URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

VLBI with the Square Kilometre Array

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Abstract

Technical advances, new calibration techniques and the inclusion of next generation radio astronomical facilities in the VLBI networks are already revolutionising how VLBI contributes to forefront research. Noteworthy examples of VLBI science cases achievable when including the SKA telescopes are outlined.

1 Introduction

VLBI networks, instrumentation and processing techniques have undergone constant improvement since the VLBI technique was born more than fifty years ago, culminating in the consecution of the extraordinary first image of the shadow of a supermassive black hole [1, Figure 1]. This trend will not stop. The imminent inclusion in the VLBI networks of the next generation of radio astronomy facilities, such as SKA and its already operational precursors and pathfinders, will provide new capabilities and therefore new ways of tackling the VLBI science.

2 New science with VLBI

Historically VLBI has been devoted to the study of relatively bright compact sources at very high angular resolutions, up to sub-milliarcseconds, but with a limited field of view. Nowadays versatile modern software correlators can define multiple phase centres to map the entire primary beam of the largest antennas in the VLBI networks and reach better sensitivities thanks to improved self-calibration techniques [2, Figure 2]. The installation of phased array feeds (PAF) in single dish antennas, the inclusion of multiple sensitive tied-array beams from the SKA, referred to as SKA-VLBI capability, and the development of wide-field imaging techniques will allow VLBI to be used as a survey instrument reaching micro-Jy sensitivities.

Relative astrometry will also benefit from these advances. The state-of-the-art "MultiView" phase calibration technique [3] has the potential to realise ultra-precise astrometry at an order of magnitude better than possible today, reaching the thermal theoretical limit for certain frequency bands.

Recent attention has been given to the richness of the sky at lower frequencies [4, Figure 3]. There has been tremendous progress towards the development of VLBI networks at the 100 MHz regime with the International LOFAR Telescope. The SKA1-LOW telescope and other arrays such as the uGMRT will definitely contribute to the improvement.

Other technical advances such as the increase of the observed bandwidth and data rates, the inclusion of new members in the networks, development of entire new networks (e.g. the future African VLBI network), and the promotion of a truly global collaboration by the Global VLBI Alliance will prepare VLBI for the next decade and ensure that it will continue contributing to the cutting edge research as the described in the VLBI20-30 scientific roadmap for the EVN [5].

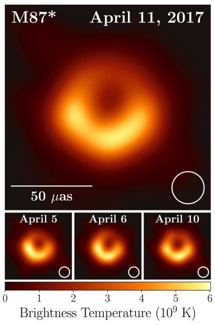

Figure 1. M87* supermassive black hole shadow [1].

3 Key Science Projects with SKA-VLBI

The two SKA telescopes, SKA1-LOW and SKA1-MID will be located in Australia and South Africa, respectively. For a fraction of their observing time, they will join VLBI arrays to carry out very high angular resolution experiments. In tied-array mode they will provide a number of VLBI beams to address unique science goals. The SKA-VLBI Key Science Projects have not been defined yet, but they are likely to come from the following areas:

- pulsar astrometry / probing the GW background
- cradle of life / 3D-tomography of Milky Way spiral arms
- gravitational wave event radio counterparts
- massive black holes & AGN feedback
- fast radio bursts & cosmology
- testing models for dark matter & dark energy with gravitational lensing

Some of these science cases could be pursued independently with SKA-VLBI, while others are more suitable as high-resolution components of major SKA KSPs. A common requirement in several of these is ultra-high precision astrometry, with the goal to reach micro-arcsecond accuracy at GHz wavelengths necessary to address ambitious science goals. For example, at this accuracy, pulsar position, proper motion and parallax measurements will enable strong-field tests of gravity [6]. Another example is detecting gravitational wave electro-magnetic counterparts, which is a rapidly emerging field. By measuring the proper motion of radio counterparts ejected in a relativistic jet produced by a NS-NS merger, one may constrain the inclination of the system which is difficult to measure for gravitational wave sirens [7]. By doing this for dozens of counterparts will constrain H_0 and hopefully put an end to the Hubble-constant debate [8].

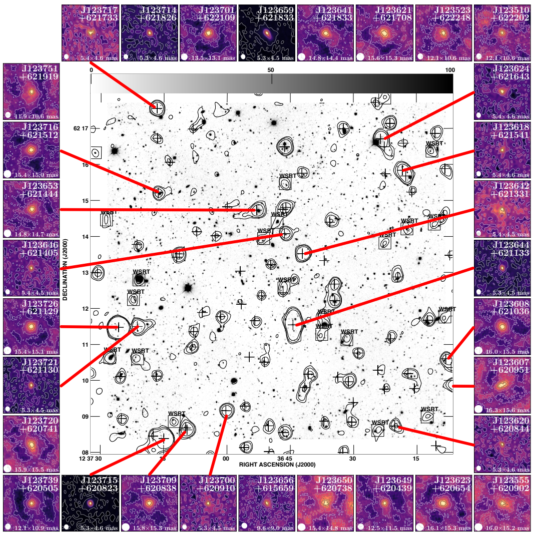

Figure 2. GOODS-N wide-field at 1.6 GHz showing the faint compact radio source population [2].

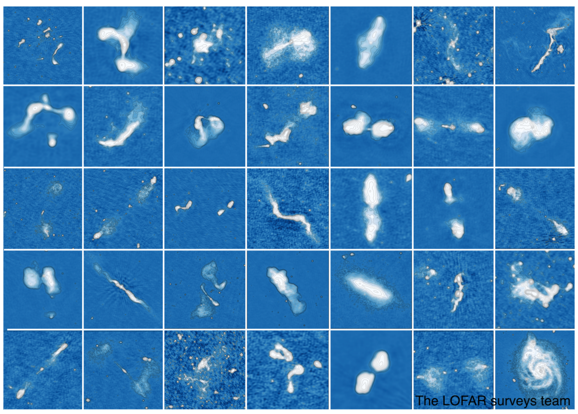

Figure 3. A montage of extended sources from the LOFAR two-metre sky survey Data Release 1 [4].

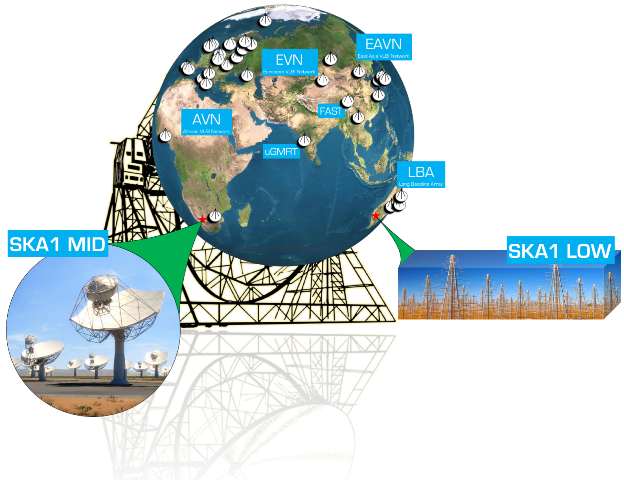

Figure 4. SKA telescopes and VLBI arrays

But the range of science topics that can be addressed is very large. A number of science use cases have been collected [9] and theses use cases have been matched to the SKA1-MID and SKA1-LOW telescopes capabilities during a community meeting on SKA-VLBI at the SKA headquarters in the fall of 2019. We can sense the excitement in the community by the new possibilities.

4 Acknowledgements

The “VLBI with the SKA" work package is part of the JUMPING JIVE project, that has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730884.

5 References

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