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Instrument Modelling for the next-generation Event Horizon Telescope

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The Event Horizon Telescope (EHT) has produced the first ever images of supermassive black holes using Very Long Baseline Interferometry (VLBI) with a global network of radio telescopes. New methods to model, calibrate, and analyse data from sparse, heterogeneous VLBI arrays had to be developed to enable the reconstruction of black hole images at such high resolutions. The next-generation EHT (ngEHT) will field ~ 10 new mm and sub-mm telescopes around the globe to form an array that improves upon the sensitivity, frequency, and baseline coverage of the EHT and enable reconstructions of the first high-resolution movies of supermassive black holes.

Building an instrument that can achieve the proposed key science goals poses unique technical challenges. Incoming electromagnetic waves from the astrophysical source of interest are acted upon by various sources of systematics that modify the original signal and set limits on what the instrument can see. A thorough understanding of the physics that underlies the observation process is necessary to design both the array and post-observation analysis software that minimize these propagation path effects.

Conventional methods for calibration and imaging are limited in the sense that they take an inverse approach to solving this problem by iteratively calibrating and imaging the data. Complex forward-modelling approaches that involve a generative model to describe the processes that give rise to the observed data have become more common as computational resources improved and have been successfully developed within the EHT for calibration and data analysis. Such a forward-modelling approach to simulate atmospheric and instrumental gains has also been used to generate synthetic data for the EHT [1, 2] and the ngEHT [3].

We present an instrument modelling package written in Julia [4], an open source, high performance language for scientific computing. We aim to model instrumental and atmospheric propagation path effects from first principles, such as the instrumental contribution to the polarization state of the signal, the effects of wide passbands, and tropospheric and ionospheric phase corruptions at mm and sub-mm wavebands. Julia is ideal for modelling and synthesizing these numbers at a large scale due to the availability of highly optimized libraries for numerical and statistical computing. The package aims to support efficient handling of various data formats commonly used in VLBI and work seamlessly with other Julia-based calibration and Bayesian imaging software packages developed for the EHT and the ngEHT [5].

References

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