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TWO RECONSTRUCTION METHODS FOR OPTICAL INTERFEROMETRY

Meimon, S.[1], Thiébaut, E.[2], Mugnier, L.[3] and Le Besnerais, G.[4]

Abstract

Current optical interferometers are affected by unkown turbulent phases on each telescope. The complex Fourier samples measured by the instrument are thus multiplied by unknown phasers corresponding to the turbulent differential pistons between each couple of telescopes. So, the only unaffected phase information is the closure phase of each coherent sub-array. Instead of considering the closures as the only phase data, we consider that we have more data and more unknowns. More specifically, we construct complex data affected by turbulent pistons, and explicitely incorporate the pistons in the inverse problem. Then, we reconstruct the object by minimizing an original metric in the object and these pistons. To do so, we minimize the metric alternatively in object and phases,i.e. we do several "calibration cycles", each one made of a step in object with a know set of phases and a step in phases with a known object. We have recently designed a metric such that the minimization problem is convex for given pistons while modelling accurately the noise statistics. Here we develop a technique to compute the global minimum of the data likelihood criterion for the phase step, in spite of the fact that the latter is dramatically non unimodal. This is achieved by exploiting the separable structure of the phase metric. We are currently testing our technique on experimental data.

[1] ONERA (Office National d'Études et de Recherches Aérospatiales)
DOTA (Département d'Optique Théorique et Appliquée)
BP 72, F-92322 Châtillon cedex, France

[2] CRAL / Observatoire de Lyon, Saint Genis Laval, France

[3] ONERA / DOTA
BP 72, F-92322 Châtillon cedex, France

[4] ONERA / Département Traitement de l'Information et Modélisation
BP 72, F-92322 Châtillon cedex, France

1 Introduction

We present here two reconstruction methods for optical interferometry developped within the framework of the Jean-Marie Mariotti Center (JMMC). Optical aperture synthesis allows to reach the angular resolution a hundred meter telescope would provide with several ten meter telescopes. One of the major challenge is to circumvent the turbulence, which corrupts the baseline phases. Until all telescopes are cophased (PRIMA), one is led to form closure phases, which remain good observables even in presence of turbulence.
Although it is possible to use radio astronomy software packages to retrieve images from optical interferometry data, it requires to approximate the actual noise model. This may bring artifacts which can be avoided by designing a software that is specifically tailored to optical data. At the 2001 meeting of the IAU Working Group on Optical/IR Interferometry, it was suggested that such existing software suites should be compared with controlled data sets. We present here MIRA and WISARD, two of the methods which took part to the IAU- Imaging Beauty Contest (Lawson et al. 2004).

2 Description of the software suites

2.1 WISARD

Context WISARD (Weak-phase Interferometric Sample Alternating Reconstruction Device) was written to support aperture synthesis imaging with the VLTI instrument AMBER. It is developed at ONERA, in collaboration with the JMMC. It follows previous studies by Laurent Mugnier and Guy Le Besnerais (Mugnier et al. 2001 and references therein).

Problem Inversion We use Bayesian inversion approach, and try to balance fidelity to the available statistics of the data on one hand, and good minimization behavior of the resulting criterion on the other hand. To handle lack of phase information, we introduce additional explicit variables to be solved for in inverse problem. The resulting criterion includes a regularizing term. We get round lack of phase information by progressively "blending" the data into the minimizer.

Implementation WIZARD is written in IDL, and the constrained minimization uses VMLM-B (Thiébaut, 2002) mixed with an exhaustive search step. It is designed to deal with optical interferometry data with weak Fourier phase information provided by phase closure. For the moment, it treats any n-elements coherent telescope array as a collection of uncorrelated triples. Thus it is optimized for triples, and does not operate at full efficiency in the Beauty Contest Final Data case. We're currently working on its adaptation to 4 or more coherent array cases, which is a more favorable case.

We use only squared visibilities and triple product phase (i.e. we drop triple product amplitude data), and of course what is needed to determine the frequency coverage. Minimization stops when the criterion stabilizes. A more precise description is to be published in months to come, and will be described in Glasgow SPIE conference.

2.2 MIRA

MIRA (Multi-aperture Image Reconstruction Algorithm) is one of the image reconstruction algorithm under elaboration at JMMC (Jean-Marie Mariotti Center, France); MIRA is designed to deal with optical interferometry data (sparse $u - v$ coverage and weak Fourier phase information provided by phase closure).

The principle of MIRA algorithm is to perform image reconstruction by minimization of a penalty criterion under positivity constraints. The penalty reads:

$$f(\mathbf{x}) = \chi^2_{\mathrm{vis2}}(\mathbf{x}) + \chi^2_{\mathrm{cl}}(\mathbf{x}) + \mu\,\mathcal{R}(\mathbf{x})$$

where $\mathbf{x}$ are the parameters (the intensity of the image pixels); $\chi^2_{\mathrm{vis2}}(\mathbf{x})$ is the likelihood term with respect to the squared visibility data; $\chi^2_{\mathrm{cl}}(\mathbf{x})$ is the likelihood term with respect to the phase closures (defined so as to be insensitive to the modulo $2\,\pi$ in phase differences); $\mathcal{R}(\mathbf{x})$ is the regularization; μ is a Lagrange multiplier tuned so that, at the solution, the likelihood terms are equal to their expected values.

The constrained minimization is done by VMLM-B (Thiébaut, 2002). At this time, MIRA is written in C and in Yorick (`ftp://ftp-icf.llnl.gov/pub/Yorick/`).

3 Reconstructions

We show in figure (1) two reconstructions performed with MIRA and WISARD from the same data set. The range of the pixel maps is 30 milliarcseconds.

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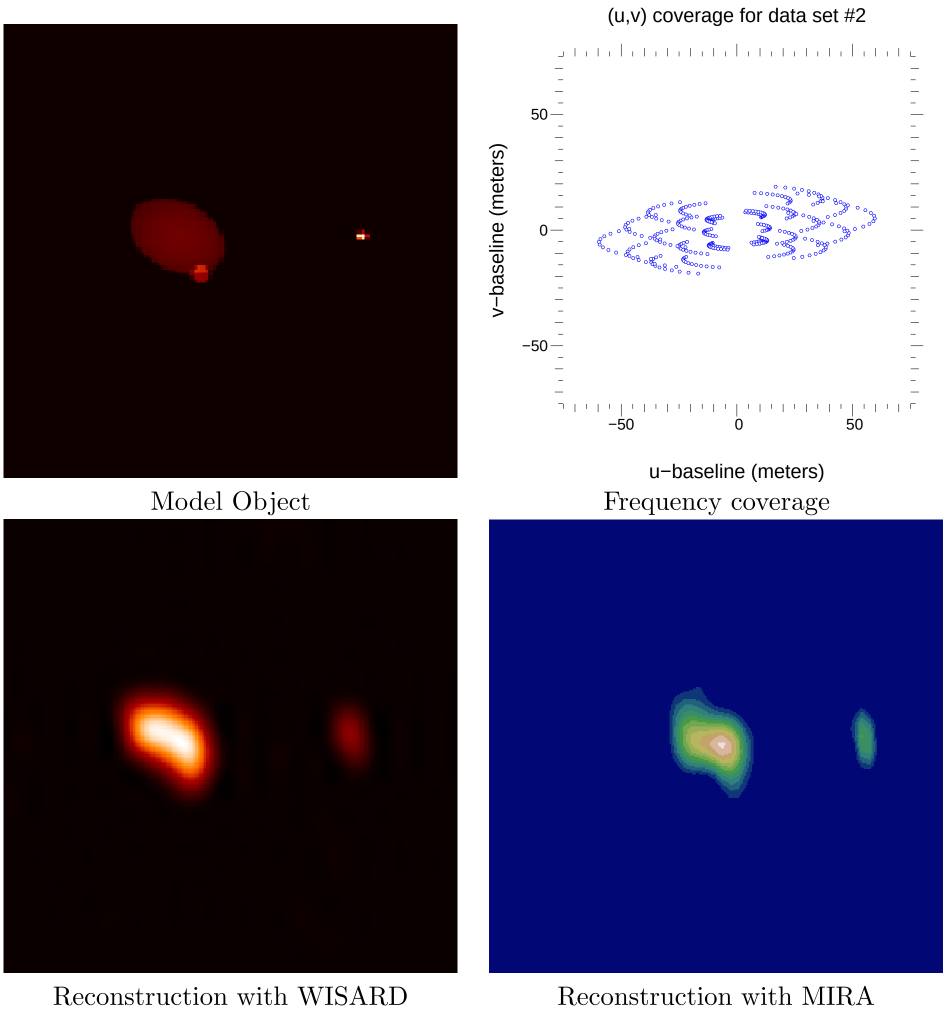

Figure 1. Two reconstructions from the same data set.