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JRA4

KICK-OFF MEETING - DESCRIPTION OF WP 2

SOFTWARE

Gilles Duvert (Gilles.Duvert@obs.ujf-grenoble.fr)
JMMC/LAOG

CHANGE RECORD

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1. Introduction

While interferometry is a powerful technique for high-resolution imaging and very precise astrometry, the processes of data reduction and interpretation are more complicated than for most other astronomical techniques. The scientific productivity of interferometric facilities is therefore frequently limited by the availability of suitable software tools. Many groups have taken the approach of modifying data reduction packages originally written for radio interferometry. Whereas this shortcut has led to a number of important results, there are fundamental differences between the data from radio and optical interferometry that cannot be taken into account in this way. The next steps in optical interferometry require using the information in the data in an optimum way, which can only be accomplished by dedicated data analysis algorithms.

The Workpackage 2 of JRP4 will develop a dedicated software package for the analysis of data from optical / infrared interferometry. This package will be developed according to quality standards used in comparable industrial efforts, under the supervision of a Software Project manager and is provisionally referred to as the European Optical Long-Baseline Interferometry (OLBI) software system. Similar packages are widely used by the astronomical community for the analysis of radio interferometer and general optical / infrared data (e.g., AIPS, MIDAS, IRAF). The data analysis package to be written by interferometry JRP will be more specialized and therefore smaller, but provide comparable functionality and be based on an extension of the same standard for the data format (FITS), which is endorsed by the International Astronomical Union. The general user of this package will benefit from a User Support group throughout the lifetime of the project (WP2.1).

The data analysis package will provide users with "one-stop shopping" for their data analysis needs, once they have properly calibrated the raw instrument outputs. This is an important step on the way to enlarging the community of interferometer users in Europe, who currently face a bewildering assortment of programs which to only part of what they need. The new data analysis package will contain utilities for input / output, general data manipulation such as sort / merge, data display and editing routines (WP2.2). It will provide tools for fitting simple geometrical models to sparse data sets, and to estimate best-fit parameters of physical source models (WP2.3). It will provide facilities for astrometric data reduction, which includes routines to determine the interferometer and source geometry from the data, to determine stellar proper motions and parallaxes, and to fit orbits of binary stars and planetary companions (WP2.4). A variety of image reconstruction algorithms will be offered, based on adaptations of familiar existing methods and on new techniques optimized for use with optical interferometer data (WP2.5).

2. Overview of the WorkPackage

The workpackage is aimed at delivering two successive versions of a software of general use in a 5 -years span, starting from 'scratch'. This software aims at facilitating the use of large modern interferometric facilities such as ESO's VLTI to an end-user non specialist of Optical interferometry. We will develop our software by integrating in an easy to use manner the basic tools used by optical interferometry specialists:

comparison of observables with models (achromatic, then chromatic models, support of classical geometrical models then support of more physical or ad hoc models), blind image reconstruction from observables, astrometry-related measurements from phase-referenced interferometry. The tool should be oblivious of the origin of the data (we expect to work on reduced, calibrated, interferometric observables, such as provided by the VLTI pipeline), and should manage comparision and merging with other data issued from other interferometers and even other observational techniques.

Due to the complex task in view, we split the work into 5 Tasks that will develop quite independently an aspect of the whole. All the Tasks are scheduled to arrive at the same time at each software acceptance release.

The Tasks are developed in the following sections. It is expected that a Task Leader (TL) will link all the persons involved in a Task with the WorkPackage management (WPL and PM)

A preliminary Software preliminary concept description document complementing this document is already available.

Unless Otherwise mentioned, The TL of Tasks is the WorkPackage Leader (WPL, Gilles Duvert).

3. WP 2.1 management and User Support

Will provide rules for programming, data formats, interfaces definitions, detailed design.

Will test the releases and changes throughout the life ot the software, check the user manual(s), help beta-testers and users, share information and educate people to the use of the software.

- *Name & institution of collaborators*
  Gaspard DUCHËNE LAOG

- *Work planned for the next 18 months*
  - Insure the existence of Users Requirements. Maintain this document.
  - Write an SFS Document.
  - Write an ICD between subsystems.
  - Write the SDD.
  - Start support for users (next calls for proposal ESO VLTI)

4. WP 2.2 Integration Tool, Data Interpretation & Mining Tool

Will provide utilities to help the design & development of other tools, to manage data formats, data retrivial. Will provide APIs and GUIs. Will insure access to, and comparison with, other data sources & observing techniques. Will provide the link with the Virtual Observatory (VO).

- *Name & institution of collaborators*
  Guillaume MELLA LAOG

- *Work planned for the next 18 months*
  - Participate to the ICD writing
  - Write SFS Document.

5. WP 2.3 Modelling Tools

Is divided in two kind of models, Achromatic and Chromatic
A USER REQUIREMENT Document is needed for this task

- *Name & institution of the PI*
  Guy Perrin
  Obsevatoire de Paris
  LESIA
  5, place Jules Janssen
  92190 Meudon

- *Name & institution of collaborators*

Eric Thiebault	CRAL	Lyon
Michel Tallon	CRAL	Lyon
Isabelle Tallon	CRAL	Lyon
Denis Mourard	OCA	Nice
Alain Chelli	LAOG	Grenoble

- *Summary of the project*
  Design and make a software to fit optical interferometric visibility data using either predefined or user models

- *Real manpower involved for the 1st 18 months*
  1.5 FTE

- *Work planned for the next 18 months*
  Contribution to Users Requirements

- *Deliverables for the first 18 months*
  Contribution to Users Requirements, SFS Document
  A USER REQUIREMENT Document is needed for this task

6. WP 2.4 Astrometry Tools

- *Name & institution of the PI*
  TBD between UNIGE and NOVA.

- *Name & institution of collaborators*
  Damien Segransan UNIGE
  Erik J. Bakker Leiden Observatory/NOVA

- *Summary of the project:*
  D. Segransan: The task of UNIGE in the astrometric software is to develop and deliver (as contribution to the OLBI) a software module that does the orbit fitting and reconstruction from astrometric data. Geneva Task leader is: Damien Segransan.

  E. Bakker: We plan to develop software which computes the parallax, proper motion, and possible residual orbital motion from Astrometric data obtained with PRIMA. Input data are projected angular separation on the baseline, exact time of observation, science source and reference source characteristics in the Astrometric FITS format as defined by ESO.

- *Real manpower involved for the 1st 18 months*
  2 months-FTE UNIGE

- *Work planned for the next 18 months*
  Work on User Requirements,
  Preliminary design study

- *Deliverables for the first 18 months*
  Contribution to Users Requirements
  Software Functional Specifications

This Task is presently to be organized from the various contributions of different groups in different countrries. We (the WPL) expect the groups invoved here to elect a person to make the link between the WPL and the subsystem's members.

7. WP 2.5 Image Reconstruction Tools

A USER REQUIREMENT Document is needed for this task

a) UK Group

- *Name & institution of the PI*
  Chris Haniff, Astrophysics Group, Cavendish Laboratory, University of Cambridge.

- *Name & institution of collaborators*
  David Busher, Astrophysics Group, Cavendish Laboratory, University of Cambridge.
  John Young, Astrophysics Group, Cavendish Laboratory, University of Cambridge.

- *Summary of the project:*
  Development of algorithms or image reconstruction of sparse interferometer data.
  The work will be managed by the PI, with the assistance of Drs David Buscher and John Young, and will likely involve the following components:
  1. Problem definition and scope.
  2. Coding of a simulator to prepare test data.

3. Investigation of MEM based algorithms for imaging.
4. Coding to allow input of exchange format data standard.
5. Study of robustness in the presence of missing closure triangles, missing visibility data, sparse uv coverage.
6. Investigation of suitability of these algorithms for typical VLTI array configurations and, if time permits, the use of multiple datasets in closely spaced spectral channels.
7. Preparation of memoranda describing the above activities.

   Once an optimum algorithm has been devised and characterised we would expect to make this available so as to be integrated in the OLBI software system.

   However, we expect most of our contribution to be associated in the design, testing and characterisation phases of the study.

- *Real manpower involved for the 1st 18 months:*
  33 man months of effort (16.5 supported by the EU and 16.5 supported by our existing staff and colleagues) to complete this work.

- *Work planned for the next 18 months*
  Our program of work will be associated with the activity denoted by 2.5D1 and milestone 2.5M1 in the sense of working towards exploring and testing appropriate image reconstruction algorithms for the OLBI software and in helping to demonstrate the capabilities of our algorithms.

- *Deliverables for the first 18 months*
  We expect to contribute to the delivery of 2.5D1 in the 1st 18 months and potentially 2.5D2 in the following period.

b) *France Group*

- *Name & institution of the PI*
  Eric Thiébaut, CRAL

- *Name & institution of collaborators*
  Laurent Mugnier, ONERA
  Serge MEIMON, ONERA

- *Summary of the project*
  We plan to develop the algorithms and (high level language) software for the reconstruction of images from optical interferometric data.

  We will have to develop specific algorithms in order to overcome the sparse coverage of the u-v plane and the weakness of the Fourier phase information provided by optical interferometry (compared to, e.g., radio interferometry).

  These algorithms will be designed to make use of various types of interferometric data (phase closures, visibilities, power spectra, ...) and account for different types of noise. The algorithms will be reconstruct images for various kinds of regularization (entropy, generalized Tikhonov, ...)

Since our developments will follow the inverse problem approach, we will be able to use our forward model as a simulation tool and therefore study the performances of the derived algorithms.

- *Real manpower involved for the 1st 18 months:*
  22 man months (9 supported by the EU and 13 supported by us and our institutes) to complete the work planned for the first 18 months.

- *Work planned for the next 18 months*
  We expect to obtain a first version of the software aimed at the processing of the data from existing instruments at this date (e.g., AMBER).

- *Deliverables for the first 18 months*
  Contribution to the Users Requirements.

  A high level language version of the algorithms to be integrated in the end-user software interface (WP 2.2).

  Performance studies and comparison between the derived algorithms.

c) *Germany Group*

- *Name & institution of the PI*
  TBD. Current list:
  U. Gräser MPI HD
  T. Henning MPI HD
  C. Weigelt Max Planck Institute for Radioastronomy

- *Name & institution of collaborators*
  T. Driebe, Max Planck Institute for Radioastronomy
  D. Schertl, Max Planck Institute for Radioastronomy

- *Summary of the project:*
  Development of image reconstruction methods for the LBT LINC-NIRVANA instrument and the AMBER VLTI instrument. (contribution by C. Weigelt)

- *Real manpower involved for the 1st 18 months:*
  9 months FTE

- *Work planned for the next 18 months*
  As above.

- *Deliverables for the first 18 months*
  Image reconstruction algorithms for the LINC-NIRVANA LBT instrument and the AMBER VLTI instrument .

d) *Poland Group*

- *Name & institution of the PI*
  A. Niedzielski U. TORUNarization (entropy, generalized Tikhonov, ...)

e) <u>*Spain Group*</u>

- <u>*Name & institution of the PI*</u>
  Dr. Lucas Lara, Universidad de Granada (UGR)

- <u>*Name & institution of collaborators*</u>
  Dr. Antxon Alberdi, Instituto de Astrofisica de Andalucia (IAA-CSIC)
  Dr. Carlos Eiora, Universidad Autonoma de Madrid (UAM)

- <u>*Summary of the project:*</u>
  Making images regularly using existing or coming optical and near infrared interferometric devices is a major goal to be achieved in the near future. Generally speaking, two possible methods of obtaining images from an interferometer can be considered:

  1. Phase-referenced imaging: This method, while successfully applied to radio data, is difficult to apply at short wavelengths because of the extremely changing atmosphere and the difficulty of finding suitable phase calibrators at small enough angular distances from the target source.

  2. Closure-phase imaging: the sum of three interferometric phases around a closed triangle of telescopes is free from all "local" contributions to the phases (e.g. atmosphere or optical systems), remainig the source structure contribution, plus other (hopefully minor) baseline based contributions. Closure phase is a good interferometric observable, although there is a loss of information which prevents accurate position determination of the target source.

     Closure-phase imaging is extensively used in VLBI radio interferometry to overcome the instability of interferometric phases measured at different baselines due to "local" perturbations associated to single telescopes. The same concept can be applied to optical interferometry. Closure phases at visible and IR wavelengths have been obtained with several interferometers: COAST (Baldwin et al. 1996), NPOI (Bensonet al. 1997) and, recently, IOTA (Traub 2003).

     The main aim of our proposal is to investigate in depth the adaptation and application of the imaging techniques used in radio interferometry to the optical and near-infrared regimes. There are important differences related with the instability of the atmosphere at short wavelengths, but provided that good interferometric observables are available (squared visibility amplitudes and closure phases), we intend to exploit the experience of radio interferometry imaging and apply/modify what is applicable to optical data. We note that this approach in not unexplored. Successful attempts of using radio interferometry imaging techniques have been reported in theliterature (eg. Baldwin et al. 1995; Benson et al. 1997; Hummel et al. 2003). One of the methods employed consists of converting the data into complex baseline-based visibilities by taking the square root of the squared amplitudes, and by solving for a set of baseline phases constrained by the value of the measured closure phases. After several iterations of phase self-calibration and deconvolution, synthesis images of several multiple star systems at milliarcsecond angular resolution have been obtained.

Following these guidelines, we intend to develope our work along three major steps:

Phase A: Investigate the application of techniques traditionally used in radio-interferometry, such as phase self-calibration (Cornwell & Wilkinson 1981) and deconvolution (CLEAN or MEM algorithms), to optical and infrared interferometric data. The use of imaging software specifically designed for the radio band, and consequently, the use of visibility amplitudes and phases as observables, is not the most efficient way of exploitation the optical data. This is mainly due to the introduction of biases in the process of transformation from the optical interferometry observables, squared visibility amplitudes and closure phases, to the radio band observables. We intend to tackle this problem, understand the limitations and propose methods of improvement.

Phase B: Design the necessary adaptation to make efficient use of radio software to optical/NIR interferometric data. Software interfaces between optical and radio data will be designed. In this stage, we propose to modify and adapt the Difmap software package (Shepherd 1997), originally written for VLBI data, so that most of its advantages of data handling, editing, modeling, visualization and imaging can be transferred to the optical range. We note that Difmap is by far more friendly and transparent to the user than the other software package normally used in radio interferometry, the NRAO AIPSpackage.

Phase C: Application of the modified package. In this stage of our project, we will apply the resulting software package to real or simulated optical interferometric data. Obtained results will be compared with results derived from other software packages developed by other groups within the network as a feedback mechanism of mutual improvement. At the end we will offer to the community a friendly and easy to use imaging software package for optical and NIR interferometric data.

- *Real manpower involved for the 1st 18 months:*
  6 month FTE

- *Work planned for the next 18 months*
  TBD

- *Deliverables for the first 18 months*
  TBD