Wind Turbulence in the Dome of the 3.6-m Telescope

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Introduction

It is a common experience that telescope tracking may be affected by strong winds, as in some cases the air flow and its associated turbulence penetrate the dome with an amplitude sufficient to perturbate the smooth operation of the telescope. Reports of this phenomenon are, however, only qualitative as no measured data were available (to the authors' knowledge) on quantities such as mean flow penetration, turbulence intensity and vortex scale in a dome with an open slit. Only some recent wind tunnel tests [1] have addressed this question, although the reliability of the results may be somewhat questioned because of the scale similarity problems of wind tunnel simulations with round buildings.

Here the results of a preliminary investigation in the 3.6-m dome are presented. The purpose of this first series of measurements was to get a quantitative evaluation of the most critical (worst case) wind effects in the dome, rather than a systematic survey representative of all observing conditions.

The Parameters of Wind Turbulence

Air flow turbulence may be characterized by several parameters. The most immediate is the velocity rms σ_u measured along the mean flow direction. Also one often refers to the turbulence intensity, which is defined as $I = \sigma_u/\overline{U}$, with $\overline{U}$ being the mean velocity.

Actually the turbulent movement within the mean flow consists of multiple vortices of different size. A measure of the mean dimension of these vortices is given by the so-called turbulence scales. The main (longitudinal) scale L_u^x is computed from the autocorrelation coefficient R (x, x, Δt) of velocity as:

$$L_u^x = \overline{U} \int_0^\infty R(x, x, \Delta t)\, d\Delta t$$

Each size of vortices generates velocity fluctuations at a given frequency. The distribution of kinetic energy along the frequency is given by the spectral power density function $S_u(n)$, computed as the Fourier transform of the autocorrelation function. This is often called the gust (velocity) spectrum and from its definition it is also:

$$\sigma_u^2 = \int_0^\infty S_u(n)\, dn$$

The tracking performance of a telescope is actually affected by the *pressure* power spectrum $S_p(n)$ which is obtained from a time series of dynamic pressure values $P(t) = \frac{1}{2}\varrho U(t)^2$, similarly as $S_u(n)$ from $U(t)$. The pressure fluctuations, represented by $S_p(n)$ (which are seen by the telescope as forces and moments) should be compensated by the tracking control loop. Therefore particularly important is the amplitude of $S_p(n)$ in the range beyond the bandwidth of the control system, typically 1 Hz, which represents fluctuations which the tracking loop will often not be able to correct and, in a worst case, which may even excite resonance modes in the telescope.

Measuring Equipment and Procedure

The measurements were taken in the upper part of the 3.6-m dome, taking advantage for access of the bridge crane there located, during the evening of a windy day when the dome anemometer indicated almost constantly a mean velocity of 18 m/s from North. The dome slit was opened as shown in Figure 2.

A vortex type anemometer (Fig. 1) was utilized, which is particularly suited for fast response measurements, having a Δt · U resolution of 6 mm. The measurements consisted of wind velocity sequences of 137 seconds each with 4096 records, therefore at the frequency of nearly 30 Hz. Several such sequences were recorded at different positions along the path of the bridge crane as shown in Figure 2. Before each sequence, the dome was rotated forth and back in order to find, rather empirically, the azimuth angle at which one would have the stronger feeling of wind flow and turbulence. Not surprisingly, this was found to be approximately facing the mean wind direction. Therefore the values measured are properly worst case quantities, as one may expect that during observation the slit would be facing the wind only a fraction of the observing time. The recordings were subsequently processed with the MIDAS system in order to get statistical parameters.

Results and Conclusions

The main results from the measurements are given in Figures 3 to 7, in function of the distance from the edge of the slit. The data of each figure are commented with reference to the corresponding parameters of the free wind flow incident to the dome. Note also that some data sequences were taken along the centre of the slit, others along the left side: this simply because we remarked that flow and turbulence were

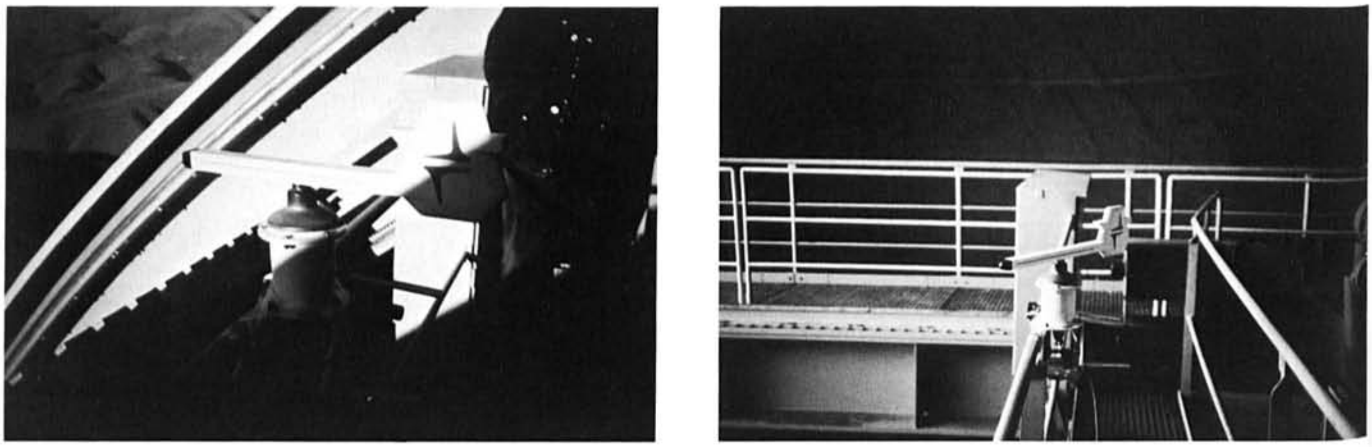

Figure 1: *The vortex anemometer placed near the slit (a) and further inside the dome (b).*

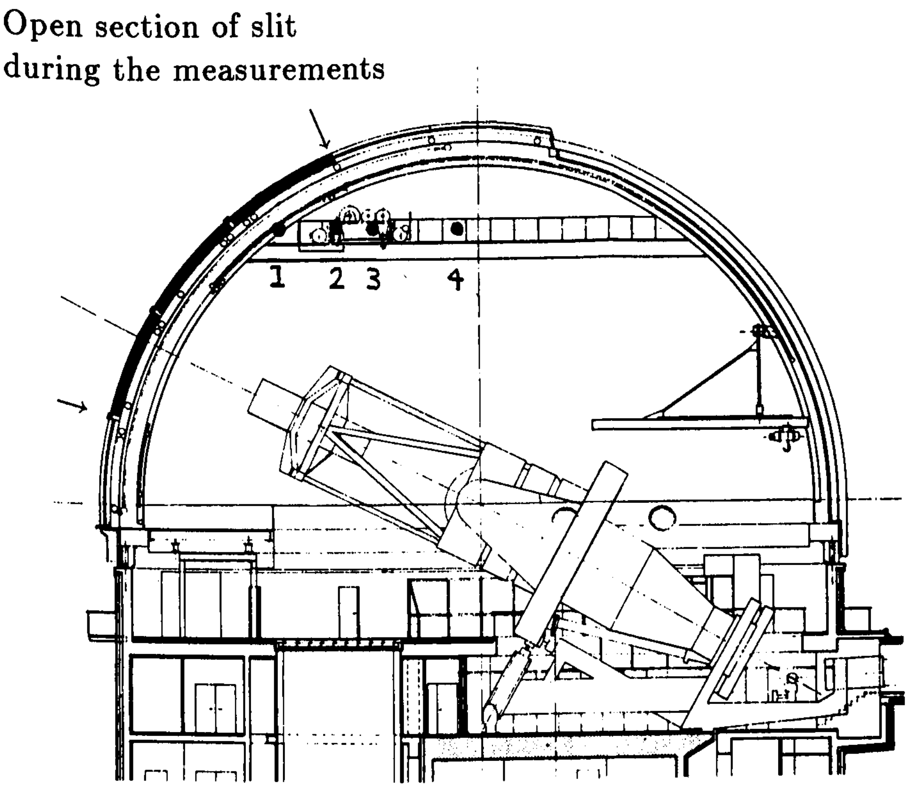

Figure 2: *Measurement locations in the 3.6-m dome.*

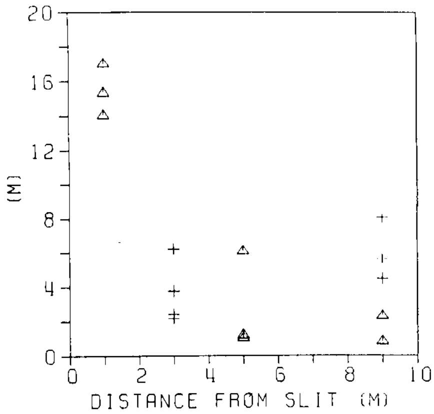

Figure 5: *Turbulence scale L_u^x. The turbulence scale in the free atmosphere at the level of the 3.6-m dome is likely to be in the range 50 to 200 metres. This free flow turbulence is still a contributing factor near the edge of the dome (L_u^x = 14–17 m); further inside we have purely slit made turbulence, with an average scale of the order of slit width.*

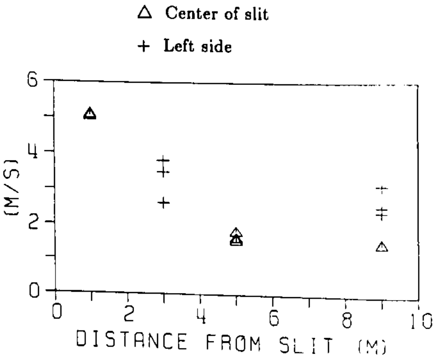

Figure 3: *Mean flow velocity $\overline{U}$. The mean wind velocity outside the dome was about 18 m/s. Already just inside the slit, this is reduced to about 5 m/s. However even further inside the dome centre, one still records up to 3 m/s.*

often stronger along the sides than along the slit midline.

We have verified that the 3.6-m dome, even with the slit facing the wind, acts as an efficient wind shield in terms of mean flow velocity. Nevertheless, the slit is the cause of velocity fluctuations inside the dome, which are definitely larger than in the original atmospheric turbulence. This dome induced turbulence has a mean scale of the order of the slit width and a peak frequency in the range 0.3 to 1 Hz. In proximity of the slit this effect causes also pressure variations which are larger than in the free atmosphere, particularly in the frequency range above 1 Hz where they might directly affect the tracking behaviour of an hypothetic telescope whose top structure would come closer to the slit than the present 3.6-m one. Further inside the dome, because of the large decrease of mean velocity (note that, from the definition of dynamic pressure, $\sigma_p \propto \overline{U}\sigma_u + \frac{1}{2}\sigma_u^2$) the amplitude of pressure oscillations is largely below the situation in the free flow.

When dealing with flow turbulence around or inside telescope domes, a question which is often raised is whether this is linked to the thermal microturbulence causing dome seeing. Although the measurements described here meant to address only the problem of wind disturbance on tracking, the evidence found of important and large flow

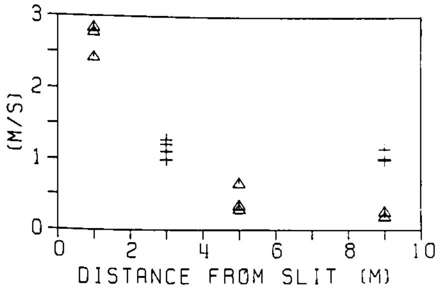

Figure 4: *Turbulent velocity σ_u. In the free flow this quantity is practically independent of height. Therefore the values measured at the same time at the meteo tower located down the ridge, 0.7–0.8 m/s, may correctly be taken as reference. Note that the values in the dome are almost everywhere higher.*

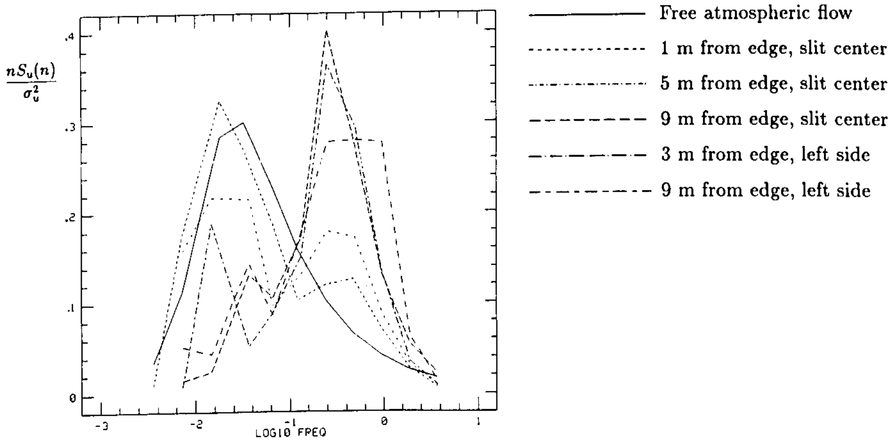

Figure 6: *Normalized gust spectra at different locations inside the dome and, for reference, in the free flow. In the free atmosphere most of the wind turbulence energy is found in the range 0.01 to 0.05 Hz. In the dome a peak in the range 0.3 to 1 Hz appears, which takes more of the turbulent energy the further away one is from the slit. Note that the spectra are here normalized with the respective σ_u^2 values.*

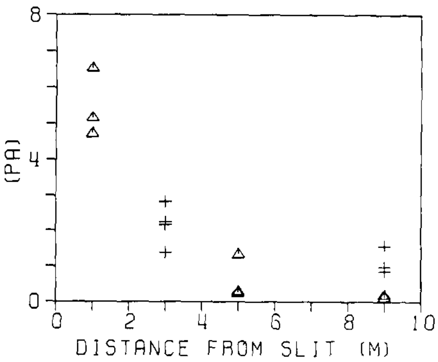

Figure 7: *Turbulent pressure high-pass filtered at 1 Hz:*

$$\sigma_{p>1Hz} = \sqrt{\int_{1Hz}^{\infty} S_p(n)dn}$$

This quantity is an approximate indicator of the dynamic wind loading which, if acting on an hypothetic telescope, cannot be compensated by the tracking control loop, assumed here to have a bandwidth of 1 Hz. The reference free flow value is 3.2 Pa: one may note that inside the dome this value is exceeded only in proximity of the slit. Further inside, the amplitude of pressure fluctuations is largely below the level in the free atmosphere.

vortices quite deep inside the dome may have relevance also to dome seeing, in particular to the energy balance of the phenomenon.

Particularly in large domes, it is unavoidable that temperature gradients exist between different sections and structures. Then any flow turbulence will increase the heat transfer between dome and air, therefore feeding energy to the microthermic turbulence which causes dome seeing. In this respect the dome mechanical turbulence may act as an intensifier of the known seeing effect created by temperature differences between air and surfaces or between inside and outside conditions.

Acknowledgements

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References

[1] Kiceniuk T. and Potter K., Internal Air Flow Patterns for the Keck 10-m Telescope Observatory Dome, GALCIT Report 10' GWT-DR 1104.

Visiting Astronomers

(April 1 – October 1, 1989)

Observing time has now been allocated for Period 43 (April 1–October 1, 1989). The demand for telescope time was again much greater than the time actually available.

The following list gives the names of the visiting astronomers, by telescope and in chronological order. The complete list, with dates, equipment and programme titles, is available from ESO-Garching.

3.6-m Telescope

April: Oosterloo/van der Kruit, Danziger/Cappellaro/Turatto, di Serego Alighieri/Tadhunter/Fosbury, Ruiz/Maza, Renzini/D'Odorico/Greggio/Bragaglia, Danziger/Moorwood/Oliva, Moorwood/Oliva, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Krautter/Starrfield/Ögelman, Bertola/Buson/Zeilinger.

May: Bertola/Buson/Zeilinger, Krautter/Starrfield/Ögelman, Scaramella/Chincarini/Vettolani/Zamorani, Ilovaisky/Chevalier/Pedersen, Surdej et al. (2-003-43 K), Schmider/Fossat/Grec/Gelly, Butcher, Molaro/Spite F./Vladilo, Butcher/Pottasch/Slingerland/Baade/Christensen-D./Frandsen, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Seggewiss/Moffat/Robert.

June: Seggewiss/Moffat/Robert, Cacciari/Clementini/Prévot/Lindgren, Piotto/Capaccioli, Pasquini, Cacciari/Clementini/Prévot/Lindgren, Perrier/Mariotti/Mayor/Duquennoy, Pottasch/Pecker/Karoji/Sahu K.C., Häfner/Barwig/Schoembs.

July: Häfner/Barwig/Schoembs, Augusteijn/van Paradijs/Schwarz, Meylan/Mayor/Dubath, Weidemann/Koester/Jordan, Ardeberg/Lindgren H./Lundström, v.d. Veen/Habing/Geballe, Krabbe/Sternberg, Véron/Hawkins, de Lapparent et al. (1-003-43 K).

August: de Lapparent et al. (1-003-43 K), Dubath, Bergvall/Rönnback, Guzzo/Collins/Heydon-Dumbleton, Neri/Grewing/Bässgen M., Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Wagner, Leibundgut/Tammann, Iovino/Shaver/Cristiani/Clowes/Pierre.

September: Iovino/Shaver/Cristiani/Clowes/Pierre, Rhee et al. (1-005-43 K), Mazure et al. (1-014-43 K), Ögelman/Gouiffes/Hasinger/Pietsch/Pedersen, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Webb/Carswell/Shaver, Bergeron/D'Odorico/Petitjean, Marano/Cappi/Held, Soucail/Cailloux/Fort/Mathez/Mellier/Pello, Schwope/Beuermann, Miley et al. (2-001-43 K), Bender et al. (1-004-43 K), Bergeron et al. (1-012-43 K).

2.2-m Telescope

April: Oosterloo/van der Kruit, Galletta/Bettoni, Katgert/van Haarlem, Giraud, Srinivasan/Danziger, Reinsch/Beuermann/Festou/Pakull, Meisenheimer/Röser, Moneti/Zinnecker/Reipurth, Moorwood/Oliva, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Tadhunter/Pollacco, Reinsch/Beuermann/Festou/Pakull, Cetty-Véron/Woltjer.

May: Cetty-Véron/Woltjer, Bertola et al. (1-008-43 K), Surdej et al. (2-003-43 K), Srinivasan/Danziger, Bertola et al. (1-008-43 K), MPI TIME.

June: MPI TIME, Chini/Wargau, Glass/Moorwood/Moneti, Ortolani/Piotto, Piotto/Djorgovski.

July: Brahic/Sicardy/Roques/Barucci, Habing/Le Poole/Schwarz/van der Veen, Brahic/Sicardy/Roques/Barucci, v.d. Veen/Habing/Blommaert, v.d. Veen/Habing/Geballe, Tosi/Focardi/Greggio.

August: Richtler/Kaluzny, Wiklind/Bergvall/Aalto, Bergvall/Rönnback, Tanzi/Bersanelli/Bouchet/Maraschi/Falomo/Treves, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Jörsäter/Bergvall, Appenzeller/Wagner, Miley et al. (2-001-43 K), Christensen/Sommer-Larsen/Hawkins.

September: Barbieri et al. (2-007-43 K), Bender et al. (1-004-43 K), MPI TIME.

1.5-m Spectrographic Telescope

April: Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Chincarini/De Souza/di Stefano/Sperandio/Molinari, Courvoisier/Bouchet, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Buzzoni/Mantegazza/Malagnini/Castelli/Morossi, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Thé/Westerlund/Vardya/de Winter, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Andreae/Drechsel.

May: Tadhunter/Pollacco, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Lanz/Artru, Gehren/Steenbock/Reile/Axer/Burkert/Fuhrmann, Spite F./Spite M., Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Acker/Stenholm/Lundström.

June: Acker/Stenholm/Lundström, Baade/Stahl, Gerbaldi et al. (5-004-43 K), Waelkens/Lamers/Trans/Waters, Pottasch/Pecker/Karoji/Sahu.

July: Courvoisier/Bouchet, Bica/Alloin, v. Genderen/v.d. Hucht/Schwarz/de Loore, Baribaud/Alloin/Pelat/Phillips, Boffin/Jorissen/Arnould, Hron, Baribaud/Alloin/Pelat/Phillips, Wiklind/Bergvall/Aalto.

August: Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Baribaud/Alloin/Pelat/Phillips, Tanzi/Bersanelli/Bouchet/Maraschi/Falomo/Treves, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Eriksson/Gustafsson/Olofsson, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Baribaud/Alloin/Pelat/Phillips, Katgert/Rhee, Baribaud/Alloin/Pelat/Phillips.

September: Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Cappi/Chincarini/Vettolani, Baribaud/Alloin/Pelat/Phillips, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Jugaku/Tekada-Hidai/Holweger, Gerbaldi et al. (5-004-43 K), Baribaud/Alloin/Pelat/Phillips, Danziger/Bouchet/Gouiffes/Lucy/Wampler/Fosbury/Fransson, Calvani/Marziani, Baribaud/Alloin/Pelat/Phillips.

1.4-m CAT

April: Franco, Baade/v. Kerkwijk/Waters/Henrichs/van Paradijs, Gratton/Gustafsson/Eriksson, Westerlund/Krelowski, Mathys, Lemmer/Dachs.