Report on the Conference

Optical Turbulence — Astronomy meets Meteorology

held at Nymphes Bay, Alghero, Sardinia, Italy, 15–18 September 2008

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"A European boost to a strategic research field on which the success of the ELTs relies."

The spatial resolution of current and future ground-based telescopes is limited by the optical turbulence of the atmosphere. An interdisciplinary conference of astronomers, meteorologists and atmospheric physicists to consider the study, characterisation and correction of atmospheric turbulence is reported.

An international conference, "Optical Turbulence — Astronomy meets Meteorology" (see *http://forot.arcetri.astro.it/otam-08)* was held at Nymphes Bay, Alghero in Sardinia to bring together researchers from different fields, including astronomers, physicists and meteorologists, to discuss the consequences of the new era of ground-based astronomy from the point of view of optical turbulence, taking account of the main challenges and critical points. The meeting was an experiment, with the aim of fostering new types of collaborations that enhanced interdisciplinary and cross-field interactions.

Optical turbulence (OT) is one of the main causes limiting the spatial resolution attainable in ground-based visible and infrared astronomical observatories. It is certainly one of the principal obstacles to be overcome in achieving the potential performance of the next generation of ground-based astronomy facilities, the Extremely Large Telescopes (ELTs). The success of these facilities strongly depends on our ability to:

1. Characterise optical turbulence at astronomical sites from a qualitative as well as a quantitative point of view.
2. Improve our knowledge of the mechanisms that produce and develop optical turbulence.
3. Predict 3D maps of optical turbulence to optimise flexible scheduling of scientific programmes and instruments.
4. Correct wavefront perturbations produced by atmospheric turbulence.

Many of the most challenging scientific programmes to be carried out with ground-based telescopes and aiming to enhance our understanding of the Universe require excellent turbulent conditions to be successful. The competitiveness of ground-based astronomy with respect to space-based astronomy is strictly related to our ability to identify and predict temporal windows of favourable atmospheric conditions in the most accurate way. New and sophisticated Adaptive Optics (AO) techniques, assisted by either natural or laser guide stars (such as Multi-Conjugate AO [MCAO], Ground-Layer AO [GLAO] and Laser Tomographic AO [LTAO]), are intended to optimise the correction of perturbed wavefronts over different fields of view, but, to achieve this optimisation of efficiency, they will also require a detailed knowledge of the vertical distribution of the OT (and not simply integrated values). This new generation of AO requires a detailed understanding of the connections between the turbulence spectrum and the shape of the point-spread function (PSF) over the entire field of view. Some specific topics, such as the precise nature and role played by the spatial coherence outer scale in high angular resolution (HAR) techniques and the turbulence spectrum features in non-Kolmogorov regimes, are still active research topics at the frontiers of the theory in this field.

From the meteorological side, Operational Numerical Weather Prediction (NWP) systems at medium and mesoscale range might play an important role for ground-based astronomy over the next few decades. 4D-Var Assimilation Data [1] employing satellite measurements has greatly improved the quality of medium range weather forecasts recently. A new challenge for meteorology recently appeared on the horizon: Mesoscale Data Assimilation. This consists of a network of surface stations and an assimilation system with a resolution of a few kilometres. Such a system is mandatory to improve the ability of mesoscale models in reconstructing the unresolved physical parameters (such as the OT) evolving at spatial and temporal scales smaller than the resolution of the General Circulation Model[2] and to improve the accuracy of meteorological weather forecast models that extend over limited surface areas. How this can be set up in remote regions of the Earth, such as those that are typically of interest to astronomers, is an important question.

This international conference was aimed at all these topics. The meeting was promoted and organised by Elena Masciadri, Team Leader of the ForOT Project [3], and was a milestone in a long-timescale programme begun a few years ago. ForOT is actively involved in studies relating to turbulence characterisation for astronomical applications, employing measurements as well simulations with mesoscale atmospheric models (Masciadri, 2006). The conference was sponsored by the European Community, which contributed most of the funding through the ForOT Project, but additional contributions were provided by ESO and INAF (Italy).

The original intention of the conference was to attempt to link the two communities of astronomers and meteorologists. This step is fundamental to guaranteeing the success of dedicated systems conceived for the prediction of the optical turbulence (seeing and related integrated astroclimatic parameters, such as isoplanatic angle, wavefront coherence time, etc.) above astronomical sites using mesoscale atmospheric models. The reason is simple. We need to apply an investigative tool developed in meteorology (atmospheric models) to do science (the

[1] In meteorology, Assimilation Data is the procedure that provides the distribution in space and time of the status of a set of variables supposed to describe the atmosphere in a given volume. The accuracy of this description depends on the nature and density of the observations (such as radiosoundings, satellites, etc.) and is fundamental for better description of the initialisation of a model.

[2] General Circulation Models (GCMs) are models that extend over the whole Earth and are used for weather forecasting.

[3] The ForOT Project (see *http://forot.arcetri.astro.it*) is funded by a Marie Curie Excellence Grant (FP6 Programme) — MEXT-CT-2005-023878.

characterisation of optical turbulence) in the astronomical field. This is a classic example of problem solving by a multidisciplinary approach between disciplines that use different languages, different strategic approaches and investigative tools.

The challenge for astronomers is to be aware just how much the success of the next generation of ground-based astronomy facilities will depend on numerical predictions of the atmosphere. This is a discipline that requires long timescales, so it is important not to ask the impossible of the current models and to optimise the work of astronomers and meteorologists to make clear the achievable challenges and to work together to attain them in the shortest time and most efficient way. As a first step in this direction, on the last day of the conference, a special session was dedicated to an open discussion moderated by the scientists managing some of most powerful current astronomical ground-based facilities, those leading operational forecasting systems and members of research groups developing atmospheric models and data assimilation systems.

Around 60 specialists (from instrumentation, atmospheric modelling and theory, AO simulations and systems) met in Sardinia to highlight their new results with around 45 oral presentations and 10–15 posters. A considerable number of meteorologists attended the event (with a strong participation from the Centre National de Recherches Meteorologiques (CNRM), Meteo France, Toulouse) with presentations covering all the key topics related to the numerical prediction of the atmosphere. The conference proceedings will be published by Imperial College Press and edited by E. Masciadri and M. Sarazin.

Main conference results

The conference started with a general introduction by two Emeritus Professors. Jacques Beckers introduced the topic of optical turbulence in high angular resolution techniques, and Rene Racine provided a personal and provocative vision of the problem of turbulence characterisation in astronomy.

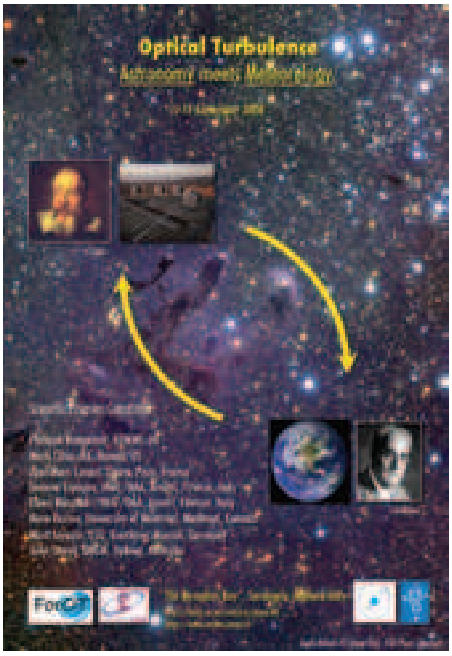

Figure 1. Conference Poster.

Subsequent sessions were dedicated to the characterisation of turbulence from measurements. The number and type of optical instruments to measure the vertical distribution (vertical profilers) has suddenly increased in recent years and many of them are conceived to monitor dedicated regions of the troposphere. One of the most interesting developments is the proliferation of vertical profilers dedicated to measuring and characterising the OT with high vertical resolution near the surface. From a typical resolution of the order of 1 km (typical of Generalised Scidar [GS]), we have moved on to resolving thinner vertical slabs of up to a few tens of metres. Concepts on which the instruments are based, and/or results obtained in first site-testing campaigns were presented for the solar and lunar scintillometers called SHABAR (solar SHAdow BAnd Ranger) by Beckers, for a lunar scintillometer by Paul Hickson, for SLODAR (SLOpe Detection And Ranging) by Richard Wilson and Tim Butterley; HVR–GS (High Vertical Resolution — Generalised SCIDAR) and LOLAS (LOw LAyer SCIDAR) were presented by Masciadri and Remy Avila, representing two different ways of improving the resolution of GS near the surface. A version of SODAR (SOnic Detection and Ranging) at high vertical resolution, called SNODAR, (Colin Bonner) and even a vertical profiler based on the measurements of the wavefront angle-of-arrival statistic (Julien Borgnino) were also discussed. Most of these instruments have been employed in recent years to characterise the first kilometre above several astronomical sites (Mt. Graham, Mauna Kea, Paranal, Cerro Tololo), providing fundamental results for the optimisation of many of the GLAO systems that are under feasibility study for existing facilities.

On the topic of surveys, we highlight the conclusions of the extended site-testing campaigns made by the Thirty Meter Telescope (TMT) group on a set of preselected sites around the world (Matthias Schoeck) and the presentation of preliminary results of a cross-correlation analysis between the results of many different optical instruments performed, at Paranal in December 2007 as part of the FP6 ELT Design Study (Marc Sarazin). Once more, the spatial coherence outer scale was confirmed to be a key astroclimatic parameter for astronomical sites (Aziz Ziad).

On the meteorological side, a very comprehensive description of a couple of European mesoscale atmospheric models, such as Meso-Nh (Non-hydrostatic Mesoscale atmospheric model) and AROME (Applications of Research to Operations at MEsoscale) were presented by Christine Lac, as well as the American Weather Research and Forecasting (WRF) model (Jordan Powers). A highlight was the description (Pierre Brousseau) of the state of the art of the Data Assimilation systems employed for mesoscale models. As explained previously, the performance of such models strongly depends on our ability to set the initial conditions in the most detailed way possible (that is, on the Assimilation Data).

Concerning the dynamical and optical turbulence simulations, considerable progress has been made in the last ten years. A key role in this section has been played by the ForOT activities (Masciadri). ForOT aims to continue the path undertaken by Elena Masciadri several years ago that led her to achieve many relevant results in this discipline and, in particular, to prove that a mesoscale model can reconstruct the optical turbulence above an astronomical site with an accuracy that is not worse than that achievable with measurements. Among the activities of this group, the interesting first simulations of the turbulence parameter C_N^2 above Antarctica, with good reliability of the model in statistical terms (Franck Lascaux), are highlighted. The main goal for this research group is to be a reference and support for observatories in developing turbulence prediction systems above astronomical sites. It is worth noting the creation of the Mauna Kea Weather Center, where astronomers hired meteorologists to make an operational forecasting system of the atmosphere above the Mauna Kea summit (Steven Businger). The general impression was that this research field is gaining interest among astronomers and this, once more, supports the thesis that it is time to boost actions to support benchmark site-testing campaigns, expressly conceived to validate the atmospheric model above astronomical sites, as proposed by the ForOT group.

There were several contributions aimed at the study of the correlation between OT and the meteorological parameters that frequently provide valuable inputs on the OT characteristics. On the topic of AO and interferometry, we report a few results concerning the implications for the turbulence constraints. In the field of MCAO, a detailed investigation of the limits of the validity of the Taylor hypothesis would provide useful insights on ways to improve the sensitivity of MCAO with natural guide stars (Roberto Ragazzoni). For GLAO systems, if the vertical structure of the turbulence decays sufficiently sharply above an astronomical site, GLAO systems in the visible can be applied over an extremely large field of view (Olivier Lai). We also discovered that new wavefront sensor concepts, such as the Differentiation Wavefront Sensor (WS), reported on by Eric Gendron, might be used to characterise the turbulence in a more efficient way than a Shack Hartmann. An exhaustive overview (Peter Wizinovich) depicted the main turbulence constraints as they depended on the type of astronomical target (Galactic, extragalactic and solar) and the observational technique.

Credit: P. Anio

Figure 2. Conference group picture taken in front of Capo Caccia, Porto Conte, Alghero, Sardinia beside a robotic Differential Image Motion Monitor (DIMM) automatic mourt.

The final session was dedicated to science operations. The studies related to OT do have a direct impact on the implementation of the science operation models that make extensive use of queue scheduling or service observing. Several 8–10-m class telescopes currently implement one of two approaches:

1. Application of a singly administered queue mode observing system (as for ESO).

2. Application of a 'partner' queue mode observing system (as for the Large Binocular Telescope, LBT).

It is evident that the selection of the strategy is widely influenced by organisational issues (the single European agency in the former case, a consortium of a few institutes in the latter) and for this reason the absolute efficiency of a telescope is not the only criterion in selecting a given strategy. However it is certainly useful to quantify these efficiencies so as to be aware of what might be lost or gained through alternative solutions. On this topic Fernando Comeron noted that, currently at the VLT, a sizeable fraction of observations (~ 20 %) have to be repeated, because conditions strayed outside constraints during execution; this is an important, hidden source of inefficiency. It is therefore obvious that a tool for the prediction of the state of the atmosphere would definitely be a major step towards increasing the efficiency of the service mode at the VLT. Thus it appears evident that the goal of OT prediction on the timescale of a few hours in advance remains an important objective for observatory operations.

The closing discussion session evinced the success of the first step towards a productive collaboration between astronomers and meteorologists. The most evident feature of such a constructive interaction was the decision, promoted by the Principal Investigator (PI) of the E-ELT (Roberto Gilmozzi), to prepare a detailed document outlining the main steps necessary to prepare an efficient site-testing campaign benchmark test expressly conceived for the validation of mesoscale atmospheric models for application to astronomy. We are all confident that this document will represent the first step on a path that this conference has definitively and unequivocally charted.

References

Masciadri, E. 2006, SPIE Orlando, 62671C

Links

Conference programme and presentations:
http://forot.arcetri.astro.it/otam-08
ForOT website:
http://forot.arcetri.astro.it