ENVIRONMENTAL CHALLENGES IN ASTRONOMY

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Summary

The detection of faint astronomical signals is limited by natural environmental factors and by artificially generated nuisances, such as radio interference and light pollution. The interference can be mitigated by choosing to locate observatories at places where the natural interference is minimised, and by controlling the nuisance emissions. This article describes the range of the nuisances for astronomy, the scope of the solutions that are available to astronomers and the social organisations that have been used to control them. It also describes the environmental contaminations made by the practice of astronomy itself, including biological contamination of the other planets, and the steps that have been taken to reduce them

1. The Detection of an Astronomical Signal and the Environment

As astronomical signal from an astronomical source, such as a star or galaxy, depends on

- The spectral distribution of radiated flux from the source F(λ; t). In general, the source will vary in time on some time scale, and possibly periodically.
- The distribution of the flux from the source on the sky. Even if the source is so distant that it is effectively a point source, in general the flux from the source will be distributed over a solid angle by natural or instrumental effects.

Astronomers attempt to measure the flux from the source over some spectral resolution in order to infer astronomical information about it. Even if the measurement is simply a detection of the source and confirmation of its existence (as in looking at it), the detection is effectively a measurement of the flux of the source by showing that it is above a detection threshold. The source may be attenuated by absorption and detected against a background noise. The background noise may have a spatial distribution and time variability, as well as a spectral distribution of its own. The larger the background noise, the less is the contrast between the astronomical source and the background and the less detectable the astronomical source.

The detection and measurement of an astronomical signal is unalterably restricted by the properties of the astronomical source. A distant galaxy is far away, the inverse square law of distance diminishes its flux, and there is nothing that can be done about this! Faint galaxies are in general not only more distant, they are also at the same time viewed as they were long ago and therefore represent the composition of the early universe. This makes some faint sources particularly valuable. Again, the larger the volume of space surveyed, the fainter the average member of its contents, but the larger the number of members that is studied and the more rare and perhaps significant examples of objects that can be found. It is thus important for astronomers to be able to detect, measure and investigate faint astronomical sources. Two things stand in their way: limitations of instrumental capability and environmental interference, whether natural or artificial.

Over the centuries, astronomers have developed the capability of their instruments to give them greater power to detect and measure astronomical sources. They have built larger and larger telescopes. They have improved the efficiency and spectral range of their detectors through technological improvements, and reduced their internal noise-generation. At any one time in history, however, the success of astronomers in building sensitive instruments is restricted by technological or financial limitations.

Astronomers have sought out favourable locations for their observatories so as to mitigate against natural environmental interference. This is the reason why many of the world's largest and most expensive observatories are located in deserts, on mountaintops or in space, in spite of the operational difficulties. Astronomers have also attempted to control artificially-generated interference, such as parasitic radio noise or light pollution, through political means.

This article is about the natural and artificial environments that restrict the development of astronomy and challenge its advances. It is convenient to describe the environmental challenges through the techniques that are used to make the measurements: optical, radio, etc.

2. Optical and Near Infrared Astronomy

Optical and near infrared (OptIR) astronomy is astronomy carried out by the detection and measurement of light and near infrared radiation, from 0.3 to 1.2 microns in wavelength (the spectral range limited longwards by silicon-based detectors, and shortwards by the opacity of air and optical equipment). The first astronomy practised by eye was optical astronomy, and there are millions of people around the world who still carry out astronomy in this way, for enjoyment and education mostly.

2.1 Natural environmental challenges

2.1.1. Scattered light

Except at solar observatories, OptIR astronomy is principally carried out at night, when light from the Sun scattered on air (daylight) is minimised. OptiIR astronomy may be limited at dusk and dawn because of twilight, and at night time according to the Moon. When the Moon is Full and above the horizon, moonlight is scattered on air at night just as sunlight is during the daytime. The natural background is bright and it is not possible to detect sources as faint as when the Moon is New (or below the horizon). OptIR astronomers divide the rota of usage of their telescopes into 'Dark Time' around the time of New Moon and when it has set, and 'Bright Time' around the time of Full Moon; 'Grey Time' is the period of transition between Bright and Dark Times. Dark Time is particularly valuable for the study of faint sources, and it is common for telescopes to be massively oversubscribed with applications to use the Dark Time. Observations that are least sensitive to moonlight are scheduled into Bright Time. This includes the measurement of bright stars, because they may far surpass the flux from moonlight. It also includes nebulae, because an emission spectrum has its light concentrated into a few, narrow spectral bands, whereas moonlight is a continuous spectrum (essentially the spectrum of the Sun) and narrow spectral bands dilute the background of moonlight.

Measurements to be made at red or near infrared wavelengths are also scheduled in Bright Time. Rayleigh scattering of light on air molecules has an inverse fourth-power wavelength-dependency, so there is not so much natural background of scattered moonlight in the red regions of the spectrum. Scattered moonlight, like scattered sunlight, is blue. However, a component of scattering in air is due to larger particles than molecules (air-borne dust, water droplets or other aerosols), and has a flatter wavelength dependency. Air-borne aerosols increase the total amount of moonlight scattered, especially at short wavelengths. To minimise the natural background of scattered moonlight, astronomers choose observatory locations that are high-altitude (minimising the column density of air above the observatory) and aerosol-free (away from the coast where waves throw sea-water droplets into the air, on sites without light dust that can be blown up by the wind, etc). However, dust may be brought to large heights by strong winds, by solar-induced convection of the air in hot areas like the Sahara desert (Murdin 1986, Whittet et al. 1987), and by volcanic eruptions like El Chichón in 1982 and Pinatubo in 1991 (see e.g. Lockwood & Thompson 1986; Rufener 1986; Forbes et al 1995; Burki et al 1995; Winkler 2000; Schuster & Parrao 2001). This dust may be dispersed by stratospheric winds all over the world.

2.1.2. Opacity

Air molecules and aerosols not only scatter light into the telescope beam and cause a background, they are also sources of attenuation. Air attenuates starlight through Rayleigh scattering, and by molecular absorption. Since the composition and density of air is stable at a given location, the wavelength dependency of the attenuation is constant. Its amplitude depends on the column density of air from telescope to star, i.e. the air-mass (column density to the star relative to the column density to the zenith). If the atmosphere is plane stratified and horizontal the air mass is equal to sec (z), where z is the zenith distance of the star (its angle relative to the zenith). Second order terms for the curvature or tilt of the atmosphere (due to local ground contours and wind flow) can be necessary but are geometrical only, so the opacity of the atmosphere can be regarded as constant in a given direction, if the air is entirely gaseous.

Aerosols are much more variable. Clouds, consisting of water droplets or ice crystals, and air borne dust reduce the source intensity and, as they pass over the telescope beam, cause variability that makes measurement problematic.

Middle and low altitude clouds (bases between 2000 and 6000 m, and up to 2000 m respectively) may affect astronomical observations from near sea level, but may lie below the summit of a high mountain. A telescope built on a high summit may protrude above the top of such clouds into the clear sky above. These types of clouds are confined to the troposphere, at altitudes near sea level, and are produced by the convective rise of humid air, warmed by contact with the ground or sea, into the colder zones at higher altitude. The air convects as high as the inversion layer, at which the air temperature starts to increase. In general, observatories experience a larger fraction of clear nights when they are located on an isolated mountain top that is higher than the local inversion layer.

Because aerosol content is variable at a given site, it affects photometric measurements.

These have to be corrected for the effect of atmospheric extinction, through the use of models of directional and spectral distributions. Variable aerosol content has anomalous spectral dependencies and uncertain directional dependency.

2.1.3. Atmospheric Background

The atmosphere emits natural radiation through various mechanisms in which air atoms and molecules are excited and de-excite spontaneously. If the excitation mechanism is collision by charged particles the resultant light emission is called aurora. If by another mechanism, such as excitation by solar UV with subsequent de-excitation at night, the light background is called airglow (Chassefiére 2000).

Auroral radiation is concentrated in the atmosphere within the auroral ovals at geomagnetic latitudes within approximately 20 degrees of the poles; few observatories are sited this close to the poles, except of course for ones intended to study the aurora and similar phenomena. Airglow is more general in geographic extent but increases with latitude by a factor of order 2. Airglow is perhaps 20% of the brightness of the diffuse light of the night sky, the rest being cosmic sources such as the Milky Way and zodiacal light. Airglow is time variable and thus a troublesome background to correct by beam chopping, because the spatial dependency of the on- and off-beams becomes mixed with the time dependency. This is less an issue for modern area detectors, where the recording of on- and off-beam intensity is simultaneous.

2.1.4. Seeing

Detection of a star-like source depends on the size of the image of the source produced in the telescope and in the atmosphere – the larger the area of the image, the more the source intensity is spread over the image and the less the detection contrast. The natural limit to the size of the star image is called ‘seeing’, and is produced by random thermal inhomogeneities in the air which act like lenses and cause the plane wavefront from the point source to wrinkle or corrugate. The wind causes the inhomogeneities to pass over the beam of the telescope and the flow of the wrinkles causes the image to spread out by varying amounts and to move. OptIR astronomers seek out geographical locations of ‘good seeing’ where the air is isothermal and stable and where the corrugation of a plane wavefront is small.

2.1.5. Vibration

Everywhere on earth has a natural vibration spectrum caused by seismic activity. Additionally, islands or mountains near the sea are excited by wave action on the shore. There are sporadic excitations from earth tremors and larger earthquakes may pose a threat to any facilities located nearby. One notable example of an earthquake that affected an astronomical observatory was the earthquake which struck the Big Bear Solar Observatory in June 1992. The tremor, which measured 6.6 on the Richter scale, occurred only 9 km from the observatory. The causeway which links the observatory with the lake shore suffered from subsidence and fractures, while the support pedestal for the telescopes and the tracking machinery were also damaged. The observatory was out of action for more than four months while repairs were undertaken. Telescopes on the volcanoes of Mauna Kea and La Palma are protected against earthquakes of a size that is thought possible there, with spring-loaded pivots pulling gears apart in the case of tremors that could damage the main bearings. The largest earthquake on Hawaii's Big Island for 20 years occurred in October, 2006, at Richter scale 6.7. Guiding and pointing systems of the Keck telescopes were affected. The earthquake tipped over heavy cabinets in the Canada-France-Hawaii Telescope's Waimea headquarters. The Gemini Telescope shook hard and moved with respect to its azimuth track. The dome of the Canada-France-Hawaii Telescope (CFHT) moved on its track and could not be rotated. All these telescopes lost several nights observing time without, however, permanent damage.

2.2. Artificial Environmental Challenges

2.2.1. Light Pollution

Light pollution is the most significant artificial environmental challenge faced by OptIR astronomy. Light pollution is light emitted by artificial sources, and scattered and reflected in the atmosphere (Crawford 1991; Mizon 2002; Schwarz 2003; Narisada & Schreuder 2004). The resultant scattered light is called skyglow. It can greatly reduce the contrast of a faint star above background. Skyglow effects on large telescopes have been calculated by Crawford (1992) and typically reduce the effective value of a telescope at Mt Palomar or Mt Wilson to 10-40% of its original value. In effect artificial skyglow may nullify the distinction between Dark and Bright Time on an optical telescope.

Sources of light pollution include road lighting, domestic lighting, floodlighting of car parks and sports fields, light to force the growth of crops in greenhouses (e.g. tomatoes grown in greenhouses in the Netherlands) or attract fish (e.g. in Japan), security lighting and lighting to display building façades at night. The sources may shine directly into the sky or light from the sources may be reflected into the sky from the ground or building surfaces. In densely populated areas a skyglow intensity of 100 times the natural sky background is not uncommon, and effectively destroys the appearance of the Milky Way. Light pollution can propagate large distances (100 km or more). Models of night sky illumination around populated areas have been developed by Garstang (1986 and subsequent papers, see Cinzano 2000).

Light pollution has been surveyed by numerous methods. Satellite measurements (Sullivan 1991; Cinzano, Falchi and Elvidge 2001, 2003) have been made with the Defense Meteorological Satellite Program (DMSP) of the US Air Force. These show the global distribution of light pollution and provide a data base for investigation of its increase since 1974. Photometric measurements of skyglow at some observatory locations are available back to 1947 (see Cinzano 2003) and show skyglow increasing exponentially over North America at the rate of 6% per year. Mass surveys of sky glow are possible by naked eye techniques, such as counting the number of stars visible by eye within the bowl of the Big Dipper (Great Bear) – such surveys carried out by mass observation have a considerable political effect in raising the level of concern about the loss of the sky viewing amenity for the general public including children.

Light pollution is worse in heavily populated areas and in developed countries. Coastal areas are particularly badly affected, and large cities. Large regions of Europe, North America and south and east Asia are useless for much professional astronomy and inhibit informal enjoyment of the night sky for the population at large. Another consideration is that light polution represents wasted energy and unnecessary carbon emissions.

2.2.2. Smoke, Dust and Contrails

The aerosol content of the atmosphere is increased by smoke, dust from mining operations, and by condensation trails (contrails) of water emitted and left by high flying aircraft (Pedersen and Schwarz 2003). Contrails can persist for days. They are globally widespread but particularly along east-west tracks across the continental USA and Europe, where of course there is a high density of jet aircraft.

Contrails have been noted as concerns for astronomers by the International Astronomical Union (IAU) in two resolutions at General Assemblies:

1964, Hamburg, Resolution No. R5: 'During total eclipses of the Sun, important scientific observations made from the ground by professional astronomers may be hampered, or even ruined, by the vapour trails from aircraft flying in the zone of totality. The International Astronomical Union accordingly requests the competent authorities in the countries concerned to regulate flights at the times and locations of total solar eclipses in such a way that their interference with scientific programmes be avoided.'1976, Grenoble, Resolution No. R9: 'The International Astronomical Union notes with alarm the increasing levels of interference with astronomical observations resulting from artificial illumination of the night sky, radio emission, atmospheric pollution, and the operation of aircraft above observation sites.'

Observatories in California (Mt Wilson, Mt Palomar, Mt Hamilton, Griffith Park), Arizona (Kitt Peak, Mt Hopkins, Mt Bigelow), Australia (Siding Spring) and the Canary Islands (La Palma) have been uncomfortably close to bush and forest fires. These can of course threaten life and buildings. The telescopes and research buildings at Canberra's Mt Stromlo Observatory were destroyed by fire in January 2003, now happily being rebuilt and put back into commission. Even if the fire remains only a close threat and proves less than catastrophic, solid aerosols may affect transparency, perhaps for weeks, and ash drifts onto delicate optical surfaces. Clearly, fire management controls are necessary in vulnerable sites.

The European Southern Observatory (ESO) maintains two observing sites in Chile, its original one on the La Silla mountain in the southern part of the Atacama desert (in the Fourth Chilean Region, some 600 km north of Santiago de Chile) and the VLT site on the Paranal Mountain (700 km north of La Silla and 130 km south of Antofagasta, the capital of the Second Region in Chile). Both observatories are in regions of mining interest – in fact the Antofagasta Region is the heart of Chile's mining industry, the country's main source of export revenue. Dust from mining operations could potentially be an issue for the operation of the telescopes, if not controlled.

2.2.3. Heat Pollution

Temperature inhomogeneities that cause deteriorated seeing are increased by solar heat absorbed by in the daytime and released at night (Barlier & Kovalevsky 1992, page 126). Artificial sources of heat are buildings heated for residential use and chimneys. The construction of a coal-fired power station immediately north of the Royal Observatory at Greenwich in 1902-1910 was one of the matters, as well as light pollution, smog and dust on the optical components of the instruments, which precipitated its move in 1947 out of London to the Sussex countryside.

Azimuthal thermal gradients, caused by a local heat source like this, disturb the symmetry of the temperature stratification of the atmosphere and thus the refraction correction for fundamental positional measurements of stars. Studies by the US Naval Observatory in Washington, DC have shown that thermal turbulence and refractive index asymmetries over the site created by large heated buildings nearby have reached the level where they compromise the astrometric value of the site.

2.2.4. Radio Frequency Transmissions

RF transmissions induce small signals in all nearby conductors. If the conductors are part of an astronomical signal detection system, the induced artificial signals may be amplified by large factors and interfere with the small natural astronomical signal. RF transmitters in or near an observatory site are thus an issue.

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Bibliography

Kovalevsky, J. (1992a) (ed.) ‘The Protection of Astronomical and Geophysical Sites’ Paris: Editions Frontières. [A comprehensive overview of environmental protection issues including specimen ordinances and treaties.]

Lewis, B. & Emerson, D. (2004) ‘Spectrum Management for Radio Astronomy: Proceedings of the IUCAF Summer School held at Green Bank, West Virginia, June 9-14, 2002.’ Green Bank WV: National Radio Astronomy Observatory. [A worth-finding but hard-to-find volume with a range of articles on radio interference protection.]

McNally, D. (1994) ‘The Vanishing Universe: adverse environmental impacts on astronomy’ Cambridge: CUP. [The proceedings of a UNESCO conference, the volume gives a general overview of protection issues and assesses their long term significance.]

Mizon, B. (2002) ‘Light pollution: Responses and Remedies’ London: Springer. [A practical guide to light pollution and its control, principally targeted towards amateur astronomers.]

Narisada, K. & Schreuder, D. (2004) ‘Light pollution handbook’ Dordrecht: Springer. [The comprehensive, one-stop reference work on light pollution control including legal and lighting engineering issues.]

Robinson, B. (1999) ‘Frequency Allocation: the first forty years’ Ann. Rev. Astr. & Astrophys, 37, 65. [Spectrum management for radio astronomers by an insider who has worked in the international negotiations for a number of years.]

Schwarz, H. (2003) (ed.) ‘Light pollution: the Global View’, Dordrecht: Kluwer. [The proceedings of an international conference on light pollution, the book covers contrails, dust emission and radio spectrum management issues as well, and describes light pollution control in the burgeoning astronomical nation of Chile.]

References

Anon (1980) ‘Guidelines for minimizing urban sky glow near astronomical observatories’ CIE, IAU publication number 1 (reproduced in McNally 1992, p. 162)

Anon (1992) ‘Guidance Notes for the Reduction of Light Pollution’ London: The Institution of Lighting Engineers (ILE); (reproduced in McNally 1994, p. 176).

Anon (1993) ‘Urban Sky Glow, a worry for Astronomy’ CIE Publication X008, Vienna: CIE.

Anon (1997) ‘Guidelines for minimizing urban sky glow near astronomical observatories’ CIE Publication 126-1997, Vienna: CIE.

Anon (2003) ‘Guidance on the limitation of the effects of obtrusive light from outdoor lighting installations’ Publication no. 150. Vienna: CIE.

Barlier, F. and Kovalevsky, J. (1992) ‘Pollution of Geophysical Sites’ in Kovalevsky (1992), p. 123.

Burki, G., Rufener, F., Burnet, M., Richard, C., Blecha, A. & Bratschi, P. (1995) ‘The atmospheric extinction at the ESO La Silla observatory’, Astronomy and Astrophysics Supplement, 112, 383.

http://adsabs.harvard.edu/abs/1995A%26AS..112..383B

Burton, M. (2004) ‘Astronomy in Antarctica’ in Organisations and Strategies in Astronomy (ed. A. Heck) vol 5, Dordrecht: Kluwer.

Cinzano, P. (2000) (ed.) ‘Measuring and modelling light pollution’ Mem. Soc. Astr. Ital., 71, 1-251.

Cinzano, P. (2003) ‘The Growth of the Artificial Night Sky Brightness over North America in the Period 1947-2000: A Preliminary Picture’ in Schwarz (2003) p. 39.

Cinzano, P. Falchi, F. & Elvidge, C. D. (2001) ‘The first World Atlas of the artificial night sky brightness’ Mon. Not. R. Astro. Soc., 328, 689.

Cohen, R.J., Delgado, G., Hardy, E., Hasegawa, T., & Nyman, L.A. ‘Radio Quiet Zones – protection of radio astronomy sites’ in Schwarz, H. (2003), p. 225.

Crawford, D.L. (1991) (ed.) ‘IAU Colloquium No. 112: Light pollution, Radio Interference, and Space Debris’ San Francisco: Astronomy Society of the Pacific Conference Series vol 17.

Crawford D.L. (1992) ‘Light pollution’ in Kovalevsky (1992) p. 31.

Chassefiére, E. (2000) ‘Airglow’ in Encyclopedia of Astr. Astrophys. (ed. P Murdin), London: Nature-Macmillan.

DeVincenzi, D. L., Stabekis, P.D. and Barengoltz, J.B. (1983) ‘A proposed new policy for planetary protection’ Adv. Space Res. 3, (8), 13.

Emerson, D. & Lewis, B. (2004) ‘Propagation Models’ in Lewis & Emerson (2004), p.48.

Forbes, M. C.; Banks, T.; Sullivan, D. J.; Dodd, R. J.; Gilmore, A. C. & Kilmartin, P. M. (1995) ‘Mount Pinatubo and atmospheric extinction at Mount John University Observatory, 1987-94’ The Observatory, vol. 115, p. 29-30. http://adsabs.harvard.edu/abs/1995Obs...115...29F

Garstang, R.H. (1986) ‘Model for Artificial Night-Sky Illumination’ Publ. Astron. Soc. Pacific., 98, (601), 364 http://adsabs.harvard.edu/abs/1986PASP...98..364G

Gergeley, T. (2004) ‘World Radiocommunication Conferences’ in Lewis & Emerson (2004) p. 114.

Howse, D. (1975) ‘Greenwich Observatory, vol. 3: The Royal Observatory at Greenwich and Herstmonceux 1675-1975’ London: Taylor & Francis.

Kovalevsky, J. (1992a) (ed.) ‘The Protection of Astronomical and Geophysical Sites’ Paris: Editions Frontières.

Kovalevsky (1992b) ‘Introduction’ in Kovalevsky (1992a), p.5.

N.M. Law, C.D. Mackay, R.G. Dekany, M. Ireland, J. P. Lloyd, A. M. Moore, J.G. Robertson, P. Tuthill, & H. Woodruff (2008) ‘Getting Lucky with Adaptive Optics: Fast AO Image Selection the Visible with a Large Telescope’, Astrophysical Journal, in press May 2008

Lewis, B. & Emerson, D. (2004) ‘Spectrum Management for Radio Astronomy: Proceedings of the IUCAF Summer School held at Green Bank, West Virginia, June 9-14, 2002.’ Green Bank WV: National Radio Astronomy Observatory.

Lockwood, G. W. & Thompson, D. T. (1986) ‘Atmospheric extinction - The ordinary and volcanically induced variations, 1972-1985’ Astronomical Journal, 92, 976-985. http://adsabs.harvard.edu/abs/1986AJ.....92..976L

McNally, D. (1994) ‘The Vanishing Universe: adverse environmental impacts on astronomy’ Cambridge: CUP.

Mizon, B. (2002) ‘Light pollution: Responses and Remedies’ London: Springer.

Murdin, P. (1986) ‘Geology and Meteorology of Saharan Dust’ La Palma Technical Note Number 41. http://www.ing.iac.es/Astronomy/observing/manuals/ps/tech_notes/tn041.pdf

Murdin, P. (1992) ‘Protection of Observatories: the legal avenues’ in Kovalevsky (1992) p. 159.

Murdin, P. (1997) ‘AlCORs: Astronomical Lighting Control Regions for Optical Observatories’ The Observatory 117, 34. http://adsabs.harvard.edu/abs/1997Obs...117...34M

Narisada, K. & Schreuder, D. (2004) ‘Light pollution handbook’ Dordrecht: Springer.

Newton I (1730) Opticks An on-line version is at

http://books.google.com/books?id=XXu4AkRVBBoC&printsec=frontcover&source=gbs_book_other_versions_r&cad=2_0

Norrod, R. (2004) in Lewis & Emerson (2004), p. 63.

Pedersen, H. & Schwarz, H. (2003) ‘Aircraft contrail pollution’ in Schwarz (2003), p. 263.

Ponsonby, J. (2004) ‘Conceptual Background to Radio’ in Lewis & Emerson (2004).

Robinson, B. (1999) ‘Frequency Allocation: the first forty years’ Ann. Rev. Astr. & Astrophys, 37, 65.

Ruf, K. (2004) ‘Mitigation techniques, mitigation factors – what are they? What are they good for?’ in Lewis and Emerson (2002), p. 175.

Rufener, F. (1986) ‘The evolution of atmospheric extinction at La Silla’ Astronomy and Astrophysics 165, (1-2), 275-286. http://adsabs.harvard.edu/abs/1986A%26A...165..275R

Schwarz, H. (2003) (ed.) ‘Light pollution: the Global View’, Dordrecht: Kluwer.

Schuster, W. J. and Parrao, L (2001) ‘The Atmospheric Extinction of San Pedro Mártir’ Revista Mexicana de Aastronomiá y Astrofísica, 37, 187 http://www.astrosmo.unam.mx/rmaa/RMxAA..37-2/PDF/RMxAA..37-2_schuster.pdf

Sizemore, W & Acree, J. ‘The National Radio Quiet Zone’ in Lewis and Emerson (2002), p. 217.

Smyth, C. P. (1858) ‘Teneriffe, an Astronomer’s Experiment: Or, Specialities of a Residence Above the Clouds’ London: Lovell Reeve.

Sullivan. W. (1991) ‘Earth at Night: an Image of the Nighttime Earth Based on cloud free satellite photographs’ in Crawford (1991) p. 11.

Walker, M. F. (1984) ‘High quality astronomical sites around the world’ Proceedings of the Workshop on Site Testing for Future Large Telescopes, La Silla, Chile. Garching: European Southern Observatory.

Whittet, D. C. B., Bode, M. F., Murdin, P. (1987) ‘The extinction properties of Saharan dust over La Palma’ Vistas in Astronomy, 30 (2), 135-144. http://adsabs.harvard.edu/abs/1987VA.....30..135W

Winkler, H. (2000) ‘Studying the Atmosphere over Africa using Astronomical Data: I - Extinction Measurements’ African Skies, 5, 10.

http://articles.adsabs.harvard.edu/cgi-bin/nph-iarticle_query?2000AfrSk...5...10W&data_type=PDF_HIGH&whole_paper=YES&type=PRINTER&filetype=.pdf

Biographical Sketch

Paul Murdin was educated at the Universities of Oxford and Rochester, NY. He started his career as a research astronomer, in which he held posts in the University of Rochester (NY), the Royal Greenwich Observatory (UK), the Anglo-Australian Observatory (Sydney and Coonabarabran, Australia), the Isaac Newton Group of Telescopes at the Observatorio del Roque de los Muchachos (La Palma, Canary Islands, Spain), and the Royal Observatory, Edinburgh (Scotland). He worked between 1994-2002 for the Particle Physics and Astronomy Research Council as a policy maker for UK astronomy. In this position he was the Director of Science at the British National Space Centre, taking care of space science matters on behalf of PPARC. He was the UK delegate to the European Space Agency’s Space Science Committee. He has been the President of Commission 50 of the International Astronomical Union on the Protection of Existing & Potential Observatory Sites. He has been a President of the European Astronomical Society and a member of the Visiting Committee of the European Southern Observatory. He joined the Institute of Astronomy at the University of Cambridge in 2002. He is the Treasurer of the Royal Astronomical Society and Visiting Professor at John Moores University, Liverpool. He is particularly interested in astronomy education, and has a secondary career as a broadcaster and writer on astronomy. He was honoured by the Queen of England in 1988 for his work in astronomy.