LOFAR Self-Calibration using a Local Sky Model

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Abstract. LOFAR Self-Calibration will be based on adaptive models. This means that instrumental, ionospheric, and sky parameters are fitted to the measured data using a Measurement Equation (ME). One of the deliverables of LOFAR will thus be a Global Sky Model (GSM) that will be an all-sky database of some 100 million objects characterised by position, shape, flux, and polarization. Once a (crude) GSM is constructed it will be updated by fitting it to new measured data. The part of the GSM that is relevant for the processing of a particular dataset is put in a Local Sky Model (LSM). There it is combined with relevant observational data and used in the Self-Calibration process. In this presentation the design and implementation of the Local Sky Model within the MeqTree System (a new module for Self-Calibration) is discussed. Initially processing will be based on Point Sources and Imaged Sources. This results in a different treatment of the two types.

1. Introduction

LOFAR is a new radio telescope currently under construction in The Netherlands. The LOFAR telescope will operate at low frequencies (20 - 250 MHZ) and it will initially consist of 77 antenna stations giving a maximum baseline of 100 km. Each antenna station will consist of about 100 simple antennas which are beamformed in software to produce between 1 and 8 beams on the sky. Calibrating the LOFAR array is a serious challenge since:

- imaging with a high dynamic range is needed for the scientific goals,
- the ionospheric variation over the array at these low frequencies is significant,
- the sky is very crowded at these low frequencies giving rise to source confusion,
- bright sources enter through the sidelobes of the station beams,
- the beam shape varies considerably in frequency and time.

In order to deal with these challenges a flexible Self-Calibration module is needed, based on a general Measurement Equation with which one can predict data for Instrumental and Sky parameters (Hamaker et al., 1996; Noordam 1996). For LOFAR such a module is being developed and the MeqTree system is
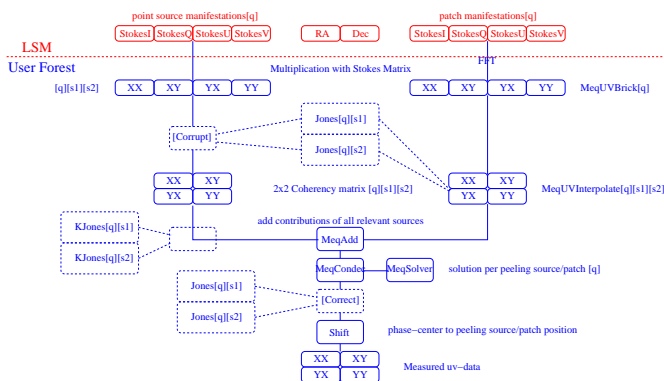
Figure 1.   Implementation of the Measurement Equation in a Tree.

a working prototype for such a module (Smirnov & Noordam, this volume). The Local Sky Model (LSM) deals with the Sky parameters in the Self-Calibration process. Through the LSM data values can be predicted and parameters can be updated. The updated parameters can then be stored in a larger database, dubbed the Global Sky Model.

2.   LOFAR Self Calibration

LOFAR Self-Calibration is based on fitting parameters for adaptive models of the instrument, the ionosphere and the sky to the measured uv-data (Mevius et al., this volume). This is done by using a general measurement equation:

$$\vec{V}_{ij}(u,v) = \int dt \int df \sum_k \mathsf{J}_{ik} \otimes \mathsf{J}^{\dagger}_{jk} \mathsf{S} \vec{I}_k.$$

Here J is a 2×2 matrix that denotes the combined instrumental and ionospheric model, which depends on the station, i, and on the position in the sky, k. The 4 vector $\vec{I}$ denotes the sky model. The LSM will contain all information of the sky model relevant to a particular dataset.

The sources in the LSM are divided into two categories. Cat. I sources are the brightest sources and they are used in order to solve both instrumental parameters and sky parameters. They are treated in order of (apparent) brightness, a process that is dubbed Peeling. Once best fit parameters are found, the sources are subtracted from the data to produce residual uv-data. Cat. II sources are the less brighter sources of which there are a great many. They are treated in Patches (small images containing multiple sources) and their parameters are updated through images of the residual uv-data.

In the LSM object the sources are grouped into Predict Units (P-Units). These units are the basic processing units for the Self-Calibration process. Currently we implement Point Source P-Units, which predict data through a DFT and Patch P-Units which predict data through a FFT. The Patch P-Units can be used to handle parameterized and / or imaged extended sources. An overview of the implementation of a Cat. I solving Tree is given in Figure 1.
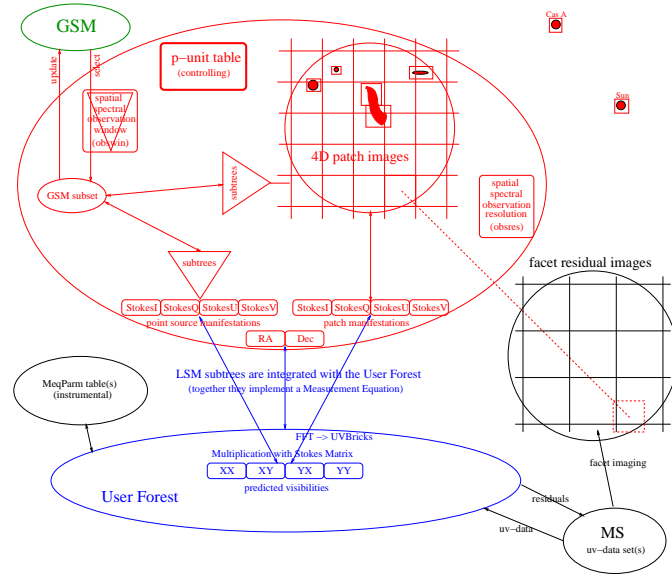
Figure 2.   The Local Sky Model: its contents and its interfaces.

3.   Local Sky Model

A Local Sky Model (LSM) object is to be used in combination with a particular dataset. For this dataset the LSM is the object that controls the relevant sources. As such the LSM has three interfaces (see Figure 2)

- **MeqTree User Forest**: the LSM calculates the four Stokes manifestations (I, Q, U, V) for the given P-Unit (Point Source or Patch Image),
- **Residual Images**: images from residual *uv*-data can be used to update source parameters, e.g. by means of a CLEAN deconvolution algorithm.
- **Global Sky Model (GSM)**: this is an all sky database of eventually some 100 million objects. The LSM gets an initial subset from the GSM and, after the data processing, updates the GSM.

The LSM object contains several sub-objects itself (see Figure 2)

- **GSM subset**: this actually contains a number of things: a source list, a Parameter table and GSM images, and MeqTree templates. For every source in the source list the MeqTree template generates the four Stokes manifestations from the parameters and / or images.
- **P-Unit list**: a list of P-Units that is the controlling object for the data processing. Each P-Unit is treated as a single unity.
- **Observational Window (ObsWin)**: the average station power beam. The ObsWin transforms to first order the intrinsic sky into the apparent sky.
- **Observational Resolution (ObsRes)**: the spatial and spectral resolution of the observation. It is used for updating source parameters from Residual Images.
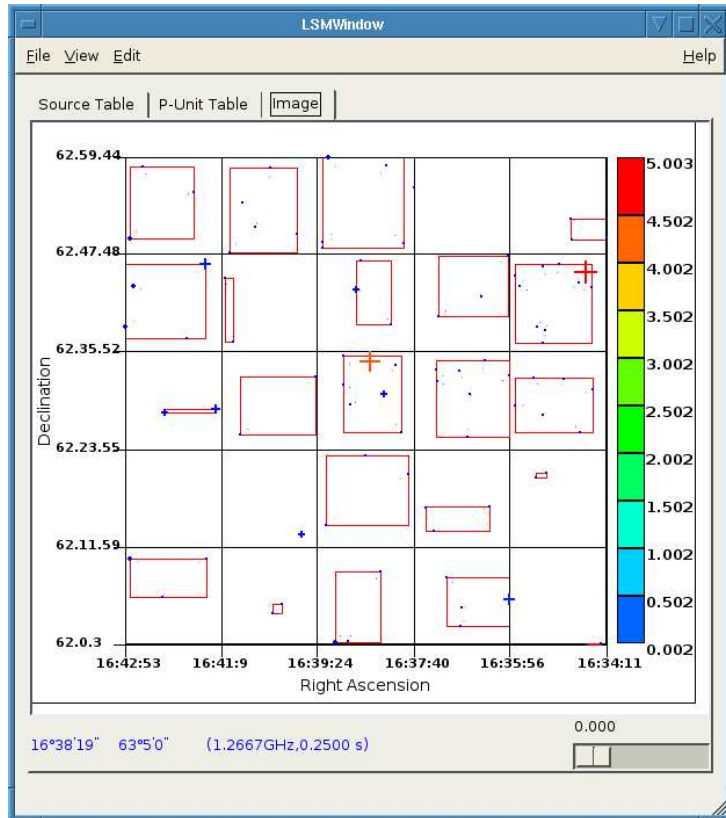
Figure 3.   A screen grab of the LSM interface. Here Point Sources (crosses) are shown to be combined into Patches (red boxes)

4.   User Interface

The LSM has its own User Interface with which it is possible to, for instance, prepare the data processing. The interface can be used to construct the P-Unit list. As an example, several Point Sources can be combined into a Patch Image. This is shown in Figure 3, where a field around 3C343.1 is gridded and then automatically Patches are created from the grid cells.

Other uses of the User Interface would be Saving and Loading of the LSM and Visualization both of the LSM and of the processing strategy.

The User Interface is implemented in Python and can be used both as a stand alone module and in connection to the MeqTree Kernel.

References

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