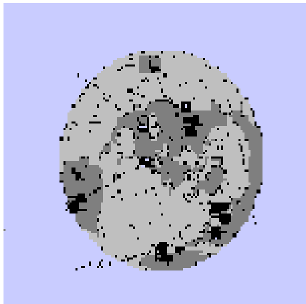
ESO SEARCH FOR POTENTIAL ASTRONOMICAL SITES (ESPAS)

Minutes of the Working Group Spring Meeting



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Edited by Marc Sarazin

ESPAS SPRING MEETING, March 18, 1996, ESO

Participants

-Pierre Bely (Space Telescope Science Institute, Baltimore, USA)
-Jean-Luc Beuzit (deputy of Michel Mayor Observatoire de Genève, Sauverny, Switzerland)
-Shuhrat Ehgamberdiev (Astr. Institute of Uzbekistan, Tashkent, Uzbekistan)
-Teresa Lago (Centro de Astrofisica, Universidade do Porto, Portugal)
-Gerard Lelievre (Institut National des Sciences de l'Univers, Paris, France)
-Ian Lub (Sterrewacht Leiden, Leiden, Holland)
-Casiana Muñoz-Tuñon (Instituto de Astrofisica de Canarias, Teneriffe, Spain)
-Paul Murdin(Particle Physics and Astronomy Research Council, Swindon, United Kingdom)
-Th. Neckel (deputy of H. Elsässer, Max-Planck Institute für Astronomie, Heidelberg, Germany)
-Sergio Ortolani (Osservatorio Astronomico di Padova, Padova, Italy)
-Holger Pedersen (Copenhagen University Observatory, Copenhagen, Denmark)
-Jean-Pierre Swings (Universite de Liege, Institut d'Astrophysique, Belgium)
-Jean Vernin (Département d'Astrophysique, Universite de Nice, France)
-ESO (partially): A. Renzini, B. Leibungut, M. Sarazin (Program Scientist Office) and J. Cuby (Instrumentation Division).
-Members excused: A. Ardeberg (Lund Obs., Sweden), D. Hall (U. of Hawaii, Honolulu, USA), J. Storey (U. of New South Wales, Sydney, Australia), P. Wood (Siding Springs Obs., Australia)

AGENDA

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-Session 2: Proposal for new sites
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-Session 4: Modalities of site intercomparison
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ESO Organizing Committee: M. Sarazin, A. Renzini, with the help of Anna Dell'Erba.
ESPAS WEB page at ftp://dimm2.hq.eso.org/public_html/espas.html

Presentation of the terms of reference

•**Jean-Pierre Swings** (Vice-president of the ESO Council, and former chairman of ESO's VLT Site Selection Working Group):
JPS explained to ESPAS how the idea of a new ESO Working Group on sites began : it was at the time of "difficulties" between ESO and the Republic of Chile concerning the erection of the VLT on Paranal. The construction of the VLT on an alternative site was considered by ESO, and by Council, and in order to put some substance to that idea (or threat ?) one had to know what (excellent) sites really did or do exist, besides Gamsberg where measurements had begun by ESO. Council, in 1994, and in 1995, requested that a small WG be set up to look into this matter, and make a comparative inventory of good astronomical sites around the world. JPS reminds ESPAS members that some (fairly vague !) terms of reference were also included in the correspondence they received from A. Renzini and M. Sarazin prior to this first meeting.

•**Alvio Renzini** (VLT Program Scientist):
Although the negative contingent situation that determined the ESO Council to explore a wider set of options for ESO astronomical sites may have completely disappeared by now, yet other, more positive reasons have suggested to take advantage of the recommendation of establishing a dedicated Working Group on astronomical sites. For several reasons ESO is indeed interested in acquiring homogeneous data for the best sites worldwide. These include a better understanding of existing ESO sites themselves, the predictability of observational conditions, and especially the exploration of new sites where ESO could develop astronomical activities, either alone or in collaboration with other partners. For example, there is the possibility that ESO may participate in the Spanish 10m telescope project on La Palma, and therefore ESO needs to know as much as possible about all the site parameters to figure out what complement of focal instruments may take the best advantage of the local conditions. Moreover, as the completion of the VLT project is approaching, it is physiologic to an institution like ESO to start thinking about a next long term project, might it be an even larger optical/IR telescope, a Sub-mm Array, a telescope on Antartica, or whatever. The assignment of the Working Group is correspondingly very broad: to acquire all available information about outstanding astronomical sites, and establish standard procedures that will help to compare different sites in a meaningful way.

Session 1: *Updates on recent and on-going site surveys*

•**La Palma (C. Muñoz-Tuñon)**
First I would like to mention very briefly what is the general organization at the "Observatorio del Roque de los Muchachos" (ORM). The ORM in Palma and the Observatorio del Teide (OT) in Tenerife, both in the Canary Islands belong to the Instituto the Astrofisica de Canarias (IAC). At the Observatories there are several User Institutions which run their own facilities (Telescopes). At the ORM the Anglo-Dutch group operates the 1m (JKT), 2.5m (INT) and 4.2m (WHT) telescopes; the Nordic countries operate the Swedish Solar Tower, the Carlsberg Automatic Meridian Circle and the 2.6m NOT; The Italian group has recently joined the International Community with the TNG scheduled to be operating by the end of 1996. There is also a project, led by Spain, for a large telescope (10m) to be built in a near future at the ORM.

Further information in this sense can be found in VISTAS IN ASTRONOMY, 1985, (vol.28), dedicated to The Observatories of the Canary Islands. Since last century there have been many studies of the quality for Astronomical Observations, both daytime and nighttime, at the OT and at the ORM. A very comprehensive review from the earliest up to 1985, is presented by Paul Murdin in the aforementioned issue.

Special attention has been paid recently to the ORM. The IAC, in collaboration with Nice University, has carried out intensive site testing Campaigns (see the results published by JV & CMT in Astron. Astrophys, 257 (1992); 284 (1994)). These campaigns followed the general philosophy established by ESO in their pioneering work in the LASSCA campaigns.

With the idea of monitoring the seeing, as a key parameter to define the optical quality, we (i.e. Nice University and the IAC) developed a DIMM (see JV & CMT, PASP, 107 (1995) for details), based on the principle proposed by Sarazin & Roddier (Astron. Astrophys., 227 (1990)). Because the instrument was cross-calibrated with ESO DIMMs in Chile it will therefore be possible to make comparisons in the future.

The IAC carried out a seeing campaign at a place near the TNG site. Measurements were taken with the DIMM working on a 5m tower, designed by D. Mancini of the TNG group, so as to avoid the surface layer. We measured 3/4 nights every week from the middle of October, 1994 until August, 1995. No measurements were obtained in December due to technical problems. The main results are given in the table below. There seems to be a

ORM Seeing	Min	Median	Mean
Best Month	0.20	0.46	0.49
All data	0.17	0.64	0.76

seasonal dependence, with better values during the summer period.

From our DIMM measurements we estimate that 72% of the total possible hours of observation were used. The rest were lost for the following reasons: 11% due to clouds, 6% because of wind higher than 15 m/s (which is the limit of the instrument) and 8% due to humidity (wrapping up of the optical surfaces).

From October 1995 the IAC group (presently composed by two observers, A.M. Varela, T. Mahoney and myself) is developing a site testing program to select the place for the future large 10 m telescope. We are taking data simultaneously in two places at the ORM. At each one we have installed a DIMM (at 5 m above the ground) and a 12 m full equipped meteorological mast. Therefore in the near future there will be a large and updated data base both on optical quality and meteorology at the ORM.

The future research we are presently developing is mostly concentrated on the study of the temporal spectra of seeing as well as its dependence with other meteorological parameters (e.g. wind direction).

At the ORM there are also other programs either being carried out or to be developed by different groups, which will certainly be of extreme utility to ESPAS. Among others and as a summary:
- Galileo site survey - forecasting seeing program (S. Ortolani et al.)
- Half arc sec. program (Anglo-Dutch Group)
- Adaptive optics program (NOT)
- Water vapour measurements/IR quality (IAC).

•The Gamsberg in Namibia (Th. Neckel)

The Max Planck Institute for Astronomy in Heidelberg was founded in order to build and operate an observatory in the northern as well as one in the southern hemisphere. In this way the german astronomers would have obtained access to big and modern telescopes in both hemispheres.

As a possible site for the planned southern observatory Namibia was taken into consideration. The cloudiness above the whole southern Africa has a minimum above southern

Namibia. First, the Great Karras mountains (-29 S, 19E) were inspected. On their highest, very steep peak (2002 m above see level) there is space for at most one or two small buildings but not for a big observatory. A further argument against the Karras mountains is the high frequency of sandstorms in that region.

After the first visit to the Gamsberg (2347 m above see level, -23 S, 16 E) this table mountain appeared to us as a possible site. Seeing measurements (first photographically using a Questar) and meteorological registrations were performed on top of the Gamsberg since September 1970. In 1971 a temporary access road was build. After that a photoelectric seeing monitor and a photometric 50 cm telescope were installed. Since 1972 many photometric measurements were performed with the 50 cm telescope.

The main points of our experience with the astronomical conditions on the Gamsberg in the last 25 years are:

1- Strong annual variation of cloudiness. The best time is winter (May to October), in the raining season (February and March) it may be very often cloudy. The total number of photometric nights is about 200.

2- Seeing was measured with identical instruments on Gamsberg, La Silla and Calar Alto. As a result, it became evident, that the seeing on the three sites is very similar.

3- The humidity in the dry season is similar to the low values found on La Silla.

4- In about 65% of clear night time the wind blows from the west ± 90 degree.

5- Atmospheric extinction was measured with the UBV photometer attached to the 50 cm telescope. The extinction coefficients in the visual are mostly in the range 0.10 to 0.14 mag, values above 0.14 are extremely rare.

6- The temperature variations during clear nights are small. The mean difference between maximum and minimum temperature is less than 3 C.

-The findings of the ESO survey (M. Sarazin):

In Spring 1994, Gamsberg was proposed to ESO as a possible fallback position in case problems in Chile could not be solved in a satisfactory manner. The instrumentation used during the VLT survey in Chile was shipped to Namibia and measurements of seeing, precipitable water vapour and meteorology started on a regular basis in July 1994, under the responsibility of MPIA. The campaign ended one year later with an exceptional time coverage: only one (Dec 24) of all clear nights was missing in the seeing statistics!

The ESO campaign came to values very close to the MPIA results with 54% photometric nights (59%, the best year and 46% the worst between 1970 and 1975). As for seeing and water vapour, the results are summarized in the Table below. While seeing statistics indicate

Gamsberg	Min	Median	Mean
Seeing (arcsec) best month (2.5 m)	0.27	0.84	0.94
Seeing All data (2.5 m)	0.27	0.94	1.08
Seeing all data (corrected for 5 m)		0.90	1.05
Prec. Water Vapour best month (mm H2O)	0.7		2.5
Prec. Water Vapour all data	0.7	5.0	5.2

a lower 50 percentile comparable to the conditions at La Silla, the upper half was fairly worse (up to 5”). With regards to cloudiness, Gamsberg again compares to La Silla and a synoptic analysis shows that there are possibly even better sites in the South of Namibia (at latitude -25 S to -26 S there is less incursion of oceanic air during summer because of a lower sea surface temperature) but with lower summits. Gamsberg remains one of the best sites known in the southern hemisphere outside Chile.

•Antartica (J. Vernin)
Since 1980, South Pole base was known to be a very good site for Heliosismology (G.Grec, E.Fossat and M.Pomerantz, 1980, Nature, vol 228, 541-544) and for millimetric astronomy (Puget, 1984). Later the Center for Astrophysical Research in Antarctica (CARA, univ. of Chicago-Yerkes) promoted the installation of many types of telescopes in various wavelengths listed in the table below. At this time, among all the scientific projects developed at South

Project	Range	Diameter (m)
ASTRO	Sub-mm	1.7
SPIREX	IR	0.6
AMANDA	Neutrino	km
COBRA	mm-CBA	2

Pole 50 % are devoted to Astronomy. Why ?
-High Altitude: most of the antarctic continent is at high elevation h >3000 m the highest point being at Dome A (4200 m).
-Very low precipitation: of the order of few cm.
-Extremely cold: from -30 C in summer (day) to -90 C in winter (night)
-Very dry: water vapor content from 0.1 mm to 1 mm.
-Continuous observations: it is possible to observe the same object without interruption during many days (summer) or nights (winter).
This set of known properties allow the opening of many windows from the near IR to sub-mm, which are very attractive in cosmology.

But nothing was known about seeing, to achieve high angular resolution imaging. We, at Département d'Astrophysique de Nice, CARA and JACARA (Joint Australian CARA) have been involved in seeing site testing at South Pole during the last two winters. From the processing of about 20 balloons, launched during the polar night, most of the image degradation come from the first hectometer, which is dominated by the katabatic winds. The rest of the atmosphere is responsible of a mean 0.4 arcsec seeing.

There is a French-Italian project to install a permanent base at Dome C, 3300 m, not only for astronomical purposes but also glaciology. In collaboration with Roma Univ. we began a site testing in December 95. Being on top of a high plateau, we expect to avoid katabatic disturbances and thus to reach seeing as good as 0.4" at ground level.

•Others (Australia, South Africa, China, India, ...)
INSU is supporting some surveys in northern Africa, Lybia, Egypt, Borneo (G. Lelievre will send report). Mexico is rather active (mm project), contacts to be established (JPS). China (Yunnan Observatory) developing a DIMM for a site survey in the frame of a joint project with other Asian countries (MSA follows-up). Indian astronomers involved in a national site survey (HPE follows-up).

Session 2: *Proposal for new sites*

•Madeira, the site for a new observatory in northern Europe (T. Lago)
Encumeada Alta (Madeira) is known to be one of the best existing dark-sky optical observing sites (Walker, 1984) in the northern hemisphere. At latitude 32 46' and longitude 16 56' , it is located within one of the regions of stable tropical maritime air in the northern hemisphere, the same as Canary Islands, were there is often a well developed inversion layer with the basis at approximately 1000 m above sea level and the top about 400 m above the base of the inversion (Walker, 1984). It is one of the sites tested in the 70's for the "Northern Observatory

site testing project" and McInnes (1981) provides month-by-month percentages of hours with seeing 1" while Walker (1984) compares with various other sites around the world. At an altitude 1784 m, Encumeada Alta presents to the north a smooth and convex surface open to the prevailing wind from the ocean, in the north-west direction and due to its location it is expected to be much less affected by the Sahara dust than the Canary Islands. There is no record of seismic activity in Madeira. Encumeada Alta is located within a protected area (natural park) free from industrial or light pollution. There is no large city or sizable commercial or tourist development on the northern coast - up to now the main development is on the southern coast of Madeira and Encumeada Alta is protected by the high ridges to the south of the site. There is very good connection between Madeira and the main European cities by regular commercial flights. A feasibility study for the development of an astronomical observatory in Madeira - a national facility open to international collaboration - was undertaken in the beginning of 1994 at request of the Portuguese government. The report was approved and successfully used for funding application both to European funds for regional development and national funds in 1995. The following step, a detailed proposal (including the set-up of the observatory and associated facilities on the site as well as the creation of a research support Institute in Funchal) was submitted still in 1995, also at the government request, at the same time as the administrative and legal organization of the future governing body were looked into. While still waiting approval by the new Minister of Science & Technology, the project is open to proposals for partnership and/or installation of telescopes at this prospective new observatory.

References:

"High Quality Astronomical Sites Around the World", M.F.Walker, 1984, "Site Testing for Future Large Telescopes" ESO Conference and Workshop Proceedings n 18, 3.

"Site Testing on Hawaii, Madeira and the Canary Islands", B. McInnes, 1981, Q. Jl. R. astr. Soc., 22, 266.

•Maidanak Observatory (S. Eghambardiev)

Mount Maidanak is located at a distance of 40 km south of the town of Kitab where the International Latitude Station is situated. It is an isolated summit belonging to the Pamir and Alai mountain system. Both in relief and vegetation the landscape of Maidanak is typical for high-mountain dry subtropics, bushes being prevailing. The relief is mainly smoothed and rock outcrops do not prevent from building. The road built together with the observatory just leads to Maidanak. The total distance between Kitab and Maidanak is 150 km long.

-Historical background: Mount Maidanak was selected as a result of ten-years site servings made by the Ulugh Beg Astronomical Institute of the Uzbek Academy of Sciences and Sternberg Astronomical Institute. By the early 90-ies many astronomical institutions of the former Soviet Union built their observatories there. About ten telescopes with apertures from 0.5 to 1 m were installed (see Table below). According to the Bishkek Agreement between independent states of the FSU dated on 1992 Uzbekistan took under its jurisdiction all these observatories and then assigned them to the Ulugh Beg Astronomical Institute of the Uzbek Academy of Science. Today we are working at Maidanak under the agreement between Uzbekistan and Russian, Ukrainean and Lithuanian astronomical institutions. The inter-government agreement to create the International Maidanak Observatory is now in progress.

-Infrastructure: an hotel and additional living rooms at the telescopes, a mechanical workshop, telephone and e-mail service at Maidanak are available. The urban observatory's base is located in Kitab where we have a hotel, e-mail, FAX and telephone communications, as well as a transport service to convey both observers and heavy equipment to Maidanak.

Type	Diameter (m)	Foci (m)	Instrumentation	Date
AZT-22	1.5	11.6	2 CCD cameras	1992
ZEISS	1.0	13.8	UBVR Photometer (Vilnuis)	1982
ZEISS	0.6	6.4	UBVR Photometer	1979
ZEISS	0.6	6.4	Planet scanner, Polarimeter	1976
ZEISS	0.6	6.4	UBVR Photometer, Spectro UAGS	1980
ZEISS	0.6	6.4	UBVR Photometer	1986
ASTRO REFRACTOR	0.23	2.3	photocamera 24x24 cm	1955

-Weather: in summer the average nightly temperature is +12 C. In winter it falls to -15 C. The temperature night-time amplitude is about 5 C. Winds are faint, their velocity not exceeding 2-3 m/s.

-Astroclimate: clear night time annual amount estimated by some authors varies from 1900 to 2000 hours. The month distribution shows the August - September period to be the most favorable, the clear night-time amount approaching 100 % of the possible one. A local peak in February is noted very often. It is important to note that there are no light pollution sources in Maidanak environs. Maidanak seeing conditions were persistently studied. However, the different author's estimates differ widely. According to Sheglov's group the seeing is better than 0.8" in 50% cases.

Some results: the observational programs carried out on Mt. Maidanak have resulted in the following data:
-ROTOR program. About 65000 UBVR observation were made of non-stationary stars on the early stage of the stellar evolution (Ae/Be Herbig and T Tau stars, fuors and relative stars) (Ulugh Beg Institute).
-40000 UBVR observations of 150 Cepheids were made (Sternberg Institute).
-Light curves with dense sampling for 50 close binary systems were obtained (Ulugh Beg Institute).
-Ground observations of X-ray sources simultaneous with space ones were made, as well (Ulugh Beg Institute and IKI).
Today the continuous monitoring of unique astronomical objects is very actual. For this kind of problems the longitude of Maidanak is of great importance. The western and eastern sites with comparable clear night-time are located in five-six hours of the longitude. Solar physics specialists have already realized these advantages, IRIS and TON projects for Solar oscillation measurements are good examples of that.

•The Greenland Ice cap (H. Pedersen)

In recent years it has become evident that the Antarctic continent offers remarkably good conditions for astronomical research. It seems justified to ask whether or not similar conditions exist anywhere in the northern hemisphere. We can only surmise that the Greenland ice cap presents those conditions, which most approach the Antarctic.

Over most of the ice cap, topographic conditions should bode for a laminar air-flow, one of the prerequisites for fine seeing. At Summit (72.6 N, 37.5 W) the ice reaches 3220 meters over the sea and winter temperatures drop below -60 C, favoring IR and microwave astronomy. Here, and at several locations within around 100 km weather monitoring has been done for several years, supported by ice core drilling projects. The registrations include basic data such as temperature, wind speed, wind direction, barometric pressure and humidity. We have studied data provided by Department of Geophysics (Copenhagen University) and American data (which can be retrieved by anonymous ftp from uwaaws.ssec.wisc.edu). Cloudiness was registered during the years 1963-70 at DYE 2 and 3, two radar installations in southern

Greenland (this data, which is of meager quality, was supplied by the Danish Meteorological Institute). During the winter months, 45 to 55 % of the time was registered as clear. Further north cloudiness is expected to be less.

During the coming two summers, a new drilling site will be established approximately 300 km north of Summit. Numerous C130 Hercules flights will establish the camp. This opportunity may be used to gather further meteorological data, launch microthermal balloons, or to install a seeing monitor for operation during the winter season. This northern site is well removed from the auroral circle.

•Stratospheric Observatories- the POST Project (Summarized from P. Bely)
The tropopause, typically at 16 to 18 km altitude at the lower latitudes, dips down to only 8 km in the polar regions, allowing access to the cold, dry and nonturbulent lower stratosphere by tethered aerostats. These can float as high as 12 km, have long operating lifetimes, and are extremely reliable. In contrast to free-flying balloons, they can stay on station for weeks at a time, and payloads can be safely recovered for maintenance and adjustment and relaunched in a matter of hours. We propose to use such a platform, located first near Fairbanks, Alaska, and later in the Antarctic, to operate a new-technology 6 m diluted aperture telescope with diffraction-limited performance in the near infrared. Thanks to the low ambient temperature (about 200 K), thermal emission from the optics is of the same order as that of the zodiacal light in the 2-3 micron band. Since this wavelength interval is the darkest part of the zodiacal light spectrum from optical wavelengths to 100 micron, the combination of high-resolution images and a very dark sky make it the spectral region of choice for observing galaxies, QSOs and clusters of galaxies at the formation epoch of galaxies.

-Atmospheric transparency and radiance: at 12 km altitude, the pressure is about 17% of the atmospheric pressure at sea level, and the column amount of precipitable water vapour above it is only a few microns. The remaining opacity from 2 to 10 micron (outside the 2.7 and 4.7 micron H2O lines) gives a transmission better than 90%. Similarly, the sky radiance in this wavelength range is one order of magnitude lower than at excellent ground based observatories.

-Winds at altitude: the mean wind speed at 12km altitude is 17 m/s for Fairbanks and 7 m/s for the South Pole. Because of the lower atmospheric density at this altitude, these velocities are equivalent to 7 m/s and 2.9 m/s at sea level respectively.

-Seeing: Models show that the Fried parameter r0 is expected to be as large as 2 m (0.05 arcsec) on average in the visible at 12 km altitude, and can reach 8 meter 5% of the time.

Session 3: *New Parameters to be surveyed*

•OH atmospheric content (summarized from J. Cuby)
OH is the main dark sky emission between 0.85 and 2.2μm and concerns several instruments of the VLT (ISAAC, CONICA, NIRMOS) for which it is the principal source of noise. OH suppressors have been proposed but still have to prove their real performances.

This parameter should be included in site surveys as this spectral range is growing in importance. The time scale of the variations of OH is one of the most important parameters, as it determines the optimum exposure time in spectroscopy. Also the relative fluctuations inside OH bands, which can reach a factor of 3, should be better understood. As a whole, extrinsic variations (nightly, seasonal, geographic, solar activity) might not contribute more than a factor 2 to 3 (the noise is the square root of that).

The current proposal is to improve our knowledge of existing data and research work, in particular outside the astronomical community.

•Measurements of outer scale length at the NOT (M.Andersen reported by H.Pedersen)
The outer scale length of turbulence defines an upper cut off in the size of turbulent structures. It is difficult to measure the outer scale length, since it requires simultaneous wavefront sensing and measurements of the wind speed up through the atmosphere. The fact, that most telescopes have very strong local turbulence (dome seeing), which may have a behavior that is completely dislike that of the free atmosphere, further complicates the situation. As a consequence, highly discordant values have been published.

We have used the 2.56 m Nordic Optical Telescope (NOT) on La Palma to obtain indirect estimates of the outer scale length. The NOT is particular well suited for this, because the local turbulence is at a very low level. Assuming Kolmogorov turbulence with infinite outer scale length, the statistical weight of Zernike aberration terms can be derived. We have measured the image motion, and find it to be only 40-50% of that predicted. Our interpretation of this is that the outer scale length is finite.

Voitsekhovich and Cuevas (JOSA, November 1995) give the statistical weight of low order aberration terms as function of (L0/D), D being the diameter of the aperture. Using this result, we find an outer scale length in the range 5-8m, measured on several nights. The implication is, that the seeing, understood as the image quality obtainable by a perfect telescope, is not only dependent on r0, but also the telescope diameter. A 10 m telescope on La Palma will essentially be tip/tilt corrected by the aperture itself.

We plan to improve the measurement of LO, by comparing the RMS amplitude of 1.st and 2.nd aberration terms.

•Temporal parameters of the turbulence (summarized from: adapt. optics-J.L. Beuzit, site measurements-J.Vernin)
Some sites could become very interesting if they provide slow moving turbulence (smaller bandpass needed for adaptive optics systems). On existing observatories, adaptive optics systems are designed for good and average conditions, and endure a strong decrease of efficiency in case of fast moving turbulence. Considering the variations of the parameters

Flight (UT)	L0 (m)	R0 (cm)	ThAO (")	ThSI (")	TauAO (ms)	TauSI (ms)	Vmax (m/s)	V0 (m/s)	H2O (mm)
09/3/92 3h30	1.55	26.5	3.0	4.1					1.9
10/3/92 3h30	1.18	29.3	3.8	4.8					2.9
11/3/92 4h45	4.10	12.1	4.1	4.3	10.9	14.8	28	3.9	2.9
12/3/92 1h30	2.38	17.2	3.5	3.8	14.5	20.5	18	4.2	2.5
14/3/92 3h30	6.76	6.7	0.4	0.8	1.2	2.2	42	18.0	4.3
15/3/92 1h00	2.09	18.5	2.0	2.9	5.2	7.4	48	11.1	5.5
15/3/92 5h00	1.70	21.7	1.7	3.2	3.4	6.2	55	19.7	4.3
16/3/92 4h10	2.11	13.7	2.5	2.7	7.9	13.3	25	6.6	3.7
24/3/92 8h12	2.40	12.1	1.6	2.1	3.9	4.9	43	10.0	3.4
25/3/92 2h43	2.51	18.1	2.0	2.6	3.3	5.8	45	22.1	1.6
25/3/92 7h11	1.30	15.9	2.2	2.5	3.5	6.3	58	16.8	3.4
29/3/92 4h10	1.48	16.1	2.8	3.2	4.9	17.7	20	11.1	4.9
29/3/92 9h15	1.92	10.9	1.7	1.9	3.3	11.6	18	9.8	5.0

Meaning of parameters:
L0: outer scale of turbulence (using Coulman Vernin Model)
R0: Fried Parameter
ThAO: Isoplanatic angle for Adaptive Optics
ThSI: Isoplanatic angle for Interferometry
TauAO: Coherence time for Adaptive Optics
TauSI: Coherence Time for Interferometry
Vmax: Maximum wind velocity (in the troposphere)
V0: Average wavefront Velocity (frozen Atmosphere)
H2O: precipitable water vapour content

involved (see the balloon sounding results at Paranal by J. Vernin), local monitoring and/or modeling is necessary to provide inputs for flexible observing mode.

Session 4: *Modalities of site intercomparison*

•The Galileo Italian National Telescope site survey (S. Ortolani)
Galileo Italian National telescope (TNG) project officially started in March 1988 when the Italian National Council for Astronomy (CRA) approved the project. At the same time we began a site survey to identify an optimum site for the 3.5 m telescope which was intended to get top performances in direct imaging as well as in visual and near infrared spectroscopy. It was clear since the beginning, after a check of a number of documents collected in the last 30 years of investigations, that the sites located in Italy could not offer the same astronomical performances of the subtropical regions. The number of usable nights, for example, are typically around 200 per year in most of the Italian observatories, against more than 250 in most of the best subtropical sites. It is also very difficult to find in Italy places with a sky background at the level of the natural brightness. Considering the request to have the telescope in the northern hemisphere, we concentrated our research on three sites already developed, or under development for astronomical use, as indicated in the following table:

Site (country)	geogr. latitude	height (m)
Mauna Kea (USA)	+20	4200
Mt. Graham (USA)	+33	3300
La Palma (Spain)	+29	2400

The first step was to define a number of fundamental properties to assess the quality of the sites:
1) seeing;
2) number of nights/hours of clear sky;
3) sky brightness and atmospheric extinction;
4) meteorological conditions (humidity, extinction, wind);
5) logistics.

The seeing was obviously considered the most important parameter for the first ranking of the sites. In spite of the extended records of seeing measurements at the telescopes, it is clear that these data are only very rough upper limits, since they give informations more on the telescope optical aberrations and thermal conditions than on the site seeing. Experience from La Silla shows that the seeing measured at the 3.6, 2.2 and Danish 1.5 telescopes is systematically higher by roughly 0.5"- 1.0" than the external seeing and, furthermore, that there is no correlation between the seasonal trends of the two sets of values. Thousands of seeing values have also been measured, in the 3 sites, from the Polaris trails recorded on photographic plates through Walker telescopes, or, in the best case as at Mt. Graham, on electronic cameras. All these measurements, however, suffer the same problems, i. e. very low height from the ground (from 1 to three meters), very low altitude and fixed position of the target, and limited dynamic range of the recorded motion frequencies. Only very recently systematic measurements based on two aperture devices, equipped with fast reading devices, are producing reliable data on some sites.

From a very generic point of view the site in Mauna Kea is potentially in the best position, due to its considerable height above sea level (Barletti et al., Astron. Astrophys., 54, 649, 1977) combined with the maritime location. The area is, however quite crowded of telescopes and it was not easy to define a relatively undisturbed position for TNG.

Another important parameter is the fraction of the usable (clear) time for astronomical observations, in particular with photometric conditions. The position of the considered sites, however, in the subtropical belt, close to the eastern part of the oceans, locate them in the best areas of the world. They are, in fact, not only in the descending branch of the equatorial Hadley cell, but also close to the region cooled by the northern cold oceanic streams (the oceanic currents are clockwise in the northern hemisphere, with southern currents at West and northern at East). These conditions make the anticyclones quite stable (Hawaii and Açôres anticyclones are all season well known anticyclonic systems) both in intensity and location. In winter Mauna Kea (as well as La Palma) occasionally suffers from cold air masses invasions associated with storms and a reduced number of useful nights. The conditions at La Palma are a bit more stable, but Sahara desert dust reduces the number of photometric nughts in summer. Mt. Graham suffers, instead, a quite strong summer monsoon, carrying humid air from Caribbean Gulf into Sonora desert from July to the beginning of September, while winter conditions are relatively stable. The precise fraction of usable time in a site is matter of definition. Photometric nights can be defined as completely clear nights or nights with at least 10 hours of cloud free sky or with a sky clear some degrees (10-15) above the horizon. Other authors define instead the fraction of photometric time in terms of usable hours. A similar inhomogeneity in the data is present in the time available only for spectroscopic use. The records reported in the observing logbooks of the telescopes are not better because the judgements of the observers change in different sites, and also the policies to close the telescopes in case of bad meteorological conditions are not the same everywhere the same. The whole situation is even more complicated due to long term weather variability. This effect was carefully studied only in Arizona, where an 11 year period, anticorrelated with El Nino Southern Oscillation, was found. Within these limitations, from the current available data, it appears that yearly averages of the available nights should not be dramatically different in the three considered sites, with a 70-75% of useful hours and 45-50% of photometric time. Probably at La Palma the numbers are a bit higher than the other two sites reaching 75-80% and 50-55% respectively (Ardeberg, ESO Workshop, Site testing for future large telescopes, p. 73, 1983). The difference with mid-latitude sites, wich have on average about 55% of spectroscopic and less than 30% photometric nights, is relevant for astronomical research when the access and the difficulty of working at the site are not a priority.

The scenario could be different if the quality of the photometry (which is the atmospheric extinction stability) is considered, but so far there are almost no data available to estimate this important parameter.

Sky brightness instead is well defined, typically measured as visual magnitude per second arcsquare at the zenith. All the sites show a basically natural background dominated by zodiacal and aurora light with typical values are around V=21.5/sqrsec. The extinction, in the optical visual range is also well defined and typically around 0.15 mag/air mass in the V band, with small changes from site to site.

Meteorological conditions are also important for the choice of a site. In the case of a telescope as TNG, a constant wind direction is important to allow a proper removal of the warm air coming from the air conditioning system. A minimum wind speed is also desirable to reduce mirror seeing. Mauna Kea has two clearly East and West prevailing directions, while La Palma, at the contrary, has a relatively broader wind rose, with a North-West predominance.

Finally a complete evaluation must consider also the costs for the logistics, transportation, remote connection facilities, as well as potential scientific collaborations with the partners.

There no unique solution from the evaluation of the above considered aspects. Any decision is strictly dependent on the kind of astronomy we want to do. This should be the core of any site selection. In the case of Mt. Graham Observatory (VLBT), for example, the priority was high resolution with good transparency in the IR at the cutting edge of the technology. A sacrifice of a small fraction of available nights was considered acceptable, while an easy access to favor any engineer effort was a priority. The site choice for TNG was more troublesome due to the broader interests of the community, economical constraints and organization problems. Mt. Graham was excluded due to problems in getting the permissions in a short time while there was a general prevailing recommendation in favor of Mauna Kea for direct imaging applications, due to its potentially best seeing. However, other considerations including costs, agreements with the local partners and the wider available area made the final decision of the Council for Astronomical Research in favor of La Palma. This site offers easier access and working conditions for European scientists and technicians and it is more suitable for multi-purpose astronomy with a reasonably good seeing, a considerable number of spectroscopic nights and good conditions for near infrared and adaptive optics.

The TNG site survey report as well as a complete list of references has been published by Ortolani et al. in "Galileo Telescope", p. 136, edited by M. Zambon, Padova, 1989.

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The actions introduced by S. Ortolani are well understood and considered as a minimum output of this WG:
Need for standardization of instrumentation
Interest of gathering sources in one single place
Definition of terms.

Indeed P. Bely insisted for a more novel approach for the WG eg: modelization, global processing, how far can you go in testing sites without a local site survey? To achieve such a task, none of the WG members having enough free time, the WG recommends full time (postdoc) position.

The lively discussion which followed is well illustrated by the following polemic:

•Site testing for astronomy (P. Murdin)

1- The best performance from an astronomical telescope can be obtained only by placing it somewhere where the conditions favor its use. The requirements vary from telescope to telescope, but the list of the Table below includes some of the criteria that are frequently used. Since the investment in a major facility is now routinely $100M and, in the case of the VLT array of 8m telescopes of the European Southern Observatory, is $1000M, it is worth investing sums of order $10M or more in the selection of the site. It may be that the alternative to the establishment of a facility (e.g. an infrared telescope) on the ground in an excellent site is to establish it in space. On such a scale of expenditure, essentially any site in the world, no matter how remote, is worth considering (e.g. Antarctic mountain tops). The surveying of the entire globe for suitable sites is a major task.

2- Hitherto, telescope sites have been discovered in the following ways:

(i) Luck. A need for a site comes together with an offer, e.g. by a patron. Who can presume to site-test in such a case?

(ii) Sifting by physical properties of candidate sites. Following Isaac Newton's suggestion, Charles Piazzi Smyth in the eighteenth century proved by visiting Tenerife that mountain tops were good places for clear viewing conditions. His work led to the establishment of the mountain top observatories in California.

(iii) Sifting by meteorological models. M Walker described in the 1960's a model of the places in which the astronomical 'seeing' (image steadiness) might be favorable. He described a mountain top site, above the inversion layer (cloud free), downwind of a cold oceanic current, and with no intervening mountains to disturb the stable, cooled air. The model was induced from the existence of the Californian observatories and those in Chile. It led to the re-discovery of the Canary Islands and the discovery of potential sites in Madeira and

Namibia, as well as California.
3- Discovery of excellent sites (Hawaii, Antarctica, India, Russia) which lie outside these paradigms shows they are not exclusive (although they are all mountainous sites).
4- The properties of a new site can be confirmed by site testing from in situ measurements; to guard against seasonal effects the sites have to be tested for a whole year, and to take account of year to year variations caused by global meteorological variations (shifts of the jet stream, oceanic currents, volcanic eruptions etc) ranked against an established site at similar latitude tested concurrently and similarly.
5- This brings to question the degree to which sites can be found and examined without going to each.

(i) Examine existing data bases:

(a) the data base of human experience. Literature searching is one possibility; in principle the use of Internet to pool a wider experience of the world's travelers might be another.

(b) meteorological data bases. Use of existing satellite archives is a possibility.

(ii) Construct theoretical models based upon up to date quantitative meteorology.

(iii) Make specific observations on a global basis, presumably by satellite. As a conjecture, it may be that a site-testing satellite can be procured at a mass of about 200 kg for, say, $25M, a steep function of launch mass and therefore of payload complexity.

6- We should bear in mind that the physically measurable properties of a site are not the whole story on what makes a successful observatory. We can all think of successful observatories, having a big impact on world astronomy, which are in average sites, and, conversely, observatories situated in excellent sites whose impact has been disappointing. The reward of identifying the ingredients for success may be very high in relation to the cost of doing so.

	Site properties of interest to astronomers (not all used as selection criteria for all kinds of astronomy)
Physical	Altitude above sea level (clarity of clear air)
	Altitude above inversion layer (proportion of time above cloud tops)
	Extent of level or near-level ground
	Access by transportation
Meteorological	Clear-sky extinction (including aerosols)
	Precipitable water vapour above the site (particularly small submillimetre amounts)
	Clear atmosphere turbulence ('seeing')
	Wind speed and wind speed profile with altitude
	Mean temperatures, extremes, temperature gradients during diurnal cycle
Logistic/social	Parasitic light contamination
	Transmitted radio energy
	Icing conditions on building (high humidity at near-zero temperatures)
	Snow cover
	Consistency of conditions, affecting planning of telescope usage
	Political considerations

Note: criteria of best properties should in principle be drawn up using these input data (possible non-linear combinations). Often in the past, the weighting given to various features has been adjusted post hoc to validate the choice already made.