RevMexAA (Serie de Conferencias), **31**, 1–9 (2007)

SITE SELECTION FOR THE EUROPEAN ELT: WORKING PACKAGE INCLUDED IN THE EUROPEAN FP6 "ELT DESIGN STUDY" CONTRACT

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RESUMEN

La selección del emplazamiento óptimo para la construcción del Telescopio Gigante Europeo (ELT), es de extrema importancia dentro del Proyecto "ELT design study", financiado por la Unión Europea. Aquí revisamos los aspectos más importantes, las hipótesis de partida, el esquema y la organización del paquete de trabajo que se encarga de la Selección del Emplazamiento del ELT. Hemos utilizado trabajos anteriores que ya habían explorado y contrastado técnicas e instrumentos. También se ha hecho uso de la historia ya existente de observatorios astronómicos, de la información y las bases de datos disponibles, así como de los estudios publicados. Todo ello ha definido de modo natural una jerarquía en sitios para la observación astronómica que ha servido para preseleccionar candidatos; no hemos partido de cero. Nuestro trabajo durará 4 años; empezó en 2005 y está organizado en sub-tareas que a su vez tienen sus propios objetivos: **WP12100**: Caracterizar extensamente dos emplazamientos conocidos por su excelencia (ORM y Paranal) y explorar otros tres alternativos (Macón en Argentina, Izaña en España y Aklim en Marruecos); Dome C está siendo investigado en detalle en otro contexto y los resultados obtenidos de sus propiedades atmósfericas servirán de elemento de comparación y estudio. El **WP12200** se ocupa de diseñar, construir y poner en marcha un conjunto de equipamiento estandar para todos los emplazamientos. En el **WP12300** se investigan las propiedades del frente de onda en escalas del orden de la apertura del telescopio en diseño (50–100 m); también se pretende la caracterización tan detallada como sea posible de la capa límite. El equipo de selección del sitio del Thrity Meter Telescope (TMT) tiene una estrategia similar a la nuestra. Por esa razón y para evitar duplicar esfuerzos y optimizar rescursos, los emplazamientos preseleccionados para el TMT no fueron incluidos en el estudio europeo.

ABSTRACT

The site selection for the future European Large Telescope (E–ELT) is a key issue within the European proposal funded by the European Union (EU), within the "ELT design study" proposal. The organization, working scheme and baseline frameworks are reviewed. For the definition of the working package **WP12000** "Site Characterization", important use has been done of previous work in the definition of techniques and tools for the study of the atmosphere above observing sites. We have also taken advantage of the number of data already available which have naturally defined a ranking among the known places which have also been taken as a base line for pre-selecting the candidate sites. The work will last 4 years, it started in 2005 and is organized in subtasks, working packages WP, whose main objectives are the following: **WP12100**: to characterize two top astronomical sites (ORM and North-Paranal) and to explore three other alternatives (Macon in Argentina, Izaña in Spain and Aklim in Morocco) suitable to install an ELT under the best conditions (Dome C is been currently under investigation, and no particular effort will be put in this site, but rather its atmospheric properties will be compared to the above mentioned sites). **WP12200** is dedicated to design, build and operate a set of standard equipment in all the sites and to perform long term campaign. **WP12300** will investigate wavefront properties over large baselines (50–100 m) corresponding to the size of the future ELT, as well as the fine characterization of the optical turbulence within the boundary layer. A similar plan is being carried out by the Thirty Meter Telescope (TMT) site selection team. For the sake of saving resources (budget and people), the TMT preselected sites (all in the American Continent) are not included in our European study.

Key Words: **SITE TESTING — TELESCOPES**

1. HISTORY, SCOPE AND ORGANIZATION

The site selection for the future large European telescope is a fundamental issue and will be undertaken within the "ELT design study" proposal funded by the European Union (contract Num.

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011863). The first meetings and contacts to define the project started in 2003. Possible interested partners and institutions were approached and a first version with the design and plans was submitted to the EC commission in February 2004. After revision, using the committee feedback, the final proposal was accepted at the end of 2004. The Site Selection work started formally in 2005 and will end in December 2008.

The organization, working scheme and baseline frameworks will be discussed, planned and summarized here. For the definition of the tasks important use have been done of all previous efforts that have been carried out during the last decade in the definition of techniques and tools reliable for the study of the atmosphere above astronomical sites.

Important also is the relevance that the studies of the atmosphere has acquired, becoming key projects for most important astronomical sites. Therefore we have also taken advantage of the number of data already available which have naturally defined a ranking among the known places which have also been taken as a bottom line for pre-selecting the potential sites.

The institutions and persons involved in the project are summarized in Figure 1.

1.1. *Scope and Organization of the Work*

This working package, WP, covers the characterization of few sites for what concerns the seeing, ground climatology, atmospheric properties, soil and seismicity. Emphasis is put on already existing astronomical sites and on new physics corresponding to such a large telescope. The final report will help to select the best reasonable location to settle the ELT.

For practical reasons the work is divided into four task, defined in order to better achieve our commitment.

- WP12000: Site Characterization, General Management Review, Discussion, Reports and Final Conclusions.
- WP12100: Review of Parameters Space.
- WP12200: Instrumentation, Measurement and Modelling.
- WP12300: Large Scale Atmospheric Properties.

For the definition of the parameter space we have made use of previous reviews, some of which are very recent and results from the increasing interest within the astronomical community in the knowledge of the atmosphere. The basic idea is to perform as much as possible observations in each site which implies to

Fig. 1. WP Institutions and participants.

reach a good statistical knowledge of its atmosphere. Hereafter are listed some of the review books which give the state of the art in site characterization in 2003, when the work started.

- "ESO workshop on Site Testing for Future Large Telescopes", 1983, A. Ardeberg & L. Woltjer (eds.)
- "The Observatories of the Canaries", Vistas in Astronomy, Vol. 28, 1985, P. Murdin & P. Beer (eds.)
- "Identification, Optimization and Protection of Optical Telescopes Sites", 1986, Flagstaff, G. Staffi & M. Ziebell (eds.)
- "VLT site selection working group; final report"(no. 62), 1990, M. Sarazin (ed.)
- "Site properties of the Canarian Observatories", New Astron. Reviews, vol. 42, 1998, C. Muñoz-Tuñón (ed.)
- SITE2000 / IAU technical workshop. "Astronomical Site Evaluation in the Visible and Radio Range", ASP Vol. 266, 2002, J. Vernin, Z. Benkhaldoun, Z. & C. Muñoz-Tuñón (eds.)

2. DEFINITION OF PARAMETERS SPACE

The definition of the Parameters Space is not restricted only to the list of important physical parameters for site characterization but includes also the instruments and tools to be implemented, and the procedure for the correct data analysis and interpretation of the results.

In summary the working package (WP) task is the following:

- Define the parameters under investigation: Optical turbulence $C_N^2(h,t)$, Wind velocity $V(h,t)$, Outer scale $L_0(h,t)$, Seeing ε, Isoplanatic angle θ_{AO}, Coherence time τ, Extinction, Dust,

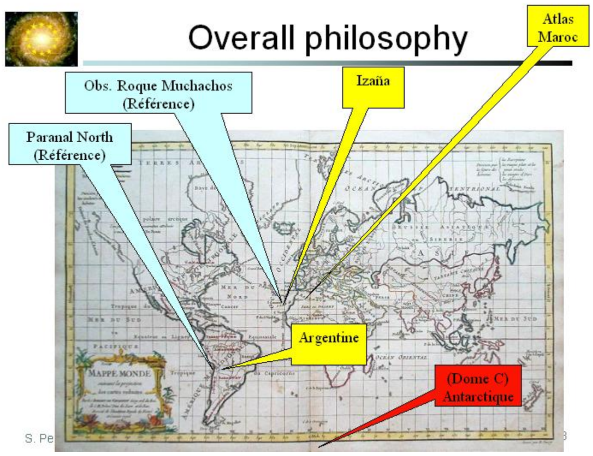

Fig. 2. Map of the world with the location of the selected sites.

Cloud cover, Humidity, Precipitable water vapor, Sky emission, Sky darkness, Light pollution, Soil properties, Seismicity.

- Define the few top sites for a comprehensive study
- Define other possible sites
- Select the adequate instruments to fulfill the goals

As a first step, we selected the sites to be investigated. To help we have taken into account the Thirty Meter Telescope (TMT) site selection programme (see Matthias Schoeck in these proceedings). In order not to duplicate our efforts, the TMT candidates (all of them in the American continent) have been excluded in the European search.

In Figure 2 we present a map of the world with the location of the selected sites.

We have preselected two sites, which will be considered as the "reference" ones: The Observatorio del Roque de los Muchachos (ORM) at La Palma in the Canary Islands (Spain), referred elsewhere as La Palma, and La Chira located 40 km north of Paranal.

Three other sites are also considered: Observatorio del Teide (OT) at Izaña in Tenerife (also in the Canary Islands), Aklim at the Moroccan Anti-Atlas (see Figure 3) and a place in North-West Argentina, Macon (see Figure 4). Dome C in Antarctica is also considered for comparisons and references but not under ELT-DS contract.

The responsibility of the measurements have been split among the following institutions, all running the WPs: European Southern Observatory (ESO), Laboratoire Universitaire Astrophysique de Nice (LUAN) and the Instituto de Astrofísica de Canarias (IAC). For practical reasons, Atlas and Dome C responsibility belongs to LUAN, while La Palma and Izaña to IAC, and finally N–Paranal and Macon to ESO.

Fig. 3. Aklim mountain in Moroccan Anti-atlas.

Fig. 4. Macon (Argentina).

There is a large number of instruments and tools designed for site characterization. However when a comparison is to be done is important to use those which have been already tested and cross calibrated and which are based on well sound physics. Instruments under development or designed to research future purposes, are not useful to fulfill our goals.

After revision and discussion we selected the following instruments: Generalized Scidar (GS), MASS/DIMM, All–Sky Camera (ASC), High Altitude Dust with Satellite Images, Automatic Weather Station (AWS), Boundary Layer Profiler, Satellite Climatology, Meteorological Models, Soil Mechanics and Seismicity.

TABLE 1

INSTRUMENTS DEVELOPED UNDER FP6 CONTRACT

Item	Quantity	Developed by
GS	2	IAC
SSS	1	LUAN
MASS	4	ESO
DIMM	4	IAC
A. Mounts	4	all

Besides, it was decided to explore the use of potential future instrumentation. This is the case of the Single Star Scidar (SSS), designed as an alternative to G-SCIDAR when no telescope infrastructure is available at the site. The work with SSS within the ELT–DS task will be study its feasibility and to construct a prototype.

The final selection was made according to few criteria such as the underlying physics, their reliability, their ability to issue quantitative measurements and finally the fact that they have been extensively used in many sites. The funding limitation have to be considered and, for example, the automatic weather Station (AWS) that have been extensively used and are known to be reliable and robust will not be purchased within the FP6, but with contribution from the host country. The AWS results will be also analyzed in the final report.

3. INSTRUMENTS AND MODELLING

In what follows we will summarize the status and design of the instruments selected for ELT–DS. The validation of data issued by the use of satellite and model will be discussed. As a summary the instrumentation specifically developed within the FP6-ELT Design Study is provided in Table 1.

3.1. *Differential Image Motion Monitor (DIMM)*

DIMM provides accurate, absolute and reproducible data although systematic control tests on the focus or saturation are however important (see e.g. Tokovinin 2003). The bases of the instrument are given in Sarazin & Roddier (1990) and Vernin & Muñoz-Tuñón (1995).

Since the early nineties, DIMMs have become very popular and copies of the prototypes provided by the French company LHESA Electronique have been used at different observatories. DIMMs are now auxiliary instruments for telescope operation and complement Adaptive Optics (AO) experiments.

For what concerns the site selection, accurate statistics is an important issue. In Muñoz-Tuñón et al. (1997) and Ehgamberdiev et al. (2002) one will find a lot of results, recorded in large databases. For example, in Ehgamberdiev et al., seeing values at La Silla, Paranal, La Palma and Maidanak are analyzed during more than two years. From this analysis, the excellent behavior of the two sites, Paranal and ORM, is clear and reinforces our pre-selection for hosting the future E-ELT.

The relative contribution of turbulence at different scale heights is very important when evaluating the feasibility of AO programmes. Today the multiconjugate adaptive optics, MCAO, is a challenge from the technical point of view.

Intensive campaigns, although expensive and complicated to carry out, are the only way to obtain a comprehensive knowledge of the atmosphere. For this purpose, simultaneous techniques such as balloon soundings ($C_{\rm N}^2$profiles, water vapor, wind velocity and direction; see Azouit & Vernin 2005), SCIDAR, DIMMs and meteorological towers equipped with microthermal sensors have been used in the past. For a general description see Vernin & Muñoz-Tuñón (1992, 1994, and references therein).

Some comparison can be made by using previous results from intensive campaigns. The ORM, La Silla and Mauna Kea have been compared in this way. The free atmosphere at the ORM has a very low contribution ($0\farcs4$), which compares with values measured at La Silla ($0\farcs34$) and Mauna Kea ($0\farcs46$). The contribution from the *surface layer (from 6 to 12 m)* at ORM is $0\farcs08$ is almost negligible (Vernin & Muñoz-Tuñón 1994).

However, the need of a statistical knowledge of the relative contribution the free atmosphere and the boundary layer to the integrated seeing required new or updated techniques. Intensive campaigns cannot provide sufficient data. In order to achieve an accurate statistical database with the relative contribution to the turbulence from the different atmospheric layers in the candidate sites, we propose the use of the G-SCIDAR and/or the MASS/DIMM.

3.2. *G-SCIDAR*

G-SCIDAR technique allows to measure the strength of the optical turbulence (C_N^2) as well as the velocity of the turbulent layers as a function of the height and time. This technique is based on the variance of the scintillation produced by turbulent layers on the light from a binary system. Since the technique was first proposed (Azouit & Vernin 1980; Vernin & Azouit 1983) it has been improved thanks

Fig. 5. Observatorio del Teide (Izaña, Tenerife). Marked the location of the Telescopio Carlos Sanchez (CST), a 1.5m telescope were SCIDAR is installed).

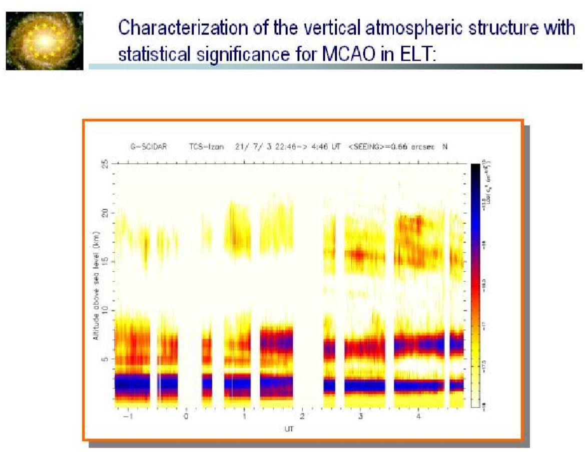

Fig. 6. Example of one night measurements taken with SCIDAR attached to the CST at Izaña.

to many efforts led by Jean Vernin and related teams. For a general description and application of SCIDAR and generalized SCIDAR techniques see the compilation by Avila et al. (2007).

Although several SCIDAR campaigns have already been carried out at several astronomical sites, the available data have not still statistical significance. With the initial aim to get a statistics of the turbulent profiles at Teide Observatory and La Palma, a prototype has been developed in a collaboration between IAC (Fuensalida) & LUAN (Vernin). The instrument has been developed and tested using the IAC 1.5-m, CST at Izaña (see Figure 5) and some results are shown in Figure 6.

In Figure 6, an example of one night measurements of turbulence profiles is also shown. Data are

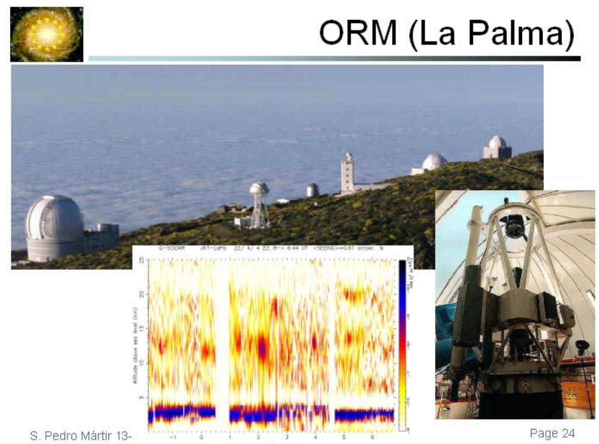

Fig. 7. Example of one night measurements taken with SCIDAR attached to the JKT (1m) at ORM (La Palma).

gathered with the IAC-LUAN SCIDAR attached to the CST (1.5-m) at Izaña. For further details see Fuensalida et al. (2007). The blue ribbon in the bottom of the figure is the signature of the dome and mirror turbulence. As one can see the turbulence in this particular night seems to be concentrated in the boundary layer (below 1 km). Note that the altitude is referred to the sea level and the observatory is located at 2400 m (the location of the most intense blue ribbon). Although they vary along the night, one can note also the persistence of the layers all along the night. Also important is the number of layers, two or three in this case if we ignore the boundary layer and dome seeing contribution. On top of Figure 6, the integrated average seeing value along the whole night is $0''\!.66$. As mentioned above, the vertical distribution of the layers at different heights is crucial for the AO designs and will be obtained—among other things like the isoplanatic angle or the coherence time—on longer temporal data bases at Paranal and La Palma within the FP6 site selection program.

Further tests have been carried out at La Palma making use of the 1m JKT (see Figure 7). Two reasons are behind that: First to see whether a 1-m telescope aperture is enough to get turbulence profiles or not, and having proved so, to be able to get statistics with SCIDAR at La Palma.

A huge effort has been made to improve the instrument, making it easier to use and simpler to process the data. A friendly version of the G-SCIDAR is now finished at the Instituto de Astrofísica de Canarias (IAC) in collaboration with Nice University. The instrument is to be duplicated and delivered

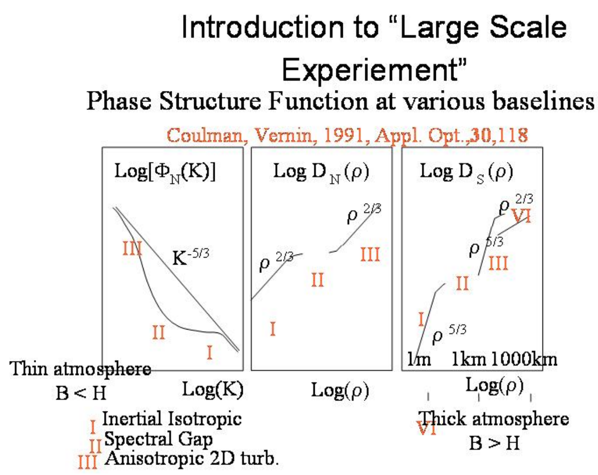

Fig. 8. Behavior of the phase structure function $D_S(\rho)$ with baseline ρ.

soon to Paranal where it will be attached to one of the Auxiliary telescope in July 2007. For details of the instrument and results at OT and ORM see Fuensalida et al. (2007). When installed, systematic observations will be carried out at Paranal.

The present status of G-Scidar instruments developed under FP6 contract is summarized as follows:

- Scidar at ORM already operating at the JKT.
- Scidar for Paranal just finished
- Control design reviewed.
- Feasibility to provide C_N^2in real time (in progress).
- Commissioning at Paranal in July 2007.

The use of SCIDAR requires all the infrastructure associated with already existing observatories. This is not the case for some of the alternative sites, like in Morocco and Argentina. The solution is to use a MASS/DIMM.

3.3. *Multi Aperture Scintillation Sensor*

This instrument detects fast variations of light in 4 concentric apertures using photo-multipliers. The 1-ms photon counts accumulated during 1 min are converted to 4 normal scintillation indices and to 6 differential indices for each pair of apertures. This set of 10 numbers is fitted by a model of 6 thin turbulent layers at pre-defined altitudes of 0.5, 1, 2, 4, 8, and 16 km above the site (see Tokovinin 2003). Another model of 3 layers at "floating" altitudes is fitted as well. Turbulence integrals J_i in these 6 (or 3) layers represent the optical turbulence profiles (**OTP**) measured by MASS. Turbulence near the ground does not produce any scintillation: MASS is "blind" to it and can only measure the seeing in the free atmosphere. MASS has been cross–compared with the G-Scidar during a campaign performed at Mauna Kea (see Tokovinin et al. 2005).

4. LARGE SCALE ATMOSPHERIC PROPERTIES

Our knowledge of the outer scale is still very poor and when one imagines to construct telescopes larger than say 40 m, it becomes important to know the statistical spatial coherence of the turbulence at such large baseline. The problem therefore is to define relative importance of possible wavefront distortion at 50/100 m scale, when the diameter of the telescope might be larger that the outer scale ($D \geq L_0$).

The task is to identify the relevant theory and experiments which give the trend of wavefront perturbations at spatial scales of the order of the telescope diameter.

The starting point was to check for the saturation of the phase structure function at large baselines. It is known that this function behaves like a Kolmogorov trend, $D_S(\rho) \propto \rho^{5/3}$ at small baseline $B < L_o$, where L_o is the outer scale of the optical turbulence. But, when $B \gg L_o$, the phase structure function begins to saturate, as shown in Figure 8 (see Coulman & Vernin 1991). But, from the same authors, it is possible that for a very large baseline the phase structure function might increase again. This point is very important for the AO applicability of ELTs.

After discussions and meetings it was decided to coordinate two "multiple instruments" intensive campaigns at the top sites considered, ORM at La Palma and Paranal, taking benefit of existing telescopes, interferometers and dedicated instruments, and using two large field wavefront sensors (due to a budget cut it was not possible to construct four devices).

In order to achieve this task, it was decided to construct a Wide Field Wave Front Sensor proposed by R. Ragazzoni (INAF, Italy) who is co-responsible of this WP. To be short, the idea is to sense wavefront distortion within a wide field of view, using a set of Shack-Hartman devices, each one working on various stars in the field of view. In Figure 9 one can see that with a single star, only an 8 m portion of the wavefront is attainable. But, if one combines a large field of view with a slant beam and at 10 km altitude, as shown in Figure 10, the full reconstruction of the wavefront is possible over a ∼100 m baseline.

Besides, we count with the participation of Adolfo Comeron group, from the Universidad

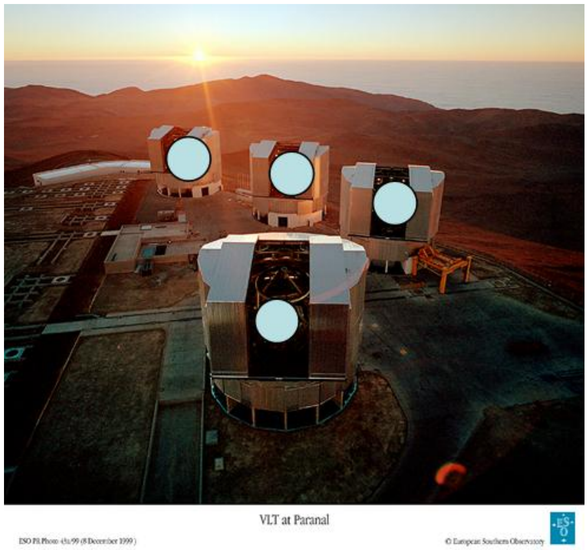

Fig. 9. Seen from a single star, one can probe four 8 m wavefronts.

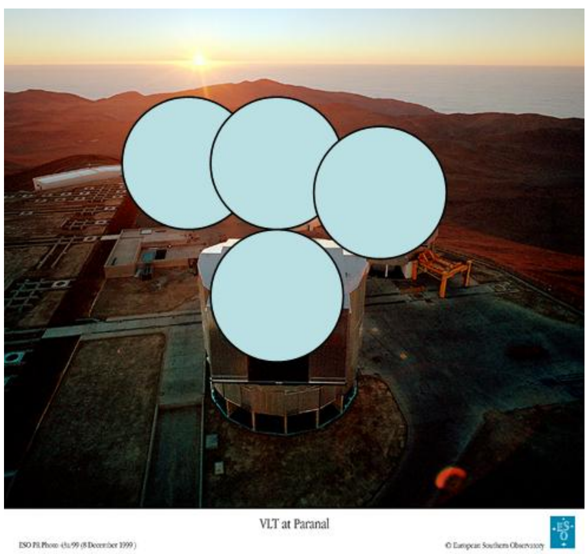

Fig. 10. Seen from many stars within an 8 arcmin field of view, at 45 degrees from zenith and for a layer moving at 10 km altitude, one can notice that each pupil is larger and they begin to overlap, allowing a full reconstruction of the wavefront over ~100 m.

Politécnica de Barcelona, which will be in charge of the boundary layer studies by using a portable LIDAR to be used in intensive campaigns, both at ORM and Paranal (see Figure 11).

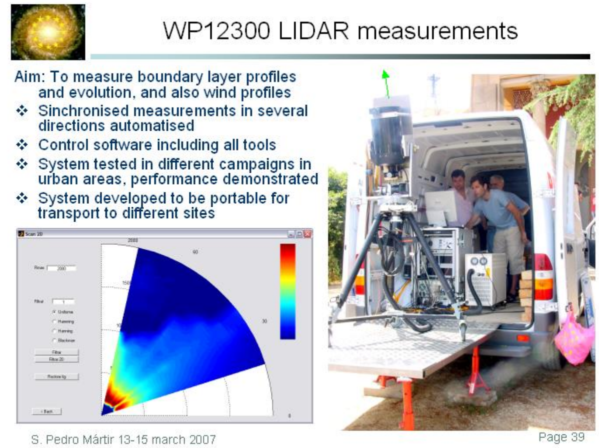

Fig. 11. LIDAR experiment of Universidad Politécnica de Cataluña, Barcelona.

5. SUMMARY

Within the "FP6-ELT Design Study" contract, the site selection is being carried out within a specific Working Group. The Site Selection WG has defined a strategy based on an intensive characterization of two reference observatories, Paranal (Chile) and ORM (La Palma- Spain). The first one was selected after various campaigns carried out in the nineties and now it hosts the ESO VLT. The second one, ORM, is a site under investigation since a long time ago and provides very good values in all parameters recognized as important for astronomical observations. Besides, alternative sites are explored: La Chira (Chile), Macon (Argentina) and Aklim (Morrocan Anti–Atlas). The alternative candidates will be compared with the two reference ones using the same criteria.

We are aware that other teams are carring out similar studies. In particular, the Thirty Meter Telescope (TMT) project is leading a similar strategy with almost the same instrumentation and tools and centered on candidate sites situated in the American Continent. For this reason and in order to concentrate our resources, excellent sites like Hawaii are not included in our work. Cerro Tololo as well as San Pedro Mártir are potential very good alternatives but are not included in the ELT–DS framework, since they are studied by the TMT team.

Two generalized SCIDAR have been designed at developed at the IAC workshops. One is already attached to the 1m JKT telescope at La Palma and the other is planned to be installed at one of the VLT auxiliary telescopes at Paranal. Four MASS-DIMMs have been developed, tested and used (see a MASS-DIMM installed at La Chira, Chile in Figure 12). New techniques have been explored (e.g. SSS) and the use of global climatic models and satelites data

TABLE 2

INSTRUMENTS CONSIDERED FOR DATA ANALYSIS WITHIN THE FP6 "ELT DS" SITE SELECTION PROJECT

Instrument/tool	ORM (La Palma)	N-Paranal (Chile)	Izaña (Tenerife)	Akrim (Atlas)	Macon (Argentina)	Dome-C (Antarctica)
GS	Y	Y	Y	N	N	N
SSS	-	-	-	-	-	-
MASS/DIMM	Y	Y	Y	Y	Y	N
R-mount[a]	Y	N	N	N	N	N
A-mount[a]	N	Y	Y	Y	Y	N
ASC	Y	Y	Y	Y	Y	N
Sat. for aerosols	Y	N	Y	Y	Y	N
AWS	Y	Y	Y	Y	Y	N
BL profilers	Y	Y	N	N	N	N
Climatology (satelites)	Y	Y	Y	Y	Y	Y
Meteo Models	Y	Y	Y	Y	Y	Y
Soil Mechanics	N	Y	N	Y	Y	Y
Seismicity	N	Y	N	Y	Y	Y

[a]Mounts could be robotic (R) or automatic (A).

Fig. 12. La Chira – 40 km north to Paranal (Chile).

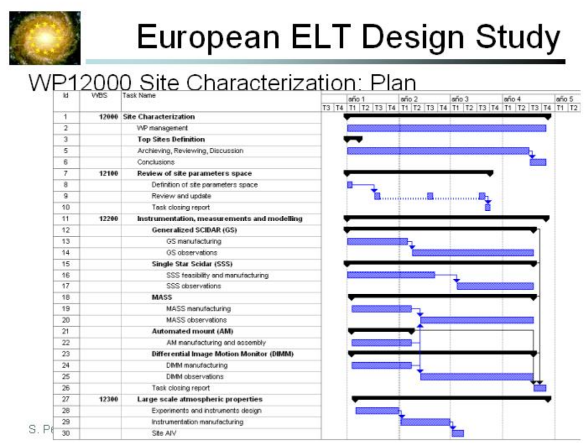

Fig. 13. WP Site Characterization schedule plan of the four tasks.

are discussed (see Muñoz-Tuñón et al. 2007; Varela et al. 2007). A large effort is devoted on validating all these techniques, and crosscompare them, and aiming, at the end, to be able to supply a battery of reliable instruments and tools for future use (see Table 2).

It is worth to mention that the statistics of the data is very important and clearly, the testing time at sites not explored before is for sure not going to be long enough. Long term databases with well calibrated and known techniques are required for a proper site selection to be done.

The temporal plan, elaborated by our project manager, Marcos Reyes, is presented in Figure 13. By the end of 2008 a report with all the deliverables of the project will be produced and we plan also to organize a scientific meeting for making public our experiences, achievements, problems, results, instruments, and techniques. We warmly invite the organizers of this nice (SPM) conference, Juan Echevarría, Irene Cruz-González, Erika Sohn and other colleagues to join us. We hope to be able to be as kind to them as they have been to all of us. Thanks.

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