Laser Guide Star Adaptive Optics for Astronomy

edited by

N. Ageorges
European Southern Observatory,
Santiago, Chile

and

C. Dainty
Imperial College,
Blackett Laboratory,
London, United Kingdom

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PREFACE

Groundbased optical and infrared astronomy is on the threshold of a new era, thanks to the invention and development of *adaptive optics*. This technique enables the theoretical limit of angular resolution to be achieved from a large telescope, despite the presence of atmospheric turbulence, or seeing. Thus an eight-metre class telescope, such as one of the four that comprise the Very Large Telescope (VLT) operated by the European Southern Observatory in Chile, will in future routinely be capable of an angular resolution of almost 0.01 arc-seconds, compared to the present resolution of about 0.50 arc-seconds for conventional imaging in good conditions. Adaptive optics on groundbased telescopes will provide higher angular resolution than space telescopes, as for the foreseeable future we shall always be able to build bigger (and much less expensive) telescopes on Earth than those to be launched into space.

All the World's major telescopes either have adaptive optics (AO) installed or are in the process of building AO systems. These first generation systems will not achieve the highest angular resolution, and probably will provide a resolution in the range 0.05 to 0.10 arc-seconds, an order of magnitude improvement on conventional imaging but still significantly below the value of 0.01 arc-seconds. To understand why this is so, we need to understand how an AO system works.

An adaptive optics system consists of three essential components: a wavefront sensor, a deformable mirror, and a control system. In the early days of AO, the technology of deformable mirrors and fast control systems were the main concerns of those developing systems, but nowadays there is fairly universal agreement that the key part of the process is wavefront sensing. If one cannot measure the wavefront deformation induced by the turbulent atmosphere, there is no hope of correcting for it. To sense the wavefront within the atmospheric coherence time, a fairly bright source is required, almost certainly brighter than the astronomical object of interest. So the strategy is usually to select the nearest bright star to the science object for wavefront sensing, but the disadvantage of this is that the sensed turbulence is not exactly the same as that experienced by the science object, an effect known as angular isoplanatism. When all the calculations are complete, it turns out a reasonable fraction of the sky can be observed using adaptive optics, with moderately good imaging quality, provided that the wavelength used for imaging is in the near infra-red. Of course, the angular resolution is proportional to wavelength, so near IR images do not provide as good angular resolution as visible light.

The solution is for astronomers to create their own *laser guide star* to facilitate the wavefront sensing process. There is a layer of sodium atoms at approximately 90 km altitude, and this can be excited by a laser to produce such a source. Alternatively, or in addition, Rayleigh scattering lower in the atmosphere may be employed, although this is not the currently favoured approach.

Since the laser guide can be created anywhere in the field of view — for example, right in the middle of the science object — and in principle (and with enough money!) can be relatively bright, it might seem that this is the ideal solution and therefore that laser guide star adaptive optics would effortlessly attain the goal of 0.01 arc-second resolution at visible wavelengths.

Unfortunately, the production and use of a laser guide star is not trivial from a technical standpoint, and in addition there are fundamental issues not directly solved by the use of a laser guide star. These provided the motivation for the NATO Advanced Study Institute (ASI) on "Laser Guide Star Adaptive Optics for Astronomy", held in Cargèse, Corsica, from September 29 to October 10, 1997, upon which this book is based. At this meeting, the key issues determining the successful implementation of laser guide stars were discussed: these included the physics of the sodium atom, the cone effect, tilt determination, sky coverage and numerous potential astronomical applications. Approximately 80 scientists participated in the ASI over a two-week period. Although there has been a significant delay between this meeting and the publication of this book, all the Chapters are fully up-to-date and should be of particular value to those now building and using the first generation of astronomical laser guide star systems.

The Advanced Study Institute was co-chaired by J C Dainty (Imperial College) and N Hubin (European Southern Observatory), who were assisted by a Scientific Organising Committee consisting of R Foy (Observatoire de Lyon), C Max (Lawrence Livermore Laboratory), S T Ridgway (NOAO, Tucson) and C E Webb (Oxford). Particular thanks go to Annie Touchant and the staff of the Institut d'Etudes Scientifiques, Cargèse for their assistance with the local organisation and their warm hospitality, and to Georgette Huber of ESO for her administrative help. The Advanced Study Institute was sponsored by the Scientific Affairs Division of NATO.

The Editors are deeply grateful to the contributors of this Volume for the care and patience they exercised in the preparation and revision of their manuscripts. We are grateful also to the many participants who provided photographs taken during the meeting. We hope that this book will stimulate those interested in developing and using new astronomical observing techniques to produce even more spectacular observations, and a greater understanding, of our Universe.

Nancy Ageorges, Galway

Chris Dainty, London

February, 2000

List of participants

Nancy Ageorges
European Southern Observatory
Casilla 19001
Santiago 19 - Chile

Jeffrey Baker
Boeing/Phillips Laboratory
PO Box 5670
Kirtland Air Force Base
NM 87185 - USA

Fabio Baroncelli
via S de' Tivoli 12
57125 Livorno - Italy

Andrea Baruffolo
Osservatorio Astronomico di Padova
Vicolo dell'Osservatorio 5
35122 Padova - Italy

Jim Beletic
European Southern Observatory
Karl-Schwarzschild-Straße 2
D-85748 Garching-bei-München - Germany

Carmen Dolores Bello Figueroa
Instituto de Astrofisica de Canarias
C/ Via Lactea, s/n
C.P. 39200 La Laguna
S/C de Tenerife - Spain

Aniceto Belmonte
Polytechnic University of Catalonia
Campus Nord UPC - Modulo D3
Despacho 118 c/ Gran Capitan s/n
08034 Barcelona - Spain

Philippe Berio
Observatoire de la Côte d'Azur
Département Fresnel
CNRS UMR 6528
06460 Saint Vallier de Thiey - France

Bruce Bigelow
Observatories of the Carnegie Institute of Washington
813 Santa Barbara St
Pasadena CA 91101 - USA

Nicoletta Bindi
Arcetri
Via Carducci n.18
50121 Firenze - Italy

Domenico Bonaccini
ESO
Karl-Schwarzschild-Straße 2
D-85748 Garching - Germany

Marcel Carbillet
Osservatorio Astrofisico di Arcetri
Largo Enrico Fermi 5
50125 Firenze - Italy

Mark Chang
51 Furrow Way
Maidenhead
Berkshire SL6 3NY - UK

Jean-Christophe F Chanteloup
Lawrence Livermore National Laboratory
University of California
700 East avenue, L-447
Livermore, CA 94550 - USA

Mark Chun
Gemini 8-m Telescopes Project
670 Aohoku Place
Hilo, Hawaii 96720 - USA

Claudio Cumani
ESO
Karl-Schwarzschild Straße 2
85748 Garching bei München - Germany

Céline D'Orgeville
Gemini Observatory
670 N A'ohoku Place
Hilo HI-96720 - Hawaii

Gérard Daigne
Observatoire de Bordeaux
BP 89, Avenue P. Semirot
33270 Floirac - France

Chris Dainty
Imperial College
Blackett Laboratory
London, SW7 2BZ UK

Francoise Delplancke
ESO
Karl-Schwarzschild-Straße 2
85748 Garching b. München - Germany

Peter Doel
Optical Science Laboratory
Dept Physics and Astronomy
University College London
London WC1E 6BT - UK

Jack Drummond
Starfire Optical Range
Air Force Research Laboratory
Directed Energy Directorate
3550 Aberdeen Avenue SE
Kirtland AFB
NM 87117-5776 - USA

Yvan Dutil
Universidad Politecnica de Catalunya
Departamendo de matematica aplicada II
Pan Gargallo 5, Edificio U
E-08028 Barcelona - Spain

Jacopo Farinato
ESO
Karl-Schwarzschild-Straße 2
85748 Garching - Germany

Orla Feeney
Osservatorio Astrofisico di Arcetri
Largo Enrico Fermi 5
50125 Firenze - Italy

Marc Ferrari
Observatoire de Marseille
2 Place Le Verrier
13248 Marseille Cedex 4 - France

Renaud Foy
CRAL/ Observatoire de Lyon
9 Avenue Charles André
69561 Saint-Genis-Laval - France

Eric Gendron
Observatoire de Meudon
Bâtiment Lyot
5 Place Jules Janssen
92195 Meudon - France

Adriano Ghedina
Centro Galileo Galilei
C/Alvarez Abreu, 70
38700 Santa Cruz de la Palma
S.C. Tenerife - Spain

Chris Holstenberg
MPE-Garching
Giessenbachstr 1
D-85748 Garching - Germany
Georgette Hubert
ESO
Karl-Schwarzschild-Straße 2
D-85748 Garching-bei-München - Germany

Norbert Hubin
European Southern Observatory
Karl-Schwarzschild-Straße 2
D-85748 Garching-bei-München - Germany

Natalia Iaitskova
Moscow State University
Physical Department
International Laser Centre
119899 Vorobyevy Gory
MSU, Moscow - Russia

Neville Jones
Imperial College
Blackett Laboratory
Physics Dept.
Prince Consort Road
London SW7 2BZ

Markus Kasper
MPI für Astronomie
Königstuhl 17
69117 Heidelberg - Germany

Ed Kibblewhite
Department of Astronomy
University of Chicago
5640 Ellis Avenue
Chicago IL 60637 - USA

Etienne Le Coarer
LAOG Observatoire de Grenoble
BP 53
38041 Grenoble Cedex 9 - France

Miska Le Louarn
ESO
Karl-Schwarzschild-Straße 2
85748 Garching - Germany

Jean-Pierre Lemonnier
CRAL - Observatoire de Lyon
9, avenue Charles André
69561 Saint-Genis-Laval Cedex - France

Gary Loos
USAF Phillips Laboratory
PL/LIMI
3550 Aberdeen SE
KAFB - NM 87117-5776 - USA

Philip Lucas
Dept. of Physical Sciences
University of Hertfordshire
College Lane
Hatfield AL10 9AB - UK

Sergio Mallucci
University of Bologna
Department of Astronomy
c/o Fusi PECCI
Vio Zamboni 33
40100 Bologna - Italy

Enrico Marchetti
ESO
Karl-Schwarzschild-Straße 2
85748 Garching - Germany

Claire Max
Director of University Relations
Lawrence Livermore National Laboratory
L-413, 7000 East Avenue
Livermore CA 94550 - USA

Patrick McGuire
Center for astronomical adaptive optics
Steward Observatory
University of Arizona
933 North Cherry Avenue
Tucson - Az 85721 - USA

Vincent Michau
ONERA
Département d'optique théorique et appliquée
29 avenue de la division Leclerc
BP 72
92322 Chatillon cedex - France

Guy Monnet
European Southern Observatory
Karl-Schwarzschild-Straße 2
D-85748 Garching-bei-München - Germany

Rhys Morris
University of Cardiff
Dept. of Physics & Astronomy
PO Box 913
Cardiff CF2 3YB - UK

Créidhe O'Sullivan
Department of Physics
NUI, Maynooth
Co. Kildare - Ireland

Vadim Parfenov
S I Vavilov State Optical Institute
12 Birzhevaya Liniya
St Petersburg
199034 Russia

Patrizio Patriarchi
CNR/ Gruppo Naz Astronomia
Largo E Fermi 5
I-50125 Firenze - Italy

Guy Perrin
Département de Recherche Spatiale
Observatoire de Paris, section de Meudon
5 place Jules Janssen
92190 Meudon - France

Yuri Protasov
Professsor of BMSTU
BMSTU
2-nd Bauman Str 5
Moscow 107005 - Russia

Andreas Quirrenbach
Prof of Physics
University of California, San Diego
Department of Physics
Center for Astrophysics and Space Sciences
9500 Gilman Drive
Mail Code 0424
La Jolla, CA 92093-0424 - USA

Roberto Ragazzoni
Astronomical Observatory of Padova
vicolo dell' Osservatorio 5
I-35122 Padova - Italy

Sam Ragland
Osservatorio Astrofisico di Archetri
Largo Enrico Fermi 5
50125 Firenze - Italy

Tom Ray
Dublin Institute for Applied Studies
5 Merrion Square
Dublin 2 - Ireland

Marcos Reyes Garcia-Talavera
Instituto de Astrofisica de Canarias
C/Via Lactea, s/n
La Laguna
38200 Tenerife - Spain

Stephen Ridgway
NOAO
PO Box 26732
Tucson AZ 85726 - USA

Francois Rigaut
Gemini Observatory
670 N A'ohoku Place
Hilo HI-96720 - Hawaii

Clelia Robert
ONERA
BP 72
92322 Chatillon Cedex - France

Tom Roberts
University of Arizona
Steward Observatory
933 Cherry Avenue
Tucson - Arizona 85721 - USA

Claudia Maria Silva Rola
Institute for Astronomy
University of Cambridge
Madingley Road
Cambridge CB3 0HA - England

Huub Rottgering
Sterrewacht, Oort Gebouw P.O. Box 9513
2300 RA Leiden - The Netherlands

Juan A Rubio
Univ. Politecnica de Catalunya
Dept. TSC
Jordi Girona 1-3. Mod. D3
08034 Barcelona - Spain

Ernesto Sanchez-Blanco Mancera
Gran Telescopiio de Canarias (GTC)
Instrumentation Group
C/Via Lactea s/n
La Laguna
38200 Santa Cruz de Tenerife - Spain

Andrew Sheinis
Lick Observatory
University of California
1156 High St.
Santa Cruz - CA 95064 - USA

Beatrice Sorrente
ONERA - DOTA/OASO
29 avenue de la division Leclerc
BP 72
92322 Chatillon Cedex - France

Jérome Vaillant
Observatoire de Lyon
9 Avenue Charles Andre
69561 Saint-Genis-Laval Cedex - France

Christophe Verinaud
Observatoire de la Côte d'Azur
06460 St Vallier de Thiey - France

Elise Viard
ESO
Karl-Schwarzschild-Straße 2
85748 Garching b. München - Germany

Keith Wilson
Jet Propulsion Laboratory
4800 Oak Grove Drive
MS 161-135
Pasadena
California 91109-8099 - USA

Andrew Zadrozny
University of Durham
Physics Dept.
South Road
Durham DH1 3LE - UK

TABLE OF CONTENTS