Aperture-synthesis imaging with the mid-infrared instrument MATISSE

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MAX-PLANCK-GESELLSCHAFT

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Abstract

MATISSE is the second-generation mid-IR interferometry instrument proposed for ESO's Very Large Telescope Interferometer. MATISSE will combine the beams of up to four UTs or ATs of the VLTI and will allow aperture-synthesis imaging in the L, M, and N bands with a resolution of a few milli-arcseconds. We report on detailed image reconstruction experiments with simulated MATISSE interferograms. Using model images as input for many of our simulations, we study the dependence of the reconstructions on the brightness and size of the target.

Introduction

The main goal of MATISSE, the successor of the two-beam combiner MIDI, is to perform aperture-synthesis imaging in the mid-infrared spectral regime with unprecedented ($\sim$ 10 mas-) resolution. The VLTI with its four fixed 8.2 m telescopes and four relocatable 1.8 m auxiliary telescopes (ATs) provides the best infrastructure for this task nowadays.

In the last decade, several image reconstruction algorithms were developed for aperture-synthesis imaging with infrared arrays consisting of a small number of telescopes; for example, BSMEM (Buscher 1994), MACIM (Ireland in Lawson et al. 2006), MIRA (Thiebaut 2002), Recursive Phase Reconstruction (Rengaswarmy 2006), BBM (Hofmann & Weigelt 1993). The performance of such algorithms was evaluated up to now in two blind tests initiated by the IAU Working Group on Optical/IR Interferometry. In this poster we study image reconstruction with the Building Block mapping (BBM) method.

Aperture synthesis imaging with simulated realistic observations

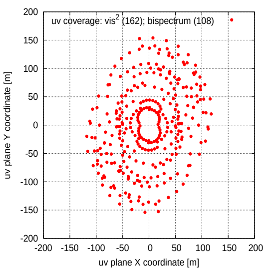
Simulation of interferometric data:

A simulator allowing the generation of a large number of individual noisy interferograms was developed. This simulator generates 1-dimensional coaxial 2-telescope interferograms (MATISSE N band data). The interferograms are degraded by photon and sky background/detector noise, and a random piston. From 1000 generated 2-telescope interferograms the average power and bispectrum is calculated. Subtraction of the noise bias in the average power spectrum, photometric calibration, and calibration with an unresolved reference star yields the calibrated visibility. For the simulations below, the number of sky background photons for a MATISSE observation with 4 ATs in N band was derived from MIDI data taken with 2 UTs in February and August 2004 during commissioning. The derived average number of sky background photons in a simulated 2-telescope interferogram (exposure time/interferogram: 900ms) is $\overline{\mathrm{M}} = 3.6 \times 10^8$.

Quality of the reconstructed images as a function of the target size:

Because of the sparse uv coverage, only relatively compact targets yield reconstructions with acceptable quality.

Observations with 4 ATs: The maximum baseline length of the uv-coverage used in these experiments (see Fig. 1) is $\sim$ 150 m corresponding to a resolution of $\sim$14 mas at $\lambda = 10.5\mu$m. The discussed experiments were performed with the target shown in Fig. 1. The target is a model of LkHa 101 (named *Target1*). Each of the simulated interferograms was degraded by sky background noise corresponding to a total number of 3.6×10^8 photons. The target intensity was chosen to get an average SNR of 20 for the calibrated squared visibilities. Table 1 gives a summary of the interferogram simulation parameters. The theoretical objects used for the image reconstruction experiments were *Target1* with diameters of 60 mas, 86 mas, 112 mas and 125 mas. Fig. 2 shows for *Target1* with 86 mas diameter, (left) one of the 1000 generated 2-telescope interferograms per data point, (middle) the average power spectrum with the fringe peak, and (bottom) the real and imaginary part of the average bispectrum. Fig. 3 shows the resulting reconstructions: *Target1* with diameters ranging from 60 mas to 112 mas could be successfully reconstructed with restoration errors of 8.3% to 14.6%, respectively. The reconstruction of *Target1* with diameter 125 mas failed.



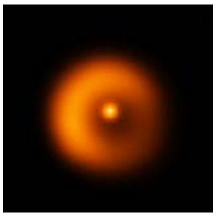


Figure 1: *Left:* Simulated uv coverage obtained with 4 VLTI ATs and 3 configurations (DEC $= -60°$, AT stations: B5-D0-G1-J3, A1-B5-D1-K0, A0-G2-I1-J6) *Right:* The target used for the MATISSE image reconstruction experiments was a model image of LkHa 101 (disk of a YSO) which was provided by P.G. Tuthill. This target is named *Target1* in the following experiments.

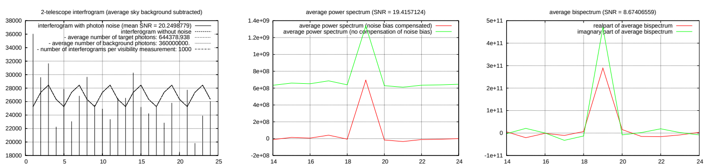


Figure 2: Simulation of the visibilities and closure phases: *left*: one of 1000 generated 2-telescope interferograms with sky background and target photon noise corresponding to an average number of 3.6×10^8 and 6.4×10^5 photons, respectively (solid line: interferogram without noise; vertical lines: pixel intensities of the interferogram including noise); *middle*: average power spectrum calculated from the 1000 generated interferograms at the position of the fringe peak (central peak of the power spectrum is removed); *right*: average bispectrum derived from the 1000 generated interferograms (calculated at the position of the fringe peak). In this example the average SNR of the squared visibilities is 20. In the average power spectrum (middle, green line) the noise bias is clearly visible. This bias-level is determined by a fit outside the fringe peak and then removed (middle, red line).

Dependence of the reconstruction quality on the SNR of the simulated raw data:

This study is based on simulated data obtained with 3 configurations of 4 ATs. The uv coverage is displayed in Fig. 1. The parameters to simulate one observation night are the same as listed in Table 2, but different values of the average SNR of the squared visibilities are tested. The theoretical object is *Target1* (see Fig. 1) with diameters of 60 mas and 86 mas. Results: *Target1* with 60 mas diameter can be reconstructed with acceptable quality (restoration errors between 6.7% to 13.8%) for all investigated SNR values of 50, 30, 20, 10 and 7. The larger target, *Target1* with 86 mas diameter, can be reconstructed with acceptable quality (restoration errors: 7.5% – 11.9%) for SNR values between 50 and 17 only. For SNR values 15, 10, and 7 the image reconstruction failed.

Table 1: Parameters used for the simulations of MATISSE interferograms.

Wavelength	10.5 μm
Start of Observation	-4.5 hours of meridian
End of Observation	4.5 hours of meridian
Maximum zenith distance	60°
Time for one Data Point	1 hour
Detector Integration Time	900 ms
Total Integration Time for one Data Point	15 min
Target declination	$-60°$
Number of interferograms per visibility value	1000
Total number of sky background photons / interferogram (ATs)	3.6×10^8

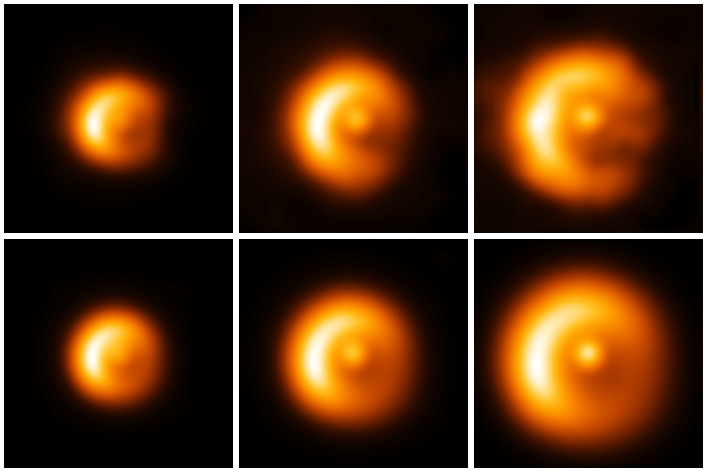


Figure 3: BBM reconstructions derived from simulated MATISSE data of *Target1* (disk of Herbig Ae/Be star LkHAlpha 101) for different diameters. The observation parameters are: 3×4ATs (uv coverage in Fig. 1), average SNR of the calibrated squared visibilities of 20. First row: reconstructions of *Target1* with diameters of 60 mas, 86 mas, and 112 mas (from left to right). The corresponding restoration errors are: 8.3% (60 mas), 11.8% (86 mas), and 14.6% (112 mas). Second row: the theoretical objects with the same diameters. All images are convolved with the PSF of a single-dish telescope with the dimension of the interferometric array.

Summary

The presented image reconstruction experiments were performed with one uv-coverage consisting of 3 different 4-AT configurations. The following results were obtained:

- Observations with **4 ATs and 3 configurations can yield reconstructions with acceptable quality.**
- It has been shown that in the case of observations with 3×4 ATs, an array with resolution of $\sim$14 mas and an average SNR of the calibrated squared visibilities of 20, **targets with diameters up to $\sim$120 mas can be reconstructed** with acceptable image quality (restoration errors $\sim$8-16%, Fig. 3).
- Furthermore, it has been shown that in the case of observations with three 4-AT configurations, a target size of $\sim$86 mas and a resolution of $\sim$14 mas, **the average SNR of the calibrated squared visibilities should be at least 17** (corresponding to an average error of $\geq$ 6%) in order to yield acceptable image quality (restoration error $\sim$8-12%). For smaller targets (target of size $\sim$60 mas) reconstructions with acceptable quality (restoration errors $\sim$7-14%) were obtained with an average SNR of the squared visibilities of 7, corresponding to an average error of $\sim$14%.

References

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