Report: mm-VLBI data processing and simulations workshop

Organizers

Ilse van Bemmel (JIVE, NL)
Vincent Fish (MIT Haystack, USA)
Ciriaco Goddi (IMAPP, Radboud University Nijmegen, NL)

Date and location

8-11 June 2015, Lorentz Center, Leiden, the Netherlands

Scope

This workshop brought together a selection of the world's leading experts on data processing and simulations for millimeter-VLBI observations. The purpose was to formulate our current understanding of the data processing from the correlator to the final science product. The focus was broad, including aspects of calibration, imaging and observing. A significant part of the workshop was dedicated to simulations of mm-VLBI data, which could be used to interpret observations, but also to verify the data processing results.
The programme covered 4 days, and included both short talks and longer tutorials. The aim of the tutorials was to have the participants actively work with the software, this was not possible for all packages. Topics that were discussed included gain calibration and correlation, fringe finding, imaging, HOPS and AIPS, polarization, ISM scattering, and simulations for both black holes (GRMHD) and observations.
The aim of the workshop was reached: participants discussed their specific choices for processing, as well as suggestions for future work. The simulations team received an extensive wish list for future work. The threshold for active discussion was low, and many participants experienced this as a very positive element of the workshop.

Outcomes

Calibration and meta-data

We understand most of the issues with correlation and calibration. An improvement can be made to settle on a standard format for meta-data. This requires discussion with the observatories to identify which data they can provide and in what format, and how this needs to be re-formatted for optimal use in the processing.

Fringe finding and fitting

There are two common algorithms for fringe finding. The AIPS (Schwab-Cotton) method obtains a global fit and antenna based solutions. The HOPS (Alef-Porcas) method is baseline based. It gives a mathematically reliable value for signal-to-noise, while the AIPS value seems more random. The AIPS method can reach better sensitivity, especially for homogeneous arrays.
Both methods still require a lot of fine-tuning and human interaction. Two experts gave a tutorial, and demonstrated that their approach to fringe finding is quite similar. They differ in the detailed settings. The use of ad-hoc phases in HOPS was presented, such as the fact that the atmosphere is non-polarized and therefore LCP and RCP phases from tropospheric fluctuations are the same. Applying the LCP phases to correct the RCP seems to do a good job.
The development of a CASA fringe finder has started with implementing the AIPS method, but eventually it should contain both algorithms. Ad hoc phases for fringe finding have good potential for automating, and should be further assessed for implementation in CASA.

Imaging
Several sparse imaging methods were presented. They are based on the Maximum Entropy Method, the main differences are in how the method is implemented. It was discussed how all the methods seem especially sensitive to very compact structures, and apparently do not pick up largescale structures. Image reliability can be tested by comparing the image at lower frequencies to traditionally made images at higher frequencies. A comment was made that current methods look similar to methods explored in the early days of radio interferometry, notably the Cornwell and Wilkinson papers, or Högbom. The sparse imaging methods are still young, but promising. More research and validation is required.

Polarization
A topic of importance and many recent new developments, polarization calibration is still a challenge. The technical aspect of combining linear and circular polarization bases was discussed and demonstrated in detail. A follow-up discussion ensued about the applicability of quarter-wave plates for broadband VLBI in general. The question was raised whether they can cover the full future bandwidth. However, a potential new method for polarization calibration requires at least one station to observe in circular basis.
The calibration of polarization leakage was discussed. For two co-located telescopes with different mounts the parallactic angle rotates differently, and this difference can be used to measure the instrumental polarization leakage.

ISM scattering
The discussion on this topic demonstrated clearly that scattering is not simply a matter of adding a Gaussian blur to the image. The physics of scattering is quite well understood, and future simulations can implement scattering models in the same way as atmospheric turbulence. The time scales are longer, which implies that for a single observation the scattering screen can be assumed to be static, which simplifies the simulations. However, accurate assessment of any observable to within a few percent will require proper correction for ISM scattering.

Simulations and theory
A presentation on the GRMHD models was given, to discuss the set-up of an end-to-end simulator. Several black hole parameters are included in the models, but some are easier to vary than others. For future simulators it is important to realize that not every request for parameter space is easily met, and requires close discussion with the theory group.
The telescope simulations are impressive. Additional instrumental effects are being added. Both MAPS and MeqTrees are working on including tropospheric turbulence and proper ISM scattering. In the discussion following both the talk and the demonstration, a long wish list was provided to the developers. The RODRIGUES web interface for basic MeqTrees simulations was actively explored by the participants, and already yielded useful results in comparing EHT observations with and without a telescope in southern Africa. Another application of simulations is optimal scheduling of the observations.

Recommendations

After concluding the talks, discussions and tutorials, there was a broad discussion on how to move forward. From this, several recommendations have been filtered.

1. We should work towards a standard data format to allow exchange of data, verify existing software and test new software. Recognizing the complimentary strengths of HOPS, AIPS and CASA, development of conversion routines between the different formats would allow users to easily switch between packages. With the long-term view of mm-VLBI in mind, the most logical choice for a standard format is the Measurement Set.

2. It was agreed that in order to support the building of a larger (mm-) VLBI community, CASA needs to be developed to support (mm-) VLBI data processing. It was stressed that any implementation of the fringe finder should at least have the same functionality as AIPS and HOPS, and preferably have additional options for e.g. ad-hoc phase corrections. The developments in CASA should not interfere or conflict with existing functionality for specific instruments.

3. The participants strongly recommend having information exchanges like this workshop occur more frequently, and preferably organized by different institutes. This serves to build a solid community and fosters collaboration across the globe. Once or twice per year seems a suitable cadence.

4. There is a clear demand from the astronomical community to educate a broader audience about data processing for VLBI and mm-VLBI. We recommend a data school to be set up early next year (February 2016) aimed at an audience with some radio interferometry background, and recommend to specifically include ARC support staff, PhDs and junior post-docs who are actively involved. This school would teach the basic data processing approach, including calibration, fringe fitting and imaging techniques.

5. In order to secure mm-VLBI for future generations, the participants recommend to develop closer ties between existing teams, easy access to data and processing methods, and a pro-active attitude towards a coherent organizational structure.

More information

The webpage of the workshop will remain online. The final programme is there, and has most of the contributions available in PDF format: http://www.jive.eu/mm-vlbi2015/