Astronomical Data Analysis Software and Systems IX
ASP Conference Series, Vol. 216, 2000
N. Manset, C. Veillet, and D. Crabtree, eds.

ESO Photometric and Astrometric Analysis Program for Adaptive Optics

D. Currie, S. Tordo, K. Naesgarde, J. Liwing, L. Close, D. Bonaccini

European Southern Observatory, Karl-Schwartzschild-Str. 2 d-85748 Garching b. Muenchen, Germany - e-mail: dcurrie@eso.org

E. Diolaiti, O. Bendinelli

Department di Astronomia, Universita di Bologna, Via Ranzani,1,40127 Bologna Italy

G. Parmeggiani

Osservatorio Astronomico di Bologna, Via Ranzani, 1, 40127 Bologna, Italy

Abstract. ESO is developing an array of software analysis packages to perform Photometry and Astrometry on both stellar and diffuse objects observed with Adaptive Optics (AO) Systems. Element programs of this ESO-PAAPAO will be made available to AO observers using ADONIS and the AO systems being developed for the 8.2 meter VLT telescopes at Paranal. The performance of the ESO-PAAPAO will be extensively quantified, both to support data analysis and as a guide for the formulation of AO observing strategies. We address the objectives of the ESO-PAAPAO, the calibrated ADONIS data sets which have been collected for distribution to contributors to the ESO-PAAPAO program, and the methods and results of comparisons among various packages, particularly, the STARFINDER program developed at the University of Bologna in collaboration with ESO which has been used on data from ADONIS at La Silla, UHAO at Mauna Kea, and HST. Results of this astronomical AO data analysis are presented, i.e. photometric precision of 0.03 magnitudes, astrometric precision of 0.1 pixel in crowded fields.

1. Introduction

1.1. Motivation and Background of PAAPAO

The imaging data obtained from the Adaptive Optics systems have many features which make the extraction of valid scientific results much more difficult and less precise than the analysis of images obtained from conventional telescope imaging. The Point Spread Function (PSF) has extended wings, and the structure of the AO PSF changes over the field of view and is not constant in time, either within an observation or from one observation to the next.

Within a year in Period 66 (starting on October 2000), CONICA/NAOS on the VLT will be used by the general astronomers of the ESO community. Our experience looking at ADONIS proposals, observations, and papers published is that users need software tools and guidelines for data reduction. These are needed because the AO observations are quite different than the experience of many users. The observing and calibration strategy must be planned having the data reduction method in mind. We see that in general, inexperienced users do not extract all the useful scientific information from the data. As a consequence there is a highly selective effect in the publication of ADONIS results, most of which are the builders, the next-door colleagues, or insiders. Some astronomers are overcome by the instrumental effects and simply blame the AO system for having defeated their expectations. We feel a data reduction toolkit is mandatory to transform the VLT AO systems into true facility instruments.

1.2. Scope and Objectives of PAAPAO

To address this problem for CONICA/NAOS and future instruments, ESO created the PAAPAO program in the Instrument Division to provide a toolkit of software packages, adapted to the ESO AO systems. A wide range of science objectives will be addressed, i.e. photometry and astrometry, stellar and diffuse or nebular objects, high and low Strehl, and well-sampled and under-sampled images. While the software is being developed in the IDL language, the interface to the astronomer does not require the knowledge of any programming language. The first element is the Spatially Invariant STARFINDER (Diolaiti 1999). The second element will address the astrometric motion of extended objects (Liwing 1999, Dowling 1996). This will be followed by the Spatially Variant STARFINDER (Diolaiti 1999), and then a version of STARFINDER to handle under-sampled images A more complete description of the elements of the ESO ToolKit and more up-to-date results on the algorithm testing may be found on the PAAPAO Web Site - http://www.eso.org/aot.

1.3. PAAPAO Program Structure

The PAAPAO program consists of three primary components. The first is the collection of algorithms to perform photometry and astrometry which will be publicly available, documented for the use by a general observer. The second component consists of the collection of AO data, both using a focused set of observations with ADONIS on the ESO 3.6 meter telescope at La Silla, and the identification and collection of data contributed by astronomers from other adaptive optics systems. The third component consists of two parts. The first part is the evaluation of the performance of the candidate algorithms for the ESO Toolkit using real telescope data. The second part is the identification of those algorithms, programs, and elements of programs, which should be developed for future inclusion in the next generation ESO Toolkit.

2. Data Collection

In this discussion, we shall consider, as an example, the analysis of one of the data sets collected using the ESO ADONIS System. These are images of the inner region of the globular cluster 47 Tuc (NGC 104). The camera optics provides 100 mas pixels and a 25 arc second FoV with the Ks filter. The diffraction-limited FWHM is 120 mas, so the PSF would have been somewhat under-critically sampled, if the Strehl ratio had been high (this data has a relatively low Strehl ratio). The data consists of four groups obtained within an hour, where the pointing for each group was offset by a few seconds. There are 10 images for each group, with individual exposure times of 10 seconds.

3. Results

We consider a set of 14 stars which were in common with all analysts, and a set of the 65 stars. Each comparison uses exactly the same set of stars. For the case of 14 stars the purely statistical error bars are about 30% of the standard deviations. Therefore, the differences between the P&A programs which were tested is not statistically significant (two sigma) using this small set of stars, although STARFINDER shows better performance in both the 14 and the 65 star sets. Earlier tests of the ROMAFOT program indicates that it is in the same domain. However, it is clear that the performance of all the programs is about a factor of 30 worse than the "theoretical" performance, that is, the photometric noise is much worse than the noise to be computed from the photon statistics, the sky noise, and the readout noise. Similar results were obtained for the astrometry, with precision at the level of 5 to 20 mas, for the same image of 47 Tuc. These statistical problems high-light the need for a careful integrated plan of data collection and data analysis, to insure a statistically significant understanding of the AO data processing.

3.1. Under-Sampled Images

In order to obtain under-sampled data with the required properties in a reasonable time scale, we have used data obtained from the WFPC of the HST, (Currie et al. 1995, Currie et al. 1996). The results showed that DAOPHOT performed significantly better than the STARFINDER (to be expected on the basis of the current structure of STARFINDER).

3.2. Effects of Prior Deconvolution

We now address the effects of performing deconvolution prior to photometry. We have used our 47 Tuc images, and performed the photometry. Then the image was deconvolved, using the Lucy-Richardson algorithm and the IDAC program. Each was performed for 500 and 2500 cycles. The deconvolutions were performed with the "standard" rules for the published algorithms. This was followed by the use of DAOPHOT and STARFINDER.

4. Conclusions

We have three primary conclusions at this time. For well-sampled images with relatively low Strehl ratios, the various programs, STARFINDER, DAOPHOT and ROMAFOT give statistically similar accuracy, although STARFINDER was better in this data set, and only STARFINDER can handle spatially variant PSFs to correct for the anisoplanatism. For Under-Sampled HST Images

- DAOPHOT performs significantly better than STARFINDER. The present approaches to deconvolution do not improve the accuracy of the photometry. Finally, although these programs are performing better than literature results, all of these methods (and all published analyses) have photometric errors which are worse by more than a factor of thirty than the theoretical errors from photon noise, readout noise, and sky noise.

5. Invitation to Community

We invite and strongly encourage interested parties to participate in the PAA-PAO program. This participation may take a number of different forms. This may consist of applying your favorite photometry and/or astrometry algorithm to some of our data sets. It may consist of contributing your algorithms for testing by the broader community. We also look to the contribution of data sets collected on other AO systems, in particular data sets which properly address the evaluation anisoplanatic effects. Finally, we are interested in "beta testers" for the programs to be released within the ESO ToolKit.

Acknowledgments. We wish to acknowledge the allocation of ESO telescope time, and the excellent support of the 3.6 meter team members at La Silla. We would also like to acknowledge the contribution of data by F. Rigaut, L. Close, S. Hippler, and M. Feldt.

References

Currie, D. G., Dowling, D., et. al. 1995 "3D Structure of the Bipolar Dust Shell of η Carinae" ESO Workshop on the Role of Dust in the Formation of Stars, Garching bei Muenchen, Germany, Kaufl, H. U. and Siebenmorgen, R. (Ed.) Springer-Verlag, 89-94

Currie D. G., Dowling D. et al., 1996, AJ, 112, 1115

Dowling D. M. 1996 University of Maryland - Ph.D. Thesis

Diolaiti, D. 1999, in ASP Conf. Ser., Vol. 172, Astronomical Data Analysis Software and Systems VIII, ed. David M. Mehringer, Raymond L. Plante, & Douglas A. Roberts (San Francisco: ASP), 625

Diolaiti, D., Bendinelli O., Bonaccini D., Parmeggiani G., & Rigaut F. 1998 in ESO/OSA - Topical Meeting on Astronomy with Adaptive Optics., ed. D. Bonaccini (Garching b. Muenchen, ESO), 175

Liwing, J. 1999 "Accuracy of Different Methods for Differential Astrometry", Master's Thesis-TRITA-FYS, Stockholm

Naesgarde, K. 1999 "Accuracy in Differential Photometry-STARFINDER vs. DAOPHOT", TRITA-Master's Thesis-FYS, Stockholm