Instrument simulator BlackHoleCam

Work-package management plan

Revision	1.1
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Version changes

Version	Date	Change
0.1	10-2-2015	First draft
0.2	11-2-2015	Included risk analysis and resources sections
1.0	24-2-2015	Included comments from JIVE MT
1.1	1-07-2015	Updated deliverables

Introduction

The purpose of this work package (WP) is to tie the theory and instrument work packages together. It will provide a framework in which images from astrophysical simulations are run through an instrument simulator. This enables testing of all kinds of instrumental effects on the final data produces, such as losing a station, poor weather conditions, mis-pointings, etc. In addition, the simulated datasets will be used to test the performance of newly developed post-processing routines.

The ultimate goal is to develop a full end-to-end simulator, in which we can test the effect of a change in any given theoretical model parameters on the observables. Using a Bayesian analysis, the main observables can be identified and tied to actual physical parameters, thus massively improving the reliability of the scientific results.

The package of choice for the BHC instrument simulator is MeqTrees. The benefits of MeqTrees are that there is pre-existing experience with this package, it has the same internal data format as the CASA package (which will be used for the post-processing pipeline), and several routines are already in place. MeqTrees has been shown to be reliable, and can potentially even serve as a calibration package. With the current availability of virtual machines and a Docker version, MeqTrees can be run on virtually any platform or machine.

JIVE is taking the lead in this work-package. The work is done in collaboration with the team in Nijmegen and simulation experts in South Africa. Expertise from external partners at MPIfR Bonn and MIT-Haystack will be acquired as needed. At the moment this package is seriously understaffed, and requires at least two additional people, one in JIVE and one in Nijmegen, to ensure a continuous work-flow and timely completion of the individual deliverables.

Scope

The work package involves the planning, development, testing and implementation of the simulator components in the MeqTrees software. It also includes development of training materials, reporting on the progress, documentation of the development and use, and a direction for future work.

Simulator components

Here we describe the required components of the simulator. A module is defined as a stand-alone part of the MeqTrees software, for which the user can define the settings during a simulation run. The simulator will eventually consist of a series of modules. The deliverables depend on the actual planning of the project, and available resources. There will be some considerable overlap between deliverables and components.

1. Measurement set (MS) and basic editing tools. The MS describes the observational set-up, and it should be possible to e.g. shorten the observing time, change the integration time, or remove a station.
2. Input module to convert theoretical model images into a MeqTrees sky model. The Theory work-package will provide a database of models.
3. Scattering module: at the moment the interstellar scattering is included in the theoretical models, but we would prefer to include this in the simulator eventually. This is a low priority component.
4. Tropospheric module: the effect of the troposphere on mm-VLBI is large. The coherence time is of order a few seconds to a minute at best, and to understand

the impact of this on the processing and data analysis is crucial. This is a high priority component.

5. Fringe noise module: MeqTrees produces observations which have been perfectly correlated. To test the fringe finder in a consistent way, a module to introduce correlator errors and noise needs to be developed. This is a high priority component, which requires development of an entirely new module.

6. Polarization module: the polarization information is an important part of the data analysis. When ALMA is included, there will be linear and circular polarization in the observations. MeqTree cannot process mixed polarization bases. This is a medium priority component, with a long-term planning.

Deliverables

The deliverables consist in part of the components listed above, but include the crucial steps to connect the modules, verify them and include additional functionality such as production of simulations for pipeline verification and Bayesian analysis.

1. Basic simulator consisting of components 1 and 2: this is the elementary step that combines an input measurement set with an input theory model and simulates without any additional instrumental or atmospheric effects. On this basis the entire simulator will be developed. This is completed in the RODRIGUES online interface: http://rodrigues.meqtrees.net/scheduler/

2. Editing tools for mm-VLBI measurement set: to adjust station sensitivity, weather conditions, observing time, bandwidth, and other observational settings. These are essential parameters to test for the scientific reliability of the actual system: this will be part of the RODRIGUES interface.

3. Development of tropospheric module: the current ionospheric module (LIONS framework in MeqTrees) will need to be updated and added to the basic simulator. Test and verification.

4. Produce a number of verification simulations. With the fringe noise module included, the simulator is ready to produce simulations for the post-processing pipeline verification. Interfacing with the data processing WP is required to set the boundary conditions for these simulations.

5. Implement interstellar scattering in MeqTrees as a separate module.

6. Requirements and development of a polarization module. A critical issue in this deliverable is the combination of linear and circular polarization, which is not possible in MeqTrees at the moment and may be a show-stopper.

7. Complete simulator, including scattering, troposphere, correlation errors and polarization effects.

8. Develop full end-to-end (E2E) simulator chain which can both simulate based on a range of theoretical input models or observing conditions, and run the post-processing pipeline to obtain science quality data.

9. Documentation of the simulator including some tutorials

10. Inclusion of the Bayesian analysis functionality. This deliverable runs in parallel to each of the other steps. When implementing a new module, the Bayesian functionality testing will be part of the verification and testing step.

Timeline and team

The planning is based on the 6 year duration, and availability of the resources as described in the original project plan: 2 person years for the 6 year duration. The workload is distributed equally over the full period, with an end date foreseen in September 2019. Involvement from the MeqTrees team in South Africa is included, but

is highly dependent on the availability of their resources, as they are not an official partner in BHC.

An important element of the planning is the interfacing with the data post-processing (DPP) work package. To deliver basic datasets for verification and testing of DPP components, the pressure is high to have the key components in place well before the DPP pipeline needs to be delivered. This is set for early 2017, so the verification data needs to be available at the latest by mid 2016. Earlier datasets can be provided at any time, but these may not included all required instrumental effects.

Deliverable	Description	Deadline	Owner
1. Basic iSim		completed	RSA
2. MS tools	MeqTrees tools to make MS	completed	RSA
3. Atmosphere	Initial implementation	Q4 2015	CS & PS
4. DPP	Provide simulations for DPP	Q2 2016	All
5. Scattering	Interstellar effects	Q3 2016	RSA
6. Polarization	Requirements and development	Q1 2017	RSA
7. Simulator	All basic functionality included	Q3 2017	PS
8. E2E	Combine iSim and DPP	Q1 2018	PS
9. Docs	Documentation and tutorials	At each step	PS
10. Bayesian	Bayesian functionality	At each step	RSA

Table 1. Timeline of the planned deliverables and owner of the process. The first person listed as owner has the main responsibility and serves as the point of contact for this deliverable. The owner acronyms are: RSA = South African team, CS = WP coding specialist at IMAPP, PS = JIVE project scientist.

At JIVE the PS, Ilse van Bemmel, is leading the WP. An additional scientific programmer (CS) is Pim Schellart at IMAPP. Another programmer/ astronomer (CS2) should be based in JIVE, but with strong ties to IMAPP or South Africa, where the MeqTrees expertise is higher. The RSA team consists of Roger Deane (Rhodes University), Tariq Blecher (Master Student) and some input from the co-supervisors Gianni Bernardi (SKA-SA) and Oleg Smirnov (SKA-SA).

The WP project scientist maintains the communications with the external project members and will be actively involved in the development of some modules. Current work load is set to maximum of 1 day per week. The coding specialists will be responsible for software (component) development and basic testing and debugging.

The WP project scientist constructs the requirements and algorithms in close collaboration with the coding specialists. The testing and verification will be done by the entire team, including experienced mm-VLBI astronomers from around the world.

Communications

There is already an ongoing telecom, twice per month, with the South African team. This will be continued for the duration of the work. Visits back and forth are also required, and several have been planned for 2015.

The table below lists the intended structure and responsibilities. The owner is responsible for calling the meetings, and where necessary to distribute an agenda, maintain minutes and inform the participants that were absent.

Type	Frequency	Format	Contents	Owner	To

Internal meeting	Every 2 weeks	Telecon	Progress and status in team	PS	All
Report to BHC MT	3-4 months	In person/ telecon	Project updates, status report	PS	all, BHC management

Table 2. Planned communications in the work-package. PS = WP project scientist, all includes all members of this work-package as described in the Deliverables section.

Resources

At the moment this WP is understaffed. For this work at least four FTE-years of scientific programmer are required, distributed over two people, one in JIVE (2 FTE) and one in Nijmegen (2 FTE). This is based only on the deliverables up to Q1 2017. The staffing for the continuation of the work package will need to be reassessed after the first full year of work is done.

The person in JIVE is expected to assist in re-developing the existing MeqTrees ionospheric module into a tropospheric module, and develop the scattering and fringe noise modules based on the experience gained. The person should have excellent programming skills, experience in Python programming, knowledge of object oriented programming and preferably understand the basics of radio astronomy at PhD beginner level. The position is in JIVE, as both JIVE and ASTRON have experts available for MeqTrees. This requires assessment of the division of the work in this work-package between Nijmegen and JIVE.

The person in Nijmegen is expected to provide an automated interface with the database containing the theoretical models. In addition, this person can run the simulations and get involved in the Bayesian analysis part of the work. The person should have both excellent programming skills, but also a strong background in statistical astronomy, preferably with knowledge of Bayesian analysis. This requires skills in theoretical astrophysics and Python programming.

Additional expertise is required for the polarization aspect of this work-package. Experts in Bonn are already part of BHC and will be included in the discussion. External high level expertise is available through Iván Agudo (Granada, Spain). Detailed processing expertise exists in Onsala as part of the ALMA Phasing Project (Iván Marti-Vidal). For the external experts there should be clarity on the formal way to include them in the BHC project.

Financial resources for this work are needed to travel between the different institutes. Especially the collaboration with South Africa requires significant travel funds. Last but not least, the WP also requires a manager to formally manage the funding.

Risk analysis

This WP has several critical components. They are listed from highest to lowest risk here. Risk mitigation is not discussed for now (next version?).

1. Polarization simulations based on linear *and* circular polarization. This is not possible in MeqTrees and is a potential show-stopper.
2. Fringe noise component. This is a new element to add into MeqTrees. A simple noise addition is low risk. The more realistic this component needs to be, the higher the risk it will carry, and the more time it will take to develop.
3. Availability of human resources. The WP relies on input from institutes that are not formal BHC partners. Though currently these institutes have a personal

interest in this project, there is no assurance that this will continue in the long term.
4. Local resources and planning. This is a new WP in the project, and it requires an effort to free up people to get actively involved. At the moment the WP is understaffed. Without a minimum of two more people the work cannot be completed on time.

Distribution list of final document

Name	Role	Affiliation
Arpad Szomoru	R&D manager	JIVE
Huib Jan van Langevelde	director	JIVE
Heino Falcke	BHC PI	Univ. of Nijmegen
Remo Tilanus	BHC project manager	Univ. of Leiden
Ciriaco Goddi	BHC project scientist	Univ. of Nijmegen
TBD (CS1)	Scientific programmer	JIVE
TBD (CS2)	Programmer/astronomer	Univ. of Nijmegen
Roger Deane	MeqTrees specialist	Rhodes University, RSA

List of acronyms

BHC   BlackHoleCam
CASA   Common Astronomy Software Applications
CS   Coding Specialist (scientific programmer)
DPP   Data Post-processing Pipeline
E2E   End-to-end
IMAPP Institute for Mathematics and Particle Physics (university of Nijmegen)
iSim   instrument simulator
JIVE   Joint Institute for VLBI in Europe
MIT   Massachusetts Institute for Technology
mm-VLBI   millimeter-VLBI
MPIfR Max Planck Institut für Radio-astronomie (Bonn, Germany)
MS   Measurement Set
PS   Project Scientist
RSA   Republic of South Africa
VLBI   Very Long Baseline Interferometry
WP   Work Package