Preface

Already during my time as an undergraduate research assistant at the Max-Planck-Institut für Radioastronomie in Bonn, I encountered for the first time the amazing and enigmatic world of Active Galaxies. These galaxies outshine normal galaxies by order of magnitudes and show emission across the entire electromagnetic spectrum. For me, the most interesting feature of these objects was the highly collimated and relativistic outflow, the so-called jets. It is impressive how stable these flows are, some of them are collimated over 100,000 light years. Besides their large extent, they show various morphologies and even internal features, some of them are straight and others show strong bends and twists, but they are believed to be generated by the same physical process. Among the zoo of active galaxies, the most powerful ones are the so blazars. The jets of this subclass of Active Galaxies point towards the earth and their flow reaches nearly 99.99 % of the speed of light.

After finishing my physics studies, I decided to write my diploma thesis at the Max Planck Institut für Radioastronomie. I started working analysing observations of a blazar called CTA 102. This object is famous, since it was the first extra-galactic object which showed variation in its radio emission. The Russian scientist Nikolai Kardshev proposed, based on these findings, that the variation could be an indication for an extraterrestrial civilisation. This claim caused a worldwide interest on this source and, up to my knowledge, CTA 102 is the only blazar which went to Top-40 of the UK Album Charts included in the Album *Younger than yesterday* from The Byrds. Later, the object was identified as a blazar and disappeared from the public interest but never lost its attraction for astronomers. Using the technique of Very-Long-Baseline Interferometry (VLBI), several radio telescopes can be connected and an unbeatable resolution (several times larger than the one of the Hubble Space Telescope) is obtained which allows to resolve the structure of the jets. Due to the development of Very-Long-Baseline Array (VLBA), a set of 10 identical radio telescopes distributed across the USA, a new area in radio astronomy began. This instruments allow us to perform monitoring of jets under repeatable environmental conditions. For my diploma thesis, I analysed several of these VLBA observations forming the observational fundament of the here presented work.

The aim of this work was to combine high-resolution VLBI observations of blazars with analytical calculations and state-of-the-art numerical simulations including emission simulation in order to improve our recent understanding of physical process in the relativistic jets of blazars. High-resolution VLBI observations allow to extract some to physical parameters characterising the relativistic flow, however, some cannot be extracted and usually observations are sparsely sampled. On the other hand, numerical simulations can provide snapshots in every required time resolution and can be used to test different physical scenarios, but the results strongly depend on the initial conditions, i.e. input parameters. Combining both, allows us to bridge the time gaps of the observations and to improve the predictive power of the simulations by using observationally confirmed input parameters.

In the presented work, I provide a short introduction to Active Galaxies and introduce the observational history of the blazar CTA 102 at the beginning, and in order to understand the radio emission generated, the basics of synchrotron emission are provided at the beginning of the second chapter. The major part of the second chapter is devoted to on one of the most common models used for the explanation of variation of the jets emission, the shock-in-jet. This model assumes that a shock wave is travelling downstream and leads to an increase of the emission due to the compression of the underlying flow and the magnetic field. The application of the shock-in-jet model to single-dish observations of CTA 102 and its modification are demonstrated in the third chapter. Furthermore, a recipe for the extraction of the uncertainties via Monte-Carlo simulations is given. One of the main results of the single-dish investigations is the hypotheses of a standing shock–travelling shock interaction. In the next two chapters, this hypothesis is further followed using VLBA observations. Using these high-resolution observations, the morphological and spectral properties are obtained. For this investigation, I developed several tools which allow to extract physical conditions of the flow and their uncertainties from VLBA observations of jets. In the last chapter of this work, I use relativistic hydrodynamics (RHD) to simulate and test the assumption of a standing shock–travelling shock interaction. The impact of the ambient medium and the initial conditions on the formation of standing shocks are investigated in detail in order, before switching to a CTA 102-tailored RHD simulation. For the comparison between the simulations and the observations of CTA 102, I developed an emission code and computed the emission based on the results of the RHD simulations. The synthetic images and single-dish light curves confirm the proposed hypothesis of a standing shock–travelling shock interaction.

In this thesis, I have demonstrated how single-dish and VLBI observations can be combined with state-of-the-art emission RHD simulations and lead to the confirmation of the observation-based hypothesis of standing shock–travelling shock interaction.

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