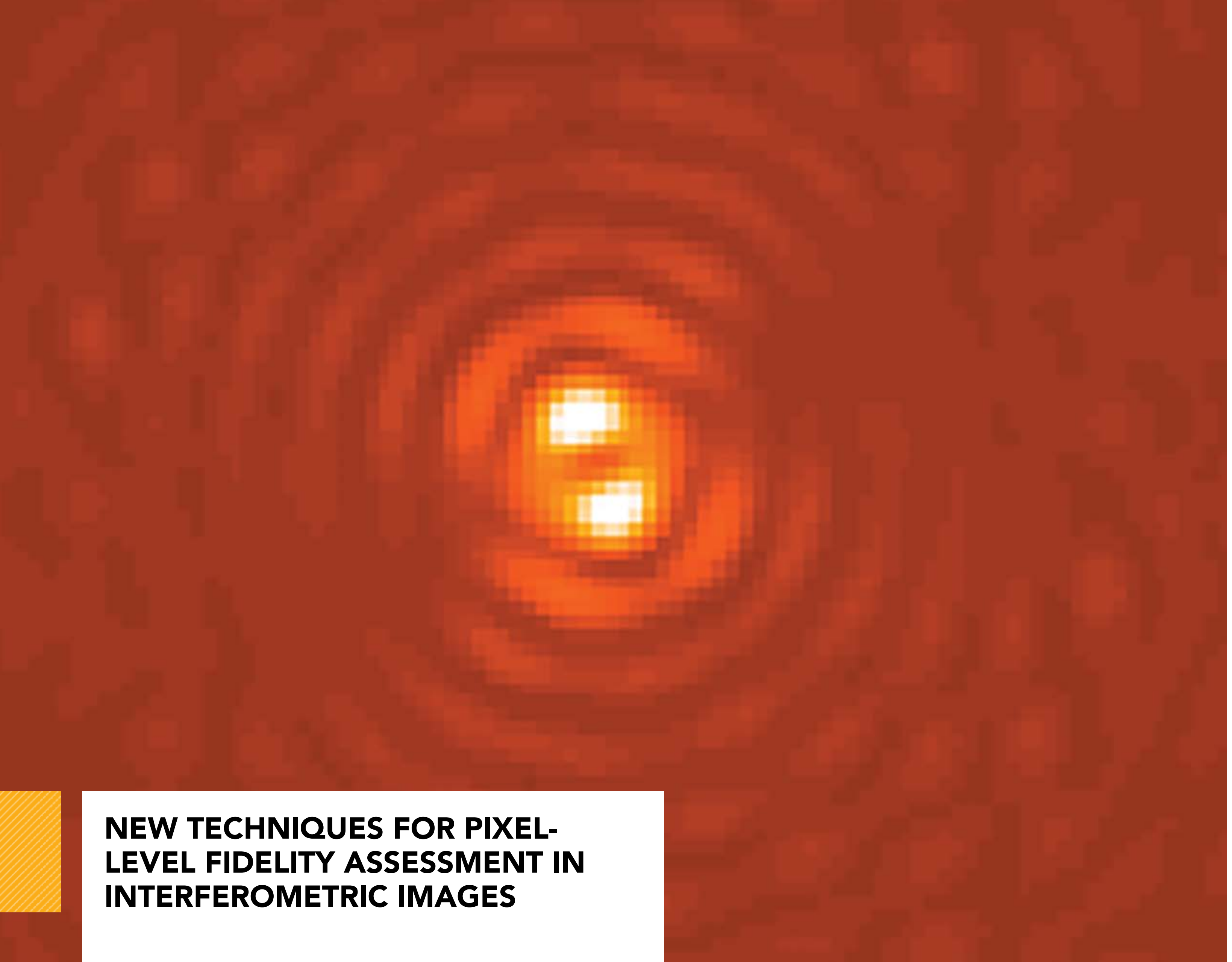

NEW TECHNIQUES FOR PIXEL-LEVEL FIDELITY ASSESSMENT IN INTERFEROMETRIC IMAGES

Allocation: Blue Waters Professor/0.28 Mnh
PI: Athol Kemball[1]

[1]University of Illinois at Urbana-Champaign

EXECUTIVE SUMMARY:

Contemporary astronomical interferometry for modern telescope arrays and future planned instruments such as the Square Kilometer Array (SKA) present grand-challenge problems, now uniquely amenable to solution using extreme-scale computing. Data rates in this domain are rapidly escalating, and these telescopes will require extreme-scale computing within a decade. My research with Blue Waters has focused on new techniques for pixel-level fidelity assessment in interferometric images, a uniquely challenging problem, as well as investigations of other issues of relevance to the computation and data challenges faced in this discipline within the coming decade.

INTRODUCTION

Interferometry is a key observational technique that enables astronomical imaging at the highest angular resolution. In this technique, the spatial coherence of the incident radiation from the astronomical source is measured by cross-correlation or interferometric combination at all projected spatial separations sampled by the configuration of telescopes in the array. These projected separations vary over time due to Earth's rotation. Therefore, interferometry creates effective telescope apertures far exceeding any monolithic telescope diameters that could easily be physically constructed but at the cost of only partial sampling of the aperture. The measured spatial coherences are connected to the astronomical source brightness distribution on the sky by an integral equation that reduces to a Fourier transform in the limit. However, the synthesized aperture is inherently sparsely sampled in interferometry, so the inverse problem is ill-posed and requires mathematical regularization for solution. In addition, the imaging integral equation contains terms representing atmospheric propagation and instrumental calibration errors at each telescope. These terms need to be accounted for along with the unknown image brightness distribution during inversion from the measured coherence data. Our project on Blue Waters has concerned several highly challenging problems in this domain, specifically an extension of prior work concerning pixel-level fidelity estimation, as well as the exploration of data analysis in this domain at petascale.

This work is important because of escalating data rates, which scale in interferometry approximately as the square of the number of telescopes in the array multiplied by increasing detector data acquisition rates enabled by exponential advances resulting from Moore's Law. This places peta- or exascale computational demands on interferometric calibration and image formation for future interferometers such as the SKA, as these arrays will have a large number of antennas and high data-acquisition rates. These facilities represent significant community investments and need to achieve their scientific goals.

METHODS & RESULTS

Our approach on Blue Waters has been to extend interferometric fidelity estimation techniques that we have previously developed [1,2] to larger scale and over a more complete parameter range. These techniques rely on statistical resampling methods using variants of bootstrap resampling for statistically-dependent data that are intrinsically computationally very demanding. Blue Waters has allowed much larger interferometer array sizes to be considered along with richer physical models. Both are more realistic in terms of anticipated future telescopes.

This domain requires extreme-scale HPC within a decade, so this work is important to the discipline. The computational intensity and I/O and computation heterogeneity are also unusual in terms of the distribution of traditional HPC user needs. These results will also allow the community to extract greater value from significant capital investments in public telescope facilities.

WHY BLUE WATERS

The scale of Blue Waters is essential to this work due to the computational demands of the algorithmic methods used and the size of the interferometer arrays considered in these studies. Blue Waters allows fundamentally new approaches to be explored due both to its scale and balance. The system and project staff are an essential element of the success of this project as they provide a level of system support that ensures high uptime and throughput in addition to a very deep level of technical expertise. A future Track-1 system would allow significant advances in the work described here, further aiding the utilization and design of expensive capital investments in this domain.

PUBLICATIONS

Seidel, E. and Allen, G. and Freemon, M. and Gammie, C.F. and Kemball, A.J., Pennington, R. and Petravick, D., Computing and Data Challenges for Multi-Messenger Astronomy, *Exascale Radio Astronomy*, (AAS Topical Conference Series Vol. 2., Monterey, California, 30 March-4 April, 2014, Bulletin of the American Astronomical Society), Vol. 46, #3, #200.01.

FIGURE 1 (BACKGROUND): Image fidelity of a region of a reconstructed interferometric image, here showing variance per pixel over two angular coordinates on the sky.