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Session 21.3 – Radio and Optical Site Protection

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Abstract. Advancement in radio technology means that radio astronomy has to share the radio spectrum with many other non-astronomical activities, majority of which increase radio frequency interference (RFI), and therefore detrimentally affecting the radio observations at the observatory sites. Major radio facilities such as the SKA, in both South Africa and Australia, and the Five-hundred-meter Aperture Spherical radio Telescope (FAST) in China will be very sensitive, and therefore require protection against RFI.

In the case of optical astronomy, the growing urbanisation and industrialisation led to optical astronomy becoming impossible near major cities due to light and dust pollution. Major optical and IR observatories are forced to be far away in remote areas, where light pollution is not yet extreme. The same is true for radio observatories, which have to be sited away from highly RFI affected areas near populated regions and major cities.

In this review, based on the Focus Meeting 21 (FM21) oral presentations at the IAU General Assembly on 11 August 2015†, we give an overview of the mechanisms that have evolved to provide statutory protection for radio astronomy observing, successes (e.g at 21 cm HI line), defeats and challenges at other parts of the spectrum. We discuss the available legislative initiatives to protect the radio astronomy sites for large projects like SKA (in Australia and South Africa), and FAST against the RFI. For optical protection, we look at light pollution with examples of its effect at Xinglong observing station of the National Astronomical Observatories of China (NAOC), Ali Observatory in Tibet, and Asiago Observatory in Italy, as well as the effect of conversion from low pressure sodium lighting to LEDs in the County of Hawaii.

Keywords. Radio astronomy, optical astronomy, RFI, light pollution, spectrum protection

1. Introduction and Background

Both radio and optical astronomy face a number of challenges relating to radio frequency interference (RFI) for radio astronomy, and light and dust pollution for optical and InfraRed (IR) astronomy. Both radio and optical sites require protection to ensure that observations are not detrimentally affected at observing sites. The differences between Radio and Optical with regard to protection strategies are small. Just like optical astronomy a few decades earlier, radio astronomy is no longer able to use radio spectrum everywhere, even for dedicated radio astronomy spectrum. It is therefore necessary for radio astronomy facilities to be installed in remote, radio quite sites far away from densely populated areas.

In some of the cases, the sites suitable for radio astronomy are also suitable for optical and IR astronomy, and therefore it is not uncommon to have both radio and optical observing facilities around the same area, examples include Kitt Peak, La Silla, Atacama Desert and Mauna Kea.

† Focus Meeting 21, Session 3 (FM21.3) presentations are available at http://www.noao.edu/education/IAUGA2015FM21

1.1. *Radio astronomy*

Radio astronomy observations from the ground are quite sensitive to radio interference from radio communications, aviation and satellites, and therefore radio sites need to be optimised for radio astronomy and should have explicit protection areas reserved as radio quiet zones (RQZs) with restrictions and regulations for the use of the spectrum. The use of the spectrum should and is managed in what is called spectrum management. Spectrum management is the politics of access to electromagnetic spectrum from 0 to 3000 GHz, mainly by a UN organ in Geneva called the International Telecommunication Union (ITU) Radiocummunication sector (ITU-R).

According to the IUT-R, a RQZ is meant to be any recognised geographic area within which the usual spectrum management procedures are modified for the specific purpose of reducing or avoiding interference to radio telescopes, thereby maintaining the required standards for quality and availability of observational data (Report ITU-R RA.2259, 2012).

1.2. *Light pollution*

For optical astronomy, light pollution is the most important challenge that need to be addressed and major observatories need to be protected from light pollution using either legislation and/or education. Observatory sites like Xinglong station of the NAOC, Ali Observatory and Asiago Observatory continue to invest in monitoring and looking at ways of reducing light pollution at their sites to ensure that astronomy continues to be viable at those sites. They continue to work on possible regulations that could be used to control light pollution at their sites.

Light pollution is a major threat to large telescopes around the world and astronomical observatories continue to engage their local governments to help set up legislations that protect optical astronomy facilities. Observatories are also involved in outreach and educational programs to teach people about the importance of preserving the night sky and protecting it from light pollution, not only for astronomy but for sky gazers and for economic savings related to reduced and efficient use of night lighting.

2. Radio astronomy protection

2.1. *Spectrum protection for radio astronomy: details, successes, failures, challenges and convergence*

Spectrum management is a big business with far more spectrum managers than astronomers†. It is however an important mechanism that provides statutory protection for radio astronomy observing sites. There have been successes, failures and challenges in the protection of radio astronomy radio quiet zones (RQZs). Successes include the protection of H I at 21 cm and OH at 18 cm, which are currently ONLY observable because radio astronomers having succeeded to protect their spectrum. There have been challenges, e.g. with GLONASS (satellite), which used to obscure 1612 MHz band, but eventually, after protracted negotiations with IUCAF [the Scientific Committee on the Allocation of Frequencies for Radio Astronomy and Space Science], left the 1612 MHz band.

Without care, the 21 cm H I will likely have very restricted availability once wireless broadband spectrum is expanded, and this will have negative effects even to using 21 cm H I as a teaching tool without heavy filtering (Figure 1). Many administrations are extremely cynical about protecting the 21 cm band. Transmitters are also moving to

† From presentation by H.S. Liszt, NRAO, Charlottesville, Virginia, USA

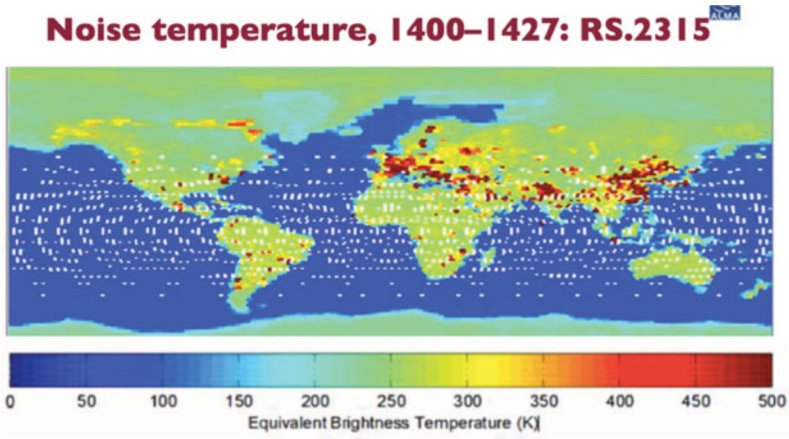

Figure 1: Radio Frequency Interference at the 21cm (or 1400-1427 MHz) HI line.

higher frequencies and broader bandwidths just when our own bandwidths are opening up, and therefore making it even more crucial to have spectrum management.

Spectrum management happens in parallel but partially overlapping sequences, which include **International allocations** at the ITU-R, the highest level, and **National allocations**, which largely track the Radio Regulations. Allocations are only the outline, the rules are the implementation, the details and the devil lives there. The ITU-R does not write the rules, it only provides some guidelines. National rules govern whether the radio allocations are usable, including

- Permitted power levels in shared bands;
- Unwanted emission levels for adjacent/nearby bands, and
- Limitations on operations in the vicinity of radio telescopes (around radio quiet and coordination zones).

Some of the allocated radio bands are unusable in some countries due to their rules, e.g. the 608 - 614 MHz in the US. Usability of 3 - 4 mm spectrum is subject to new radars, 7/8 allocated since 2000 but no rules until now. There is a global struggle to be carried out, country by country. Many of these battles are already lost.

There are a number of functioning spectrum management bodies world-wide, regionally and nationally, including IUCAF (global), CRAF (Europe and South Africa), RACAP (Asia-Pacific) and CORF (USA)†.

2.2. *Radio Quiet Protection at the Australian Square Kilometre array site*

The Australian Square Kilometre Array (SKA) and its pathfinders site is at the Murchison Radio-Astronomy Observatory (MRO), 350 km from the nearest populated centre. It has a large Radio Quiet Zone (RQZ) that is managed under a range of legislative agreements‡ (Figure 2). Murchison is sparsely populated with a population of about 120 people. The MRO site for SKA covers an area of about 50 km radius centred on the Australian SKA Pathfinder (ASKAP) centre.

There are still a range of challenges regarding the protection of the SKA site in Australia, including the challenge of having to protect a large frequency range, 70 MHz - 25.25 GHz, most of which is unprotected bands. The physical reach of the telescopes (long baselines), the time frames (50 years or more), as well as technical, social and

† See H.S. Liszt presentation for websites of these organisations
‡ From presentation by L. Harvey-Smith, CSIRO, Epping, New South Wales, Australia

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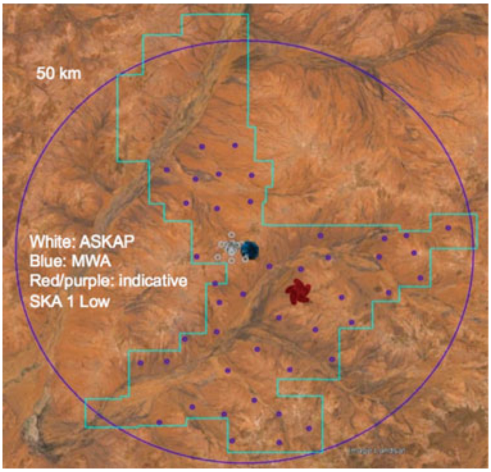


Figure 2: Radio Quiet Zone for the Murchison Radio-Astronomy Observatory.

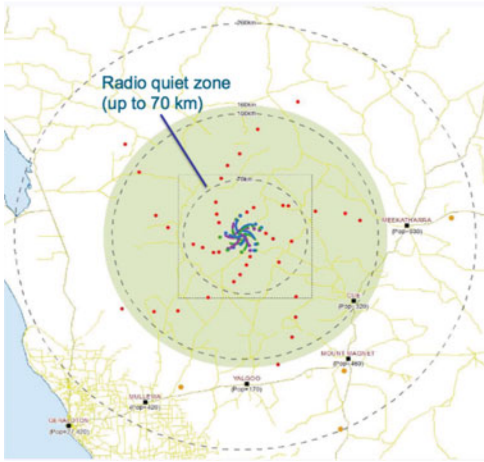


Figure 3: Radio Quiet Zone for the Australian Square Kilometer Array.

economic implications of restricting radio usage, are some of the challenges faced in trying to protect the spectrum for the SKA. Radio astronomers need to appreciate that other uses of the spectrum are also vital.

The site protection of the Australian SKA include the radio quiet zone up to 70 km radius from the centre of the array where radio astronomy is the primary user of the spectrum, and the coordinated zone, which extends up to 260 km (Figure 3). Between the 70 km and the coordination radius, applicants must assess power spectral density at the centre and power over 50 km radius. Within the 70 km radius, radio communication transmitters are secondary to radio astronomy with regard to spectrum use and control of radio interference. Spectrum licences held by mobile network carriers exclude a region in the RQZ. Users of radio devices within 70 km radius, once notified, must not cause interference to radioastronomy. Activities such as mining within the 70 km radius of the RQZ centre are to submit a radio emission management plan.

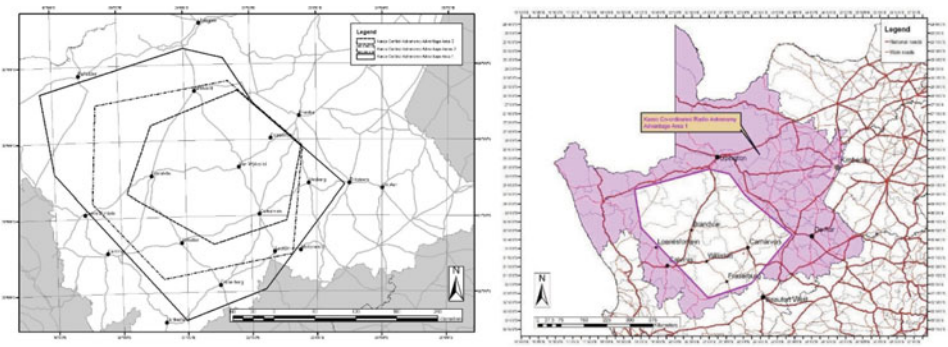
Policies are in place for limits on self-generated emissions by the telescopes as well. Every radio frequency transmitter (9 kHz to 275 GHz) must be licensed in Australia. The RQZ, however, does not guarantee absence of radio inference to radioastronomy observations. Current regulations do not cover frequencies below 70 MHz, aircraft and satellite transmissions, and transmitters beyond 260 km from the centre of the observatory.

2.3. *On the Development of Radio Astronomy and Protected Astronomy Reserves in South Africa*

Recent initiatives to take advantage of various geographic locations in South Africa that exhibit excellent conditions for astronomical observations (optical and radio) have resulted in the establishment of a number of world class astronomical facilities, including the 10-m class Southern African Large Telescope (SALT), the 64-dish MeerKAT radio telescope (under construction), and the future Square Kilometre Array†.

The Northern Cape Province (NCP) in South Africa, which is over 1000 km across, and has very low demand on wireless services due to low population density, was identified as the natural geographic advantage area for both optical and radio astronomy. It is high

† From presentation by A. Tiplady, SKA South Africa, Johannesburg, Gauteng, South Africa



100MHz – 25.5 GHz 100MHz – 2.17 GHz (to be declared)

Figure 4: Declared Astronomy Advantage Areas

and dry, and its topographical features provide a shield to radio interference. It is remote, but also has a bulk of infrastructure already available.

To preserve these natural astronomical advantages in the NCP, a unique legislation, the Astronomy Geographic Advantage Act, No. 21 of 2007 (or the AGA Act), was promulgated to establish astronomy reserves. These reserves are protected through a unique set of regulations that enable protection of astronomical facilities located in declared areas from any current, and future, sources of potential interference. The legislation empowers the South African minister for Science and Technology (DST) to declare protected areas around strategic astronomy sites (radio, optical and other multi-wavelength astronomy). The legislation also allocates all the spectrum to radio astronomy services.

The legislation gives three tiers of protected areas, including:

- *Core area* – the physical area of the observatory / instrument;
- *Central area* – surrounds the core area. Minister prohibits certain activities / categories of activities in this area;
- *Coordination area* – the Minister sets standards which activities must comply with.

The AGA Act prevails over existing Electronic Communications Act where protection of radio astronomy is concerned. Protected areas apply to both existing and new activities. The Astronomy Management Authority within the DST is responsible for enforcement of the AGA Act related regulations.

The Central Areas for the radio astronomy have been declared and the 100 MHz to 25.5 GHz bands are protected under the AGA Act regulations (Figure 4). A protection standard, which gives the protection levels that should not be exceeded, has been adopted. There are, however, some drawbacks: Protection levels are inadequate for the next generation surveys, and the narrow band is no longer the only risk, but the broadband EMI (often self-generated) is also becoming a major risk, which can be more detrimental due to complete contamination of the RF spectrum.

Implementation requires buy-in from different stakeholders, such as telecommunication operators and government. Protection requirements are implemented through all government policies. Working with telecommunication operators to optimize existing coverage and reduce impact, as well as development of alternative means of delivery of telecommunication services, are vital to ensure increased spectrum efficiency.

Management policies require that everything brought on to the site is measured, characterized and issued a permit with conditions for use to ensure protection from self-generated EMI.

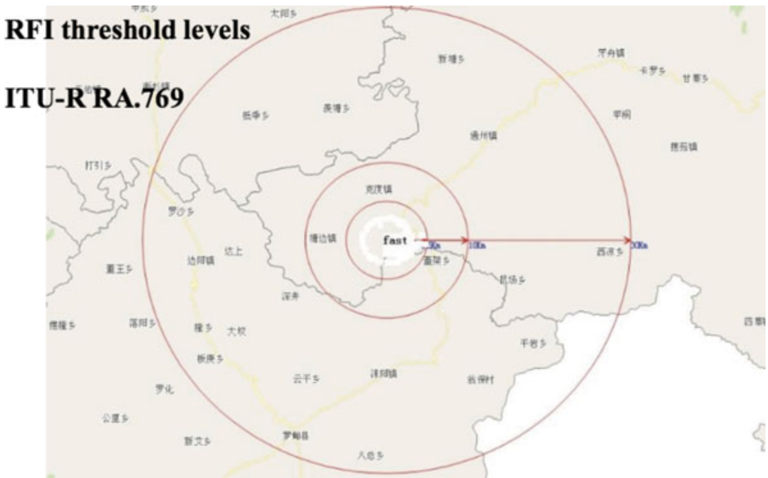


Figure 5: The outer circle represents the 30km radius of the FAST Radio Quiet Zone.

2.4. *RFI Mitigation for FAST*

The Five-hundred-meter Aperture Spherical radio Telescope (FAST) is a Chinese mega-science project to build the largest single dish radio telescope in the world. The construction was officially commenced in March ,2011, and the first light of FAST is expected in 2016†.

Due to the high sensitivity of FAST, RFI mitigation for the telescope is required to ensure the realization of the FAST scientific goals. In order to protect the radio environment around FAST efficiently, the local government has established a radio quiet zone with 30 km radius around the site (Figure 5). Moreover, Electromagnetic Compatibility (EMC) designs and measurements for FAST have also been carried out and some examples, such as EMC designs for actuator and focus cabin, have been introduced.

3. Light pollution and protection measures

3.1. *Light pollution and site protecting of the Xinglong Station, NAOC*

The Xinglong station of National Astronomical Observatories of China (NAOC) is one of the most important astronomical sites in China. The site has 9 optical telescopes at the station, including LAMOST, a 2.16 meter reflecting telescope and several other optical/IR telescopes‡.

The results of urbanisation has had negative effects on the night sky brightness at Xinglong observing station. Using Walker (1977) Population-Distance relationship model, $P \sim D^{2.5}$ shows that Xinglong observing station is at same level of light pollution as the United States was in the 1970s.

Sky brightness measurements carried out in the past 15 years between 1996 and 2011 show that Xinglong station's brightness has increased by 0.5 magnitude in i-band (Figure 6). Measurements using SQM-LE meters in February 2011 give night sky brightness of about 19.9 to 20.0 in V. Monitoring of the night sky brightness using SQM is done

† From presentation by H. Zhang, National Astronomical Observatories of CAS, Key Laboratory of Radio Astronomy of CAS, Beijing, China

‡ From presentation by Y. Zhao, National Astronomical Observatories of China, Beijing, China

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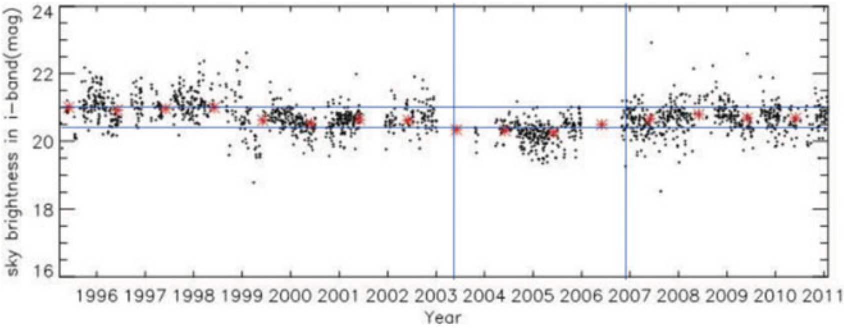

Figure 6: The Beijing-Arizona-Taipei-Connecticut (BATC) survey shows Sky Quality Meter data from 1996-2011. The i-band shows an increase of 0.5 magnitudes in sky brightness during the 15 years.

regularly to ensure that changes in observational conditions at Xinglong station are observed and the efforts to protect the site are implemented.

The protection area around Xinglong station is limited to within 5 km radius of the observing site. There are also some efforts to control dust levels around the observing station, as well as educational awareness on the effects of light pollution in the neighbouring villages.

3.2. *Site Protection Program and Progress Report of Ali Observatory, Tibet*

The Ali Observatory, Tibet, is a promising new site identified through ten year site survey over western China†. It is of significance in establishing guidelines for site protection during site development of the Ali Observatory.

The site protection program is done by looking at five aspects, including site monitoring, technical support, local government support, specific organization, and public education. The long-term sky brightness monitoring is ready with site testing instruments and basic light pollution measurements. The monitoring also includes directions of main light sources, providing periodic reports and suggestions for coordinating meetings. The technical supports with institutes and manufacturers help to publish lighting standards and replace light fixtures. The research done pays special attention to the blue-rich sources of light, which has serious impact on light pollution.

Ali Government has established an official group that leads development and protection of astronomical resources. One of the group's tasks is to issue regulations against light pollution, including special restrictions on airports, mines, and winter heating, as well as supervise lighting inspection and rectification.

A site protection office under the official group and local astronomical society is organized by Ali observatory. The office will coordinate activities at government levels and promote related activities. A specific website operated by the protection office releases activity programs, evaluation results, and technical comparisons with other observatories.

Both the site protection office and Ali Observatory take responsibility for public education, including popular science lectures, light pollution and energy conservation education. Ali Night Sky Park has been constructed and was opened in 2014. The Park provides a popular place and observational experience.

The establishment of Ali Observatory and Night Sky Park has brought unexpected

† From presentation by Y. Yao, National Astronomical Observatories, Chinese Academy of Sciences, Beijing, China

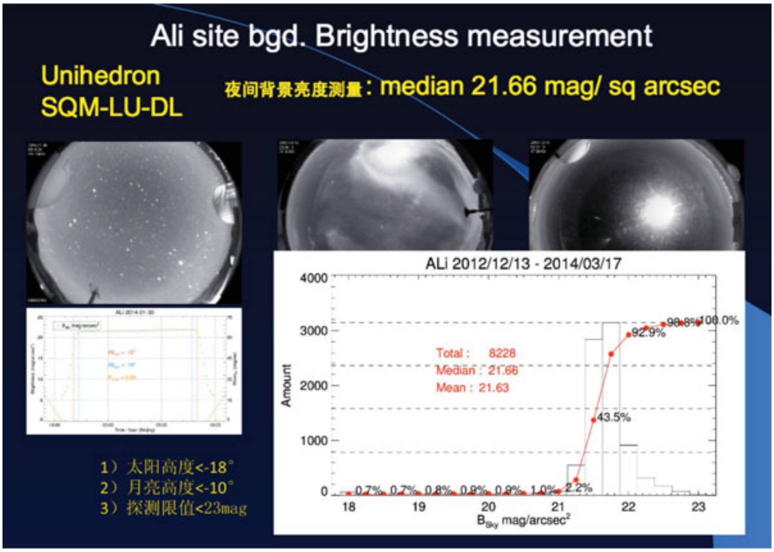

Figure 7: SQM data logger measurements of the night sky brightness of Ali Observatory averaged over a 15 month period (Dec 2012 to March 2014) give a median of 21.66 mag/sq arcsec.

social influence, and the starry sky trip to Ali has become a new form of culture-oriented travels in China. The related news reports and network programs have drawn attention of national top leadership to instruct further investigation into the national support policies.

A number of telescopes are planned to be sited at Ali Observatory, including two 1-m LCOGT telescopes, which are under construction, and a 1.0m infrared solar telescope. Average night sky brightness measurements using SQM-LU-DL during 2012-2014 is 21.7 mag/arcsec^2, which makes the Ali Observatory one of the potentially good observatories for optical astronomy in terms of limited light pollution (Figure 7).

3.3. *County of Hawaii - A Unique LED Street Light Conversion*

In 2010 the County of Hawaii was paying \$0.40/kW-Hr for electricity, \$1.5 million annual bill for 8,500 street lights. Over the past 20 years, costs have increased on an annual average of 7%. Inventory maintenance frequency for the 8,500 lights was 35%, which meant 3,000 visits per year for maintenance. The current Low Pressure Sodium (LPS) street lights were nearing 20 years of service and a complete replacement was imminent, a significant cost for the County of Hawaii and its 185,000 citizens†.

The astronomy community impact was identified early on and discussions conducted for an acceptable conversion path. Key concerns centred on the blue light content of the LED and reflected light.

A demo project with Federal ARRA funds installed 1,000 LED full cut off fixtures, achieving an energy savings of \$200,000 annually. The results were extremely successful and were loudly applauded by both the general public and the Astronomy Institute. Hence, the Traffic Division recommended to the County administration changing the remaining lights, now numbering 9,000, to new LED lights. The County administration approved the change to the LED lights and an upgrade to the outdoor lighting ordinance.

The remainder of the conversion, amounting to \$6 million for materials and labor, is

† From presentation by R.L. Thiel, Public Works, County of Hawaii, Hilo, Hawaii, USA

expected to yield an energy savings of approximately $800,000 annually with a 5 year recovery of costs that includes both energy savings and maintenance reduction.

Additional benefits achieved from using full cutoff fixtures include reduction in glare for drivers, pedestrians, and elimination of trespass light onto neighbouring residences.

Benefits achieved by using a filtered LED includes reducing blue light to <1%, diffusing the harshness of the direct LED light and the ability to use the most energy efficient lumen producing fixture to achieve in excess of 63% reduction in energy costs.

Additional aspects of this conversion will include steps to gather quantitative data showing reduction in light pollution, aerial and satellite surveys for gathering before and after ground level brightness plots along the roadways, and interpretive spectral analysis on skyward impacts.

3.4. *Checking the light pollution sources at Asiago Astrophysical Observatory from photometric and spectroscopic observations. Results from a unique experiment*

The results of recent sky brightness measurements at Asiago Observatory, in Italy, with the goal of understanding the sources and the propagation of light pollution are presented†, and show some interesting results.

The Asiago Observatory, which has four telescopes in two locations (Pennar and Ekar), is found north-east of Veneto region, and has a population of 4.9 million inhabitants. Although the region's population has been increasing slowly for the last century (by a factor <2; compare with LA with increase by a factor of about 20), its luminance has been increasing at an average of 6% per year. The region appears like a big city at night, with substantial amount of light pollution.

Light pollution regional protection law was developed between 1997 and 2009, with a committee that included astronomers, tasked with checking the effects of the law and reporting to the regional administration. From 2011, three SQMs were installed to monitor the night sky brightness.

There are actually two main models for the light pollution: one is based on a dominant Lambert diffusion. A recent model, instead, includes a cavity effect in the urban centers, limiting the low angles horizontal propagation. The effects of the local vs. distant light centers on the brightness of the night sky at the observatories are different in the two models and the regulations required to limit the light pollution are also different.

A unique experiment was carried out at Asiago Observatory in order to clarify this ambiguity, turning off more than 5000 public street lights in a 500 km^2 area around the telescopes, in a clear, moonless night. The sources of the emission lines in the spectra and their evolution were investigated.

In 2009, the Veneto regional law passed two innovative concepts, one being *upon request from the Astronomical Observatories, in connection with specific events, the local administrations agree to turn off completely (or reduce) the public outdoor illumination, up to 3 nights per year*. The 5000 street lights were indeed turned off during photometric night of 28 March 2014, in a population of about 20,000 people covering about 700 km^2. Photometric measurements were carried out using four SQMs, and observations were obtained at 3 telescopes. The main villages were in silent spectral darkness dominated by shining stars around the zenith.

The sky brightness differences between the March 28 and 30 (another photometric night), 2014, at Ekar and Pennar show some interesting results with a considerably higher gain at the nearby Pennar (50%) than at the relatively far Ekar (30%). There was

† From presentation by S. Ortolani, Dipartimento di Fisica e Astronomia, University of Padova, Padova, Italy

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no tight correlation on the gain increase through the night. During the 'dark' night, both sites had the same night sky brightness.

From the results of this unique experiment, it is concluded that (i) distant lights (50-200 km) significantly affect the sky brightness over observatories, and (ii) the contribution of the private illumination, including parking lots, sport activities, bus or train stations, gardens, etc. is relevant and can account for about 50% of the total light pollution, and therefore should be controlled.

4. Summary

Both radio and optical astronomy are affected by man-made activities at ground based observing facilities. Radio observations are sensitive to RFI, and therefore require spectrum management and national legislations to ensure that activities that are detrimental to radio astronomy are regulated. Both South African and Australian governments have promulgated legislations that protect radio astronomy sites for the SKA in those countries. There is also a need to continue to engage with the ITU-R to ensure that standards are set and selected spectra for radio astronomy are reserved only for radio astronomical use.

Radio astronomy in Australia and in South Africa shares the spectrum with many other radio systems. The Australian SKA is naturally radio quiet and it is protected by a range of state and federal legislation and emissions management protocols. In South Africa, the radio quiet astronomy reserves are protected by the AGA Act of 2007, which also protects the optical astronomy instruments such as SALT in the Northern Cape Province.

Optical astronomy at observatory sites affected by light pollution need to engage with their communities and work together with relevant authorities to ensure that suggested mitigations against light pollution are implemented. Only gathering data and confirming that a site is indeed suffering from light pollution is not enough.

References

Mitigating Threats of Light Pollution & Radio Frequency Interference, `http://www.noao.edu/education/IAUGA2015FM21`, [FM21.3: Radio and Optical Site Protection]

Report ITU-R RA.2259 2012, `http://www.itu.int/pub/R-REP-RA.2259-2012`

The Astronomy Geographic Advantage Act, 2007 (Act No. 21 of 2007), *Government Gazette* No. 31157, 17 June 2007

Walker 1977, *PASP*, 89, 405

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