European Science Foundation

35 CRAF News

The newsletter of the ESF Expert Committee on Radio Astronomy Frequencies

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Contents

Editorial

In an earlier issue of the CRAF Newsletter, the concerns of radio astronomers have been expressed at the demands of commercial organisations for the use of even more of the radio spectrum, in spite of them already having had a major increase in the spectrum allocation for their commercial use during the last few years. The long-term negative effects of the use of large numbers of satellites are still not quite so obvious to most people, but it is now becoming more and more obvious, even to the very large numbers of 'amateur' astronmers using their own smaller optical telescopes, that our concerns are very real, when it would appear that the sky (i.e. the Universe in which we live) is slowly, but surely, being closed off to us. It has been common knowledge for a long time that one needs to go to a dark place on the earth to see, and therefore investigate, our Universal surroundings. However, even in these somewhat remote places on the Earth's surface, images of the heavens are being corrupted by the tens of thousands of satellites that are now being launched into the skies.

One might think that radio astronomers might not be so badly affected. The sites for the SKA telescope have been chosen to be in desert regions of Australia and South Africa, well away from human activity apart from a few communications transmissions from satellites at specific frequencies allocated for these. Unfortunately, this is now far from the actual situation, as is illustrated in the article in this issue concerned with 'Dark and Quiet Skies for Science and Society'. It has been clearly demonstrated that the **random** noise signals from a large number of satellites add together to the signals received by a radio telescope, so that the random noise generated by the satellite equipment would have to be better than (i.e. lower than) not only the CISPR standard for electrical equipment emission, but the military standard by at least a factor of ~10 not to affect radio telescope observations. At the present time, there has been no indication that the electrical equipment in these satellite constellations has been produced to meet a standard which is more than a factor of 10 better than the military standard for electrical equipment. There is great concern about the future of radio astronomy as well as optical astronomy in the presence of satellite constellations.

Peter Thomasson

Cover: The Ventspils 32 m radio telescope.
Credit: Travel Addicts Club and Tomas Terekas

The Ventspils 32 m radio telescope after renovation. When initially taken over by the Ventspils International Radio Astronomy Centre (VIRAC) of Ventspils University of Applied Sciences (VUAS), not only was the surface in a very bad state, but one had to take great care in walking along the structure behind the dish that one would not fall to the ground through the decayed structure. See Figure 1 in the article concerning the Ventspils International Radio Centre for an indication of the state of the telescope prior to renovation.
Credit: Mârcis Donerblics, VIRAC

Report from the 68th CRAF Meeting.

The 68th CRAF Meeting, which was a 'virtual' meeting because of the continuing coronavirus situation, was organised by the CRAF Chairman and the CRAF Management team. The meeting was organised in three sections:

1. Closed Meeting for CRAF Members only
2. Closed Meeting for CRAF Members and Directors
3. Open Meeting with CRAF Members, Observers, Global Representatives and Guests.

In addition to Nicolas Walter, the Chief Executive of the ESF and its services division (Science Connect), there were 18 CRAF members present. Professor Simon Garrington, the current Chairman of the Stakeholders Forum, was present, as well as 7 other Directors of the individual observatories, who were present at appropriate times, in particular during the Closed Meeting involving the CRAF Members and Directors. In addition to 3 members of an ESF Review Panel – Pierre Cox (its Chairman), Markus Dreis and Hermann Opgenoorth – who were present, there were also 4 global representatives, L van Zee (USA CORF chairman), Anastasios (Tasso) Tzoumis (Chairman of ITU WP7D), J. Williams (USA, NSF) and M. Ohishi (NAO, Japan). There were 4 observers present; F. DiVruno and O. Braam from the SKA, H. Smith, a consultant to CRAF, and Gie Han Tan (ESO). In addition to the above there were also 9 guests present for the 'open' part of the meeting, 3 of whom were 'incoming' CRAF members. Also included in the 9 guests were Leif Morten Tangen and Susana Garcia-Espada, both of whom were representing the Norwegian Mapping Authority based in Svalbard, which was considering joining CRAF.

This report will only consider the Open Meeting, with reference as appropriate to the two closed meetings.

Following the adoption of the Agenda, there were 'roundtable' introductions by all present and a review of the Action Items from the CRAF 67 Web meeting, the minutes of which were reviewed and approved.

The CRAF Budget

Pietro Bolli had already provided a detailed review of the state of the CRAF Budget, which had shown that it continued to be run on a sound basis. Travel restrictions, because of Covid19, had continued to result in less expenditure than in the years prior to the appearance of the virus, primarily because of less expenditure on meetings and publications. However, it was noted that there would be increased demands on the budget during 2023 because of the WRC, which will take place in Dubai in the United Arab Emirates in November / December.

WRC23 + WP7D Progress report

Benjamin Winkel, Federico di Vruno and Waleed Madkour, the Frequency Manager, provided details of the current state of the WRC23 Agenda Items of greatest concern to CRAF, which were being studied at both a national and European level in preparation for the World Radio Conference (WRC) in November / December 2023. The proposals of greatest concern to radio astronomers in general, and to CRAF in particular, were those which could result in possible frequency allocations for International Mobile Telecommunications systems (IMT) at frequencies that were close to or the same as those used for radio astronomy observations. In particular, and perhaps top of the list of concerns, is Agenda Item 1.2, in which a frequency allocation has been proposed for IMT in the frequency range from ~6 to 7 GHz, in which frequency range there is a very important spectral line arising from the methanol molecule (CH3OH) at a rest frequency of 6668.518 MHz. The inner regions of 'clouds' in which star formation is taking place cannot be seen optically, but the presence of these methanol spectral lines provides the certainty that star formation is indeed taking place in its earliest stages, which can therefore be studied. Consequently radio astronomers are able to follow the formation of stars from their earliest stages, which is very important.

It would take several pages of this newsletter to cover the other Agenda Items of considerable concern to CRAF, and in particular others concerned with IMT, such as the potential use of high altitude platforms (Agenda Item 1.4). In fact, perhaps not surprisingly, many are concerned with communications between the Earth's surface and vehicles in 'space' in general e.g. aircraft, drones and satellites.

Work Items (WI) Teams

In addition to the reports considered above in connection with the WRC, it is clear that the Work Items Teams system, brought into being some time ago now, has continued to function quite well, although it is clear that additional manpower is desireable, particularly when one considers what appears to have been 'an explosion' in radio communications. The minutes of the CRAF meeting include reports covering a total of over 20 pages of text, which is much more than can be accomodated in this newsletter.

Observatory Reports

As at every CRAF plenary meeting, each CRAF member present gave a report on new or ongoing interference from which their observatories were suffering.

WP 7D Questions and Possible Actions

As was noted in the last Newsletter, the International Telecommunications Union (ITU) is the organisation dealing with spectrum allocations, and a first interaction with this organisation involving the allocation of radio spectrum for an individual group (e.g. as was the case for the geodetic VLBI community, for which there was a lack of suitable documents for the radio regulators), is the submission of a "Question" to the ITU Radio Communication Sector Study Group 7 (SG 7 - Science Services) to be considered initially by the ITU Working Party (WP) 7D (radio astronomy). Thus, two questions were submitted to WP 7D for detailed examination, with a view to producing a Report giving answers to the 2 questions, ultimately to be approved by SG 7 before consideration at the next World Radio Conference (WRC). This was achieved and, if approved at the next WRC, documentation would now exist showing the existence of the community, which requires the allocation of spectrum for its use in the future. The CRAF Spectrum manager has noted that there are several Questions associated with WP 7D, which are still under discussion, some of which are important for radio astronomy and are time limited to expire in 2023. He made all the CRAF members aware of these, so that appropriate action could be taken.

Date of Next Meeting

It was too early to decide if the next meeting would be face-to-face or not because of the Covid19 situation. In the event, all further CRAF meetings in 2020 & 2021 have been 'virtual' meetings.

Joe McCauley and **Peter Thomasson**

Ventspils International Radio Astronomy Centre (VIRAC)

The Ventspils International Radio Astronomy Centre (VIRAC), a part of Ventspils University of Applied Sciences (VUAS) in Latvia, was established in 1994 with the aim of developing research activities in radio astronomy, astrophysics and space sciences. Currently, the most important instrumentation for the centre comprises two fully steerable parabolic antennas, RT-16 and RT-32 (i.e. antenna or 'dish' diameter sizes of 16 m and 32 m), and a LOFAR station (LOFAR-LATVIA). The intensive reconstruction and instrument refurbishment, carried out at the antennae site in the years 2014-2019, have made it possible to use the radio telescopes, either as 'stand-alone' instruments or in international collaborations concerned with both fundamental and applied research in the field of radio astronomy. The most important aspect of this work has been participation in Very Long Baseline Interferometry (VLBI) international experiments. Figure 1 shows a photo of RT32 prior to its renovation. At that time the greatest care was required when attempting to set foot on any part of the telescope structure.

Figure 1.
The 32 m radio telescope of the Ventspils International Radio Astronomy Centre (VIRAC) prior to renovation.
Credit: Peter Thomasson with permission of observatory staff

During their renovation, the radio telescopes were equipped with two channel, Right and Left hand Circular Polarisation (RCP & LCP), cryogenic, broad-band receivers covering the frequency range from 4.5 to 8.8 GHz, with an instantaneous bandwidth of approximately 1200 MHz. The receivers are cryogenically cooled to 14 degrees Kelvin, which nominally results in total system noise temperatures of 30 to 50 K throughout the whole bandwidth. A secondary receiver is also available on RT-32 for observations in the band from 1.40 to 1.72 GHz. This receiver is uncooled with dual (RCP and LCP) polarisation channels, which achieves system temperatures of 60 to 100 K. Each telescope has the necesary equipment available for VLBI observations, which includes Active

Hydrogen masers, DBBC/FlexBuff data registration backends and a 10 Gbit optical fibre network. The maximum azimuth and elevation tracking speeds of both telescopes are up to 5 degrees/s with RMS tracking accuracies of 4 arcsec, thus enabling tracking of Near Earth satellites.

In addition to the above, radio telescope, RT-32, has been used for routine, spectral, polarimetric observations of the Sun using both circular polarisations, and using a multi-channel (16 frequency channels), spectral polarimeter, covering a wavelength range of 3.2 - 4.7 cm (6.3 - 9.3 GHz). This new multi-channel spectral polarimeter, installed in 2022, is also expected to be used for observations of right and left circular polarisation emission from the Sun within the wavelength range 2.1 - 7.5 cm (4.1 - 14.3 GHz), this latter frequency range being divisible into 12 frequency bands. The dynamic range of the new receiver is up to 36 db; the signal/noise ratio (referred to quiet Sun brightness temperatures) is 22-24 db.

Since 2019 VIRAC has also obtained a Low Frequency Antenna array to be used as a station of the International LOw Frequency ARray, LOFAR-Latvia. It comprises 96 low band (LBA - 10 to 90 MHz, total area 3200 sq.m) and 96 high band (HBA - 110 to 240 MHz, total area 2400 sq.m) antennas.

As indicated above, one of the main scientific uses for the VIRAC radio astronomical observatory is to contribute to VLBI observations in centimetre and metre wavelengths in collaboration with the global VLBI networks, such as the European VLBI network (EVN), LOFAR, the International VLBI Service (IVS) and others, as appropriate. The new receiving and recording systems include a high stability, time, reference frame, which is a prerequisite for the VLBI observations. Since October 2015 VIRAC radio telescopes have regularly taken part in many international VLBI sessions.

Continuing its fast evolution, VIRAC does not intend to confine itself solely to radio astronomy and astrophysics, and today the Institute also includes strong scientific groups in satellite communications and receivers, satellite development and high-performance computing. VIRAC's main target is to become a global research service provider in the field of space technology research, thus speeding up the international growth of companies in the engineering industry in Latvia and Ventspils. VIRAC is carrying out this task by providing research and research services of high quality, using a client driven approach in close cooperation with the European Space Agency (ESA) and other Research & Technological Development (RTD) organisations and companies with similar aims.

Vladislavs Bezrukovs

The high-frequency upgrade of the Sardinia Radio Telescope

In June 2023, the project proposed by the National Institute for Astrophysics (INAF) to upgrade the Sardinia Radio Telescope (SRT – see Figure 2) to enable high efficiency observations at frequencies up to 116 GHz will reach its conclusion. This project started in 2019 and was awarded almost 19 Million Euros by the National Operational Programme (PON) issued by the Italian Ministry of University and Research (IMUR). In making the award, it was stated by IMUR that 15% of the budget could also be used for upgrades of the radio telescopes at Medicina and Noto. In fact, the INAF proposal resulted from the outcome of a survey to investigate the interests of the Italian radio astronomical community to help determine the development and future use of existing and new front-end receivers to be installed at the national radio telescopes, a primary aim of which was to maximise the scientific return and to harmonise the efforts and resources of the Institute. The result of the survey clearly highlighted the interest in the use of receivers at high frequencies (>20 GHz). Two main constraints of the funding scheme were imposed, according to which were the budget destination (i.e. funding could only be used for equipment purchase) and the time-scale of the project (32 months plus an extension as a result of delays caused by the COVID-19 pandemic).

A team of approximately 60 INAF people has been involved in the upgrade of the SRT to high radio frequencies. The project foresaw the acquisition of new state-of-the-art receivers and digital backends, an advanced metrology system, dedicated computing resources, equipment for microwave technologies as well as the instrumentation to integrate these.

New high-frequency receivers

A main goal of the funding was the acquisition, installation and bringing into an operational state new high frequency radio astronomical receivers. These included:

- a multi-beam cryogenic receiver operating in the 70 - 116 GHz frequency band (W Band) for SRT. This receiver, which is fundamental for the detection of complex organic molecules through polarimetric studies of galactic and extragalactic sources, has 16 double linear polarisation beams.
- a multi-beam cryogenic receiver operating in the 33 - 50 GHz frequency band (Q Band) for SRT. This receiver, which is to be used for surveying large areas of

Figure 2.
Photo of the Sardinia Radio Telescope
Credit: Sergio Poppi

the sky in radio continuum emission and in broadband spectral-polarimetry, has 19 double circular polarisation beams.

- a bolometric millimetre camera for SRT operating in the 77 - 103 GHz frequency band composed of an array of 408 detectors (pixels) that simultaneously sample a wide field of view. This receiver is suitable for observations of extensive and diffuse emission with low surface brightness.
- a simultaneous, microwave, compact Triple-Band receiving system to be installed on all the three Italian radio telescopes (SRT, Medicina and Noto). These three triple band, cryogenic, microwave receivers operating simultaneously in the K / Q / W Bands (18 - 26 GHz, 34 - 50 GHz and 80 - 116 GHz) on all the three Italian antennas, strengthen the role of SRT in both the Italian and European VLBI networks.

State of the Art Backends

New backends are necessary to fully exploit the fleet of receivers. Three digital signal processing systems have been designed for this purpose as part of this project, and will gradually replace the current backends. The first one uses 10 SKARAB (Square Kilometer Array Reconfigurable Application Board) units for a total of 40 processed signals. The second one uses the Digital Base Band Converter 3, a platform developed specifically for VLBI. Finally, a platform based on the Radio Frequency System on Chip (RFSoC) technology uses 8 commercial boards from the Abaco System for up to 64 input channels. These new platforms will strongly enhance the data quality in terms of its dynamic range, as data will be sampled with up to 14 bits for each sample. One of the major burdens concerns the overall, instantaneous bandwidth provided by the multi-feed receivers: up to 38 signals with an aggregated bandwidth of up to 56 GHz has to be digitised and properly processed for many different scientific applications, including wide-band high-frequency resolution spectroscopy. The high processing capabilities of the new generation FPGAs enable, for each feed, a spectral resolution of up to a few hundred Hz, even in the case of a bandwidth of up to 1 GHz. A mixed FPGA-GPUs hybrid solution is required for specific applications (for example real-time pulsar search). For this reason a high performance computing cluster of 5 GPU based nodes is also part of the system, connected to the acquisition backends and to the station computing centre by a high speed (40-100 Gb) network.

Metrology system for the SRT

To reach a maximum frequency of 116 GHz, the radio telescope must have a pointing precision of approximately 1 arcsec and a surface quality of the primary mirror of approximately 150 µm (RMS, compared with the ideal profile). These goals will be achieved through a sophisticated measurement and control system of the active surface of the primary reflector and of the entire mechanical structure of the radio telescope. To this goal, the SRT is being equipped with a metrology system for the optimisation of the pointing and the gain of the antenna at all the elevations. The active surface of the primary reflector and the sub-reflector will be constantly adjusted in quasi real-time thanks to look-up tables (LUTs). The metrology system will provide a fine calibration of the LUTs allowing, on the one hand for the correction of systematic effects arising from gravity, and on the other hand for the measurement, modelling and compensation for the non-systematic effects because of thermal variations.

System integration, High Performance Computing, and equipment for microwave technologies

The set of acquired goods will be integrated together through a "turnkey" supply of electronic and mechanical interfaces, allowing the radio telescope as a whole to operate at high frequencies, optimising its frequency agility. The integration of these parts includes the transmission of the signal through coaxial cables and broadband fibre optic links, new servo systems to allow a quick switch of the telescope optics to enable use of all the installed receivers, and new mechanics for positioning the receivers at the primary focus.

Data Storage and fast computing facilities.

The provision, installation and startup of storage and high computing facilities, necessary for archiving and analysing the data obtained with SRT, is also part of the project. There are two clusters, both consisting of computational and storage nodes, distributed between the computing centre at the SRT site and the computing centre located at the INAF - Astronomical Observatory of Cagliari. The division into two parts is linked to the optimisation of the activities. The computing centre at the SRT site is necessary for the rapid analysis of the quality of data acquisition, and for the data preservation in the short term. The computing centre at the INAF - Astronomical Observatory of Cagliari is dedicated to the full exploitation of data for scientific purposes and their optimised analysis, as well as their archiving.

Electronic and Mechanical Laboratory Equipment

Finally, within the project, state of the art equipment has been acquired for the electronic and mechanical laboratories located at the INAF - Astronomical Observatory of Cagliari and also at the Sardinia Radio Telescope site. This includes very high performance, high frequency, measuring instruments for the microwave laboratory and some CNC high precision, milling machines and lathes.

At the time of writing this contribution (March 2023), out of a total of nine Work Packages, four have been fully completed and five are in a very advanced phase and will be completed by June 2023. Immediately after, the integration, commissioning and first light of the new four receivers in the Sardinia Radio Telescope will be conducted by the local team.

In conclusion, the PON project has been a great opportunity for the upgrade of the Italian radio telescopes enabling scientific programmes of great demand to be undertaken. At the same time, it posed significant technical, management and administrative challenges to fully accomplish the proposed objectives. The INAF team has invested a lot of effort into this project to ensure its successful completion.

Acknowledgements

The Enhancement of the Sardinia Radio Telescope (SRT) for the study of the Universe at high radio frequencies is financially supported by the National Operative Programme (Programma Operativo Nazionale - PON) of the Italian Ministry of University and Research "Research and Innovation 2014-2020", Notice D.D. 424 of 28/02/2018 for the granting of funding aimed at strengthening research infrastructures, in implementation of the Action II.1 - Project Proposal PIR01_00010.

Federica Govoni and **Pietro Bolli**

Car Radars

Since the beginning of 2022 car radars operating in the 24 GHz bands are no longer allowed to be installed in modern-day cars, and in particular in modern-day self-driving cars. The operating frequency range must now be in the 76 - 81 GHz range. Although this change has been welcomed by the car industry because of the enhanced performance of their equipment arising from the increased angular resolution resulting from the more than three times increase in the frequency of operation, it has not been welcomed by the Radio Astronomy Community, which has both PRIMARY and SECONDARY frequency allocations within the frequency range 76 - 81 GHz (see Table 1). This means that astronomical observations could suffer considerably when a functioning vehicular radar overlaps a PRIMARY RAS band. In addition to the above, all the bands within this frequency range have been identified as RR 5.149 bands, (i.e. bands in which administrations are urged to take all practicable measures to protect the radio astronomy band).

In the 76 - 81 GHz band, important detections of molecules in the interstellar medium have resulted from observations with first-class radio telescopes. Of great

Frequency (GHz)	RAS status	
76.0 - 77.5	PRIMARY	5.149 Band
77.5 - 78.0	SECONDARY	5.149 Band
78.0 - 79.0	SECONDARY	5.149 Band
79.0 - 81.0	PRIMARY	5.149 Band

Table 1. RAS frequency allocation from 76 to 81 GHz

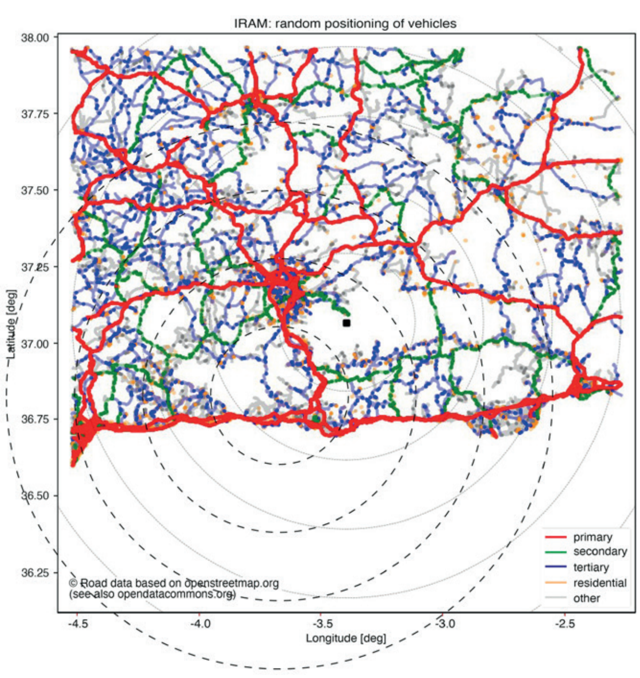

Figure 3.
An example of a random vehicle distribution around the IRAM 30m telescope in Spain.

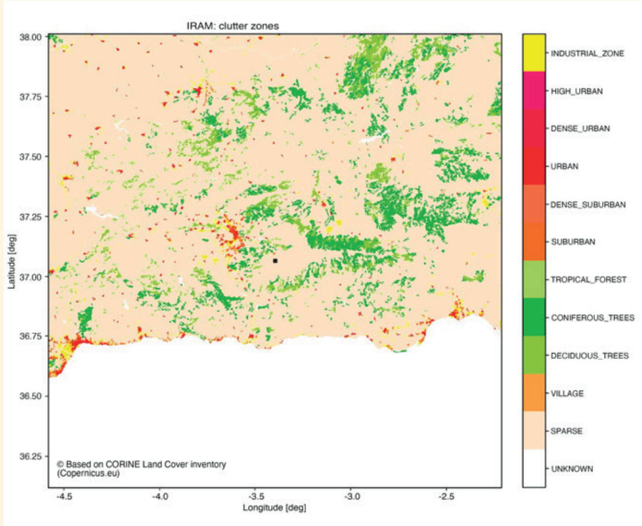

Figure 4.
Clutter area around the IRAM 30m. The data are freely available from the CORINE database.

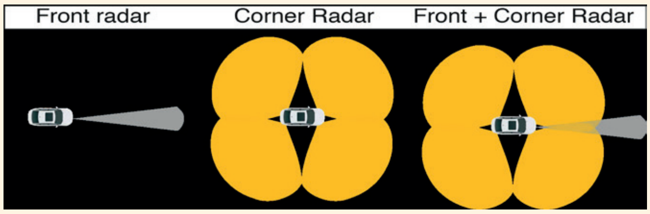

Figure 5.
Schematic view of radar directions for 3 scenarios considered in the simulation.

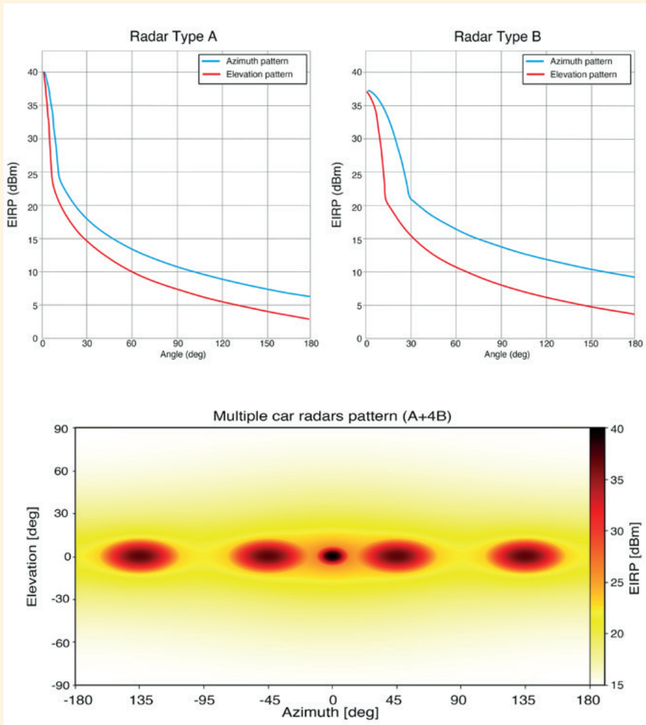

Figure 6.
Top. Antenna emission as a function of the angle (aximuth & elevation) for Types A and B.
Bottom. 2D antenna emission for multiple radars A + 4B.

scientific interest is the detection of the N2D+ molecule arising from the spectral line resulting from the J = 1-0 transition at 77.1 GHz, which is very important to be protected, as it is one of the best indicators / trackers of pre-stellar conditions. Another research field in the 76-81 GHz frequency range is the study of the emission of galaxies using measurements of highly redshifted carbon monoxide (CO) spectral lines. Analysis of these lines is necessary for an understanding of star formation within galaxies.

Automotive radars have been categorised into 2 classes based upon their required coverage range. Thus, each class is defined to have specific parameters agreeing with an appropriate antenna model and a maximum power that cannot be overcome. For example, a 'long-range' radar (usually adopted for autonomous braking) is the one with the highest power, which can cover up to 250 m using a bandwidth of up to 1 GHz and a maximum EIRP of 40 dBm.

As automotive radar applications are expected to grow in the near future, CRAF has studied and proposed to CEPT an aggregate study with the aim of defining a protection zone around radio telescopes which operate in this band: i.e. a defined area in which the radars are disabled so that they do not interfere with the RAS. The study was undertaken using pycraf – a python open-source package focused on electromagnetic compatibility calculations for RAS – involving 10 radio telescopes: NOEMA (France),

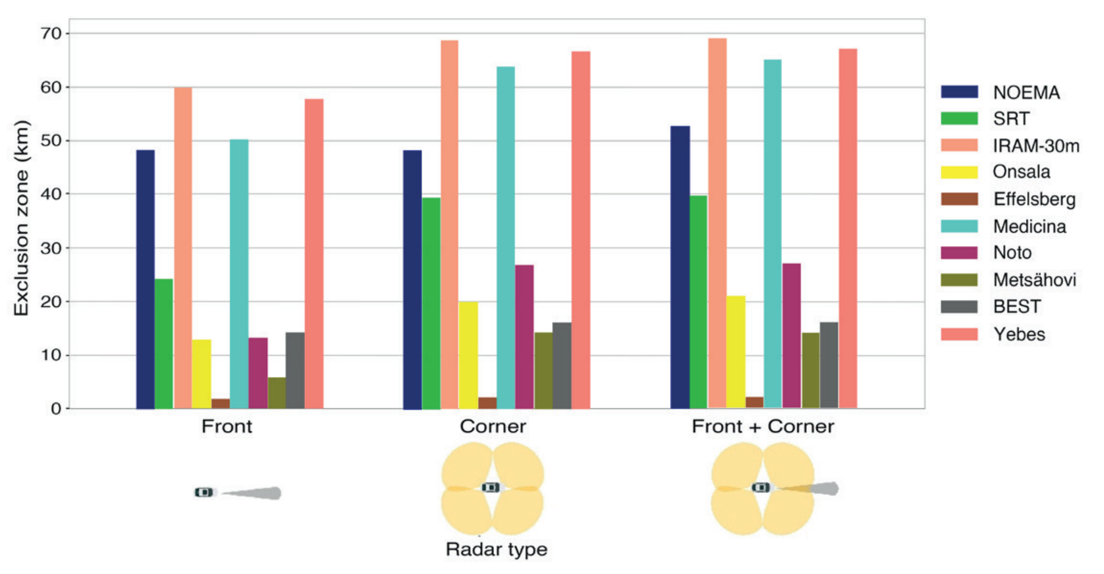

Figure 7. Summary of the exclusion zone radius for the different radar configurations for the 10 different telescopes considered.

SRT (Italy), Yebes (Spain), Best (Hungary), Onsala (Sweden), Effelsberg (Germany) Noto (Italy), Metsähovi (Finland), IRAM (Spain), and Medicina (Italy). It has been conducted by simulating a distribution of moving cars around the radio telescopes according to the road classification given by the Open Street Map. Figure 3 shows an example vehicle distribution around the IRAM-30m radio telescope in Spain, in which the coloured lines (red, green and blue) indicate major, lesser and minor highways respectively. The corresponding coloured dots along these highways give examples of the vehicles travelling along the highways, with the orange and grey coloured dots representing vehicles associated with residences or on even more minor roads. Figure 4 shows the corresponding distribution of clutter (i.e. absorbing material - shown at a reduced scale) to be taken into account in assessing the interference level at the IRAM-30m telescope. For each of the telescopes considered, the positioning and the density of the cars was varied during 100 iterations with the aim of emulating traffic fluctuations that might occur between day and night and throughout the year. In the study, a large computation region (200 km × 200 km) was assumed and the attenuation of the car radar signals was modelled according to Rec. ITU P.452, while the estimate of the clutter (vegetation and buildings that attenuate the signal) was acquired from the CORINE cartographic database.

It has been assumed that there are 2 types of vehicle radars – front of the car radars, which are considered to be of type A, whilst corner radars (note that a car was assumed to have four corner radars) are of type B, which are of less strength. Figure 5 shows the schematic coverage of each radar. The combination of both, called A + 4B, helps to understand the impact of RAS compliance whilst considering an almost realistic scenario.

Figure 6 illustrates the antenna EIRP emission of radars A & B, and the power distribution in the space of multiple radars A + 4B. Type A, because of its greater power and narrow field of view, causes the most interference when the car (whilst being driven) points towards the radio telescope, whereas type B, installed as a corner radar, ensures wide coverage for the car, but causes varying interference with the various movements of the car. The ability to enable or disable the radars when a car is close to a radio telescope could ensure the reduction of interference, but for this to occur it is necessary that the car has a GPS system to detect its position in real time. A summary of the exclusion zones for the radiotelescopes under test is given in Figure 7. The results for the 10 different sites show a huge spread between locations because of the high dependence upon terrain attenuation for each site. For vehicles with type A radars (i.e. front radars), it appears to be this radar alone that normally determines the exclusion zones (mostly more than 20km) for most sites. In conclusion, excluding Effelsberg, which is located in a valley surrounded by hills that well shield the antenna, it would appear that the other radio telescopes that have been studied require an exclusion zone with a radius of at least 10 km. An extended study has been proposed to ECC-CEPT under the SE24 group.

Fabio Giovanardi

Dark and Quiet Skies for Science and Society

a) Introduction

Advances in technology have made access to electromagnetic emitters efficient and cheap in the optical (lighting systems) as well as in the radio regime (radio transmitters such as mobile phones). Their usage has significantly increased in recent years. A positive effect of this is increased global accessibility to these resources, whereas the negative consequences are light and radio pollution. The establishment of light emitting diodes (LEDs) as the main emitters in the lighting industry, the impending commercialisation of space exploration and the aim to supply customers globally with mobile broadband internet access pose a threat to astronomy, the bio-environment and indeed human health in various ways, especially since national and international regulations are lagging well behind the rapid technological developments. The first launch of the Starlink satellite constellation in May 2019 has led to a reaction in the astronomical community. Movements to protect the dark and quiet skies in collaboration with industry and regulators have come into being and are now been reinforced. Amongst other activities, a working group has been formed to gather all the required information concerning the current status of light pollution and its projected development for the foreseeable future.

A number of major international conferences have been organised, amongst which has been an international meeting, organised by the United Nations Office for Outer Space Affairs (UNOOSA) and the International Astronomical Union (IAU), which took place during the week of 3 - 8 October 2021. Originally it was supposed to take place in Santa Cruz on the beautiful island of La Palma, but the hosting institution, the Instituto de Astrofísica de Canarias, had to make arrangements for 'remote' participation for all, this time not because of COVID, but because of a volcano eruption on the island.

The conference had two main purposes:

- to critically review an existing report, which followed the progenitor workshop Dark and Quiet Skies for Science and Society (https://www.unoosa.org/static/publication/dqskies-book-29-12-20.pdf)
- to work towards the formulation of a set of recommendations with the aim of protecting astronomy, human beings and the bio environment from the negative impact and interference resulting from the new technologies.

The conference was divided into two (partly overlapping) sessions dealing with Artificial/Anthropogenic Light at Night (ALAN), Satellite Constellations (with the emphasis on Low-Elevation-Orbit, LEO, satellite constellations or "mega-constellations") and radio astronomy. Delegates representing all stakeholders attended - astronomy, industry and regulatory bodies. Special attention was given to the legal backbone of potential regulatory recommendations. The workshop schedule and reports, together with uploaded presentation slides, is still available online (see 'Dark and Quiet Skies for Science and Society II – October 2021'). This newsletter report provides a summary of the findings and a brief overview of the events in the wake of the conference.

b) Artificial or Anthropogenic Light at Night (ALAN)

The session initially discussed state-of-the-art research into the potentially negative impact of ALAN on various systems such as the bio environment, human health and astronomy. Actual measurements of the strength and the impact of ALAN were then presented and finally potential recommendations. Figure 8 shows a world map of light pollution based on satellite data, showing bright and dark areas on the Earth's surface. Results from the progenitor workshop, working groups and contributions at the conference may be summarised as follows:

ALAN definitely has a negative impact on the bio-environment and human health. In particular, blue light with a Correlated Colour Temperature (CCT) > 3000 K is damaging (i.e, light with "neutral white" to blue colour at a CCT > 3000 K) as opposed to "warm white" to red light with a CCT < 3000 K. Better still is "amber" light, with a CCT < 2200 K. However, it has been noted that some organisms, including human beings, also react to some extent to red light. This means that not only should the CCT be adjusted, but that light pollution should be reduced in absolute terms.

ALAN has a profound impact on the (human) circadian rhythm and results in a reduced production of Melatonin (a sleep hormone). In fact, it is clear that ALAN carries various risks to human health: cancer, obesity, diabetes, cognitive and affective impairments, as well as being a safety issue. ALAN is a major bio-environment risk as many species rely on the day/night rhythm. Its contribution to insect extinction is significant, and it has also been shown that water organisms as well as vertebrates are affected directly or indirectly, to various degrees. ALAN (trivially) has a negative impact on optical astronomy as it creates skyglow (Figure 9), a brightening effect of the sky seen over hundreds of kilometers. The

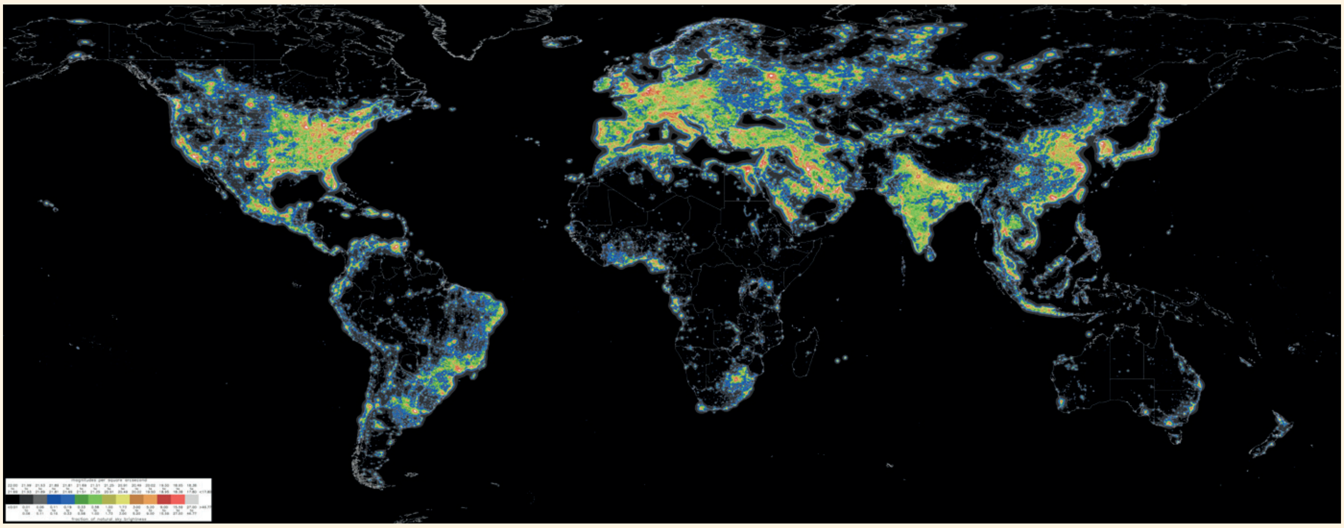

Figure 8. Light pollution atlas 2020. Credit: D. Lorenz

Figure 9. Light dome and light pollution in Villach, Austria. Credit: A. Hänel

effect is that in front of a bright sky, darker foreground objects are increasingly difficult to detect, which is why during the daytime stars are not visible, but at most one or two planets. Dark Sky conditions (~22 mag/arcsec^2 or 174 µcd/m^2 for the specialists), in which the sky is only illuminated by natural sources, is the ideal condition for astronomical observations and any individual wishing to enjoy the dark skies. Sometimes moonlight and polar light are present. The atmosphere itself has a shimmer of variable brightness, the atmospheric airglow. Reflections of sunlight on interplanetary dust and gas cause the so-called zodiacal light, and the stars always illuminate the night. Such conditions can be established in the most remote places, but astronomy is now being threatened even in those remote places. Currently, the modest request of astronomers is not to allow the sky brightness to grow by more than 10 percent above the natural level at big astronomical sites. Unfortunately light pollution has indeed increased substantially over the past two decades, often for simple reasons. Thus, blue light creates a worse sky glow as it scatters more efficiently in the atmosphere and LED illumination usually has a high blue component. Since LEDs are energy-saving, they are being used more and more, even endorsed by administrations, for good reasons: their usage helps to reduce the carbon footprint for illumination. Unfortunately, the negative effect is that even more light is produced than necessary. It can be shown that the measured light pollution (in terms of total emitted power) has increased by 50% in the past 25 years. As the satellites used to observe this light pollution from space are usually less sensitive to blue light, this is probably a lower limit, and the true increase in light pollution is much higher. Even LEDs with a CCT of 3000 K would contribute to a major increase of light pollution. The illuminants of choice are High-Pressure-Sodium (HPS) lamps emitting at a CCT of 2200 K, which used to be most common. Alternatively, LEDs without or with the minimum amount of blue contribution should be used.

A non-neglectable effect of ALAN is the loss of the dark night sky as a cultural heritage. Ancient cultures and even some modern religions refer to the dark night sky and there are some cultures that even depend on the night sky. Many children, living in cities under conditions where barely a single star is visible, have never seen the Milky Way across the sky.

Several recommendations were discussed. A first action would perhaps be to increase the awareness of light pollution as a severe problem and to draw attention to the unwillingness of official bodies to take action. Potential stakeholders were discussed, a possible partner being the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS), its secretariat being UNOOSA, one of the co-organisers of the conference as indicated above. Since astronomy is 'the oldest' subject concerned with the exploration of outer space, playing a major role in the interpretation of space missions and ensuring earth security through asteroid detection, astronomy may perhaps fall under the cover of COPUOS protection, which would send a strong signal to administrations worldwide, perhaps leading to international regulations for the protection of astronomy.

A further proposal was to coordinate with the International Union for Conservation of Nature (IUCN), since ALAN has not only implications for astronomy, but also profoundly impacts all life on earth. However, whilst there are severe wide-ranging effects of ALAN, it has its largest impact on the surroundings of light pollution sources. Local solutions to establish dark zones (e.g. around telescopes) should therefore be established. As a regulatory measure, the introduction of an additional environmental lighting zone LZ-0 into the existing zoning scheme (LZ-1 to LZ-4) of the International Commission on Illumination (CIE) was proposed, thus defining a new dark zone. Using this, local and international authorities could update light pollution legislation and recommend or enforce general rules for light protection (based on zoning). The following simple measures, known for a long time, which could be taken when coupled with adaptable standards dependent upon the local zoning are:

- Reduce the emitted power
- Reduce the light cones
- Control the colour (towards red)
- Use adaptive lighting, which means time-regulated and reactive lighting. In practice, this means the use of light only when required; e.g switch it off in less populated areas after midnight and use light sensors to regulate lighting.

Whilst these measures may be regulated and enforced, there is no reason why an individual cannot voluntarily apply them, both for the benefit of the individual and also for the communities and environment. Many people do not know about the impact of light pollution and would react if they knew. Therefore educational campaigns could play a big role.

c) Satellite Constellations

Optical interference, caused by low-earth-orbit satellite constellations, is a topic of growing importance. The recent, rapid commercialisation of space exploration, and in particular the growth of commercial carrier providers, has already resulted in an 'exploding' number of satellite launches, with several more thousands already being planned. This is likely to lead to a situation in which, in the near future, approximately every tenth object on the visible sky might be moving. Low-earth-orbit (LEO) satellite systems are particularly threatening for astronomy. In the optical, satellites reflect sunlight and can therefore produce satellite trails on CCDs (Figures 10a and 10b) as well as contributing to a general enhancement of the sky brightness.

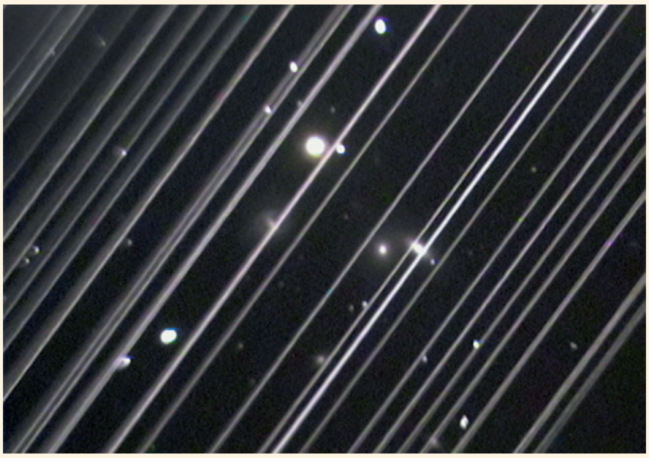

Figure 10a.
Image of the Galaxy Group NGC 5353/4 taken with a telescope at the Lowell Observatory in Flagstaff, Arizona, on 25 May 2019. The trails represent 25 of 60 Starlink satellites launched into orbit.
Credit: V. Girgis, Lowell Observatory

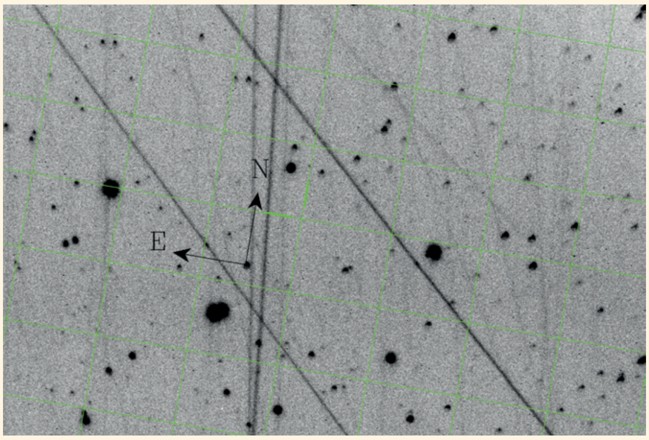

Figure 10b.
Satellite trails in an observation with the REM telescope on 21 October 2020, La Silla.
Credit: Emilio Molinari, INAF

In the radio regime, LEO constellations are active emitters as, although their main purpose is to supply mobile broadband internet access by radio transmission, they also radiate through unintended emission in the radio regime. Whilst radio and optical observations are both affected, the conference first addressed the impact of LEO constellations on optical astronomy and on the introduction of potential technical, computational and regulatory counter measures.

A conclusion from the SatCon1 workshop report was that satellites should be deployed in orbits at lower altitudes. Lower orbits are generally better as they are

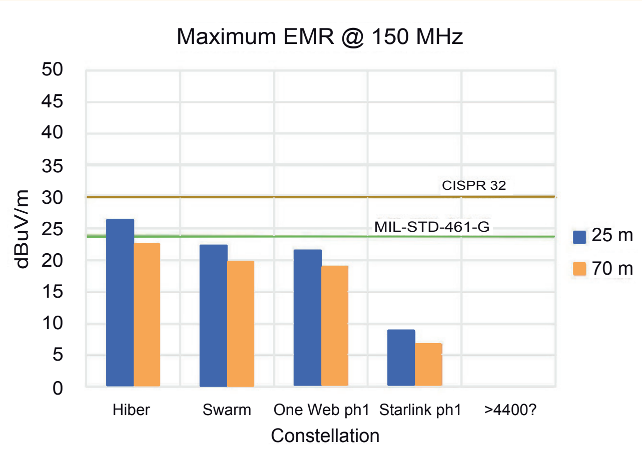

Figure 11.
The required thresholds for unintended radiation **per satellite** for several constellations to guarantee that the aggregate signal (i.e. that resulting from all the satellites in particular constellations) falls below ITU limits. The calculations have been made assuming both a 25-m and a 70-m radio antenna.

visible for a smaller fraction of the night and closer to the horizon. As a second rule, satellites ought to be fainter than a V-band magnitude 7.0 + 2.5 log (r/550km), where r is the distance from the observer to the satellite. In human terms this means that no satellite, including those in the lowest Earth orbits, should be visible by eye at night, even under good conditions. Otherwise, in the near future every 10^{th} object in the sky will be moving. In addition, the formula expresses the fact that satellites should become fainter with altitude, because they are effectively moving at a lower angular speed and therefore cover fewer CCD pixels, which in turn would more easily saturate to a damaging level.

Unfortunately, measurements show that even this goal has not been achieved by the existing satellite constellations to date. The estimated impact on optical observations is the loss of several percent of the data, which has a non-negligible financial impact. A global atmospheric glow as a result of light scattering by satellites does seem to be at a negligible level at present. However, it should be noted that in the above calculations the effect of micro-lensing and obscuration by satellites has been ignored. Further studies dealing with these effects are required. It is clear that for mitigation of the impact of satellites on astronomical observations, standardised tools for tracking (in real time) and for the prediction of satellite orbits are required, as is the ability to automatically mask out satellite trails in images. The relevant international bodies, which regulate the use of satellites and the allocation of their orbits are potentially COPUOS and the International Telecommunications Union (ITU), which latter also regulates access to the radio transmission bands. It is viewed as somewhat remarkable that parts of the space industry, in particular SpaceX/Starlink, has not tried to avoid expenses in working with astronomers to reduce the impact of LEO constellations with measurable results. It can be hoped that this collaboration will become a precedent for collaboration between research and industry and will lead to solutions to the benefit of all parties involved.

d) Radio Astronomy

As CRAF members know only too well, because of the exponentially increasing use of radio transmission as a means of communication, radio astronomy already has a severe dark sky problem. Radio astronomers, however, have something of an advantage over optical astronomers in that they have had a long-standing involvement in regulatory processes, which already exist. Radio Astronomy Services are already recognised and partly protected as so-called passive services by the ITU. However, the scarce resource of radio frequencies has now resulted in an immense, frequency allocation problem and the increasing usage of satellite communications is making the allocation of localised radio-quiet zones especially problematic. It became very clear from the radio session of the DQS2 that International Mobile Telecommunication systems with larger and larger advertised bandwidths pose an increasing threat to radio astronomy. As already indicated, radio astronomers have already been engaging for a long time with national and international regulatory bodies and industry to mitigate the impact of the increased usage of radio communications. Within Europe, this is one of the core responsibilities of CRAF. Whereas coordination zones and/or radio quiet zones can protect major radio astronomy sites from terrestrial interference, satellite transmissions reach even the most remote observatories, such as the ALMA and SKA sites. Thus, LEO satellite constellations add another dimension to the general threat. On top of this, it would appear that smaller facilities are likely to have a lower level of regulatory protection, although it must be said that this not only applies to satellite RFI, but also to terrestrial interference.

In a presentation by CRAF member Federico Di Vruno, based on contributions of several CRAF members, the additional potential threat from LEO constellations was highlighted. Their transmissions might not only affect radio astronomy in frequency bands close to their allocated carrier signal, but also because of their unintended radiation, which is unrelated to the transmitting system. This is the radio noise which all electronic devices emit, and which is not regulated by the ITU. The sheer number of planned satellites of this type is now leading to the conclusion that the EMC resulting from the equipment on the satellites has to be better by more than a factor of ~10 than the military standard for the suppression of such noise in order not to impact radio astronomical measurements. In Figure 11, the horizontal lines represent household (CISPR 32) and military (MIL-STD-461-G) standards for unintended radiation for electronic devices. Clearly shown is that nearly all satellites have to perform much better than the military standard by a large factor, not at all easy, if even possible.

e) Conclusions

The DQS2 workshop had a significant impact both for optical and radio astronomy. To a large extent influenced by the discussions and the outcome of the conference, a new IAU centre, dedicated to the protection of the dark and quiet skies was created. CRAF supported the bid by the Square Kilometre Array Observatory (SKAO) and NoirLAB (the US centre for ground based astronomy) to host the IAU Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference (CPS), which was inaugurated on 1 April 2022 and launched on 3 June 2022. CRAF continues to actively support the CPS. CRAF member Federico Di Vruno is Co-Director of the CPS, and several CRAF members have joined the CPS to contribute to the various working groups.

The SKAO, ESO, and IAU are now permanent observers in COPUOS, enabling them to bring astronomy matters at a UN level in this powerful gremium. In fact, at the 58th session of the COPUOS Scientific and Technical Subcommittee from the 19th to 30th April 2021, a paper submitted by Chile, Ethiopia, Jordan, Slovakia, Spain and the International Astronomical Union containing recommendations to Keep Dark and Quiet Skies for Science and Society was discussed. The CPS is seeking further attention by the international community at COPUOS.

While the conference had quite a few effects in the field of satellite constellations, it remains to be seen whether it was also able to boost the efforts within the astronomical community, society and industry to reduce ALAN. CRAF will continue its work, with a particular new focus on the study of LEO constellations, building upon the preliminary studies presented at the DQS2 conference. It is pleasing that there is now a strong group within the optical astronomical community endeavouring to protect astronomy at an international, regulatory level.

(Workshop virtually held in Santa Cruz de La Palma, Canary Islands, Spain; 3-8 October, 2021)

A Report by G. I. G. Józsa, B. Winkel, and F. Di Vruno

Observations of the Taurus Molecular Cloud (TMC) – Discovering complex molecules in space

Introduction

Although it appears to be not far from the Pleiades and Hyades star clusters, but is very unlike the Orion Nebula in appearance, the very dark Taurus Molecular Cloud (TMC) is perhaps of greater interest to radio astronomers and to those searching for life in the Universe. TMC-1 appears to be a cold starless core located within Heiles' Cloud 2 in the Taurus constellation. It has been the target of numerous studies as it has been recognised as a rich molecular source. Within the Taurus cloud complex, several dark cores show similar physical characteristics, but TMC-1 stands out as the one where the largest amounts of carbon-bearing molecular species have been detected. All recent discoveries of new molecules in TMC-1 have been made by two sensitive spectral line surveys at low frequencies, the GOTHAM spectral survey (https://greenbankobservatory.org/science/gbt-surveys/gotham-survey/) which uses the Green Bank 100 m radio telescope in the X, K, and Ka bands, and the QUIJOTE line survey (https://www.iff.csic.es/discovery-of-benzyne-o-c6h4-in-tmc-1-with-the-quijote-line-survey/) which is based on the observations in Q-band (31.5-50.3 GHz) with the 40 m radio telescope of the Yebes Observatory.

Receivers and 'Backends'

New receivers and 'backends', built under the frame of the European Research Council (ERC) synergy project "Nanocosmos", were installed at the Yebes 40 m telescope in 2018 (Figure 12). The front-end is an ultra-wide band (UWB) device consisting of two cold HEMT amplifiers covering the 31.0-50.3 GHz band with horizontal and vertical polarisations, followed by room-temperature down-converters (IF: 1-19.5 GHz), RF over fiber optic signal transportation, signal distributors and a bank of base-band converters. The receiver temperature is 16 K at 32 GHz and 25 K at 50 GHz. The back-ends are 2 × 8 × 2.5 GHz FFT spectrometers with a spectral resolution of 38.15 kHz providing the whole coverage of the Q-band in both polarisations. A detailed description of the telescope, the front-end, down-converters and spectrometers, and the system performances, is given in Tercero et al. 2021 (A.&A., 645, A37).

Figure 12.
Photo of the Yebes telescope taken during the wintertime.
Credit: H. Martin Perez-Martinez

Observations

The observations were carried out during different observing runs with the Yebes radio telescope between November 2019 and October 2022, with a total observing time on the source of 758 hours. The sensitivity of the QUIJOTE observations is a factor of 50 times higher than for previously published line surveys for this source at the same frequencies. The result has been the detection of a ‘forest’ of weak spectral lines, many of them arising from the iso-topologues of abundant species, but most interestingly also from new molecular species. As an example of the quality and sensitivity of the data, Figure 13 shows the lines assigned to indene (highlighted in red), c-C9H8, the first non-functionalised Polycyclic Aromatic Hydrocarbon (PAH) discovered in space together with cyclopentadiene (Cernicharo et al., 2021, A.&A., 649, L15). The results from TMC-1 also show that there is an interesting carbon-rich chemistry that leads to the formation of long carbon-chains, radicals, cations and anions, and neutral, closed-shell molecules such as cyanopolyynes. The cold dark core also hosts a number of nearly saturated species, such as CH3CHCH2, more typical of hot star-forming cores. The QUIJOTE line survey has detected more than 40 new molecules in TMC1 in the last two years, many of them being linear or ‘bent’ hydrocarbons and cycles. Moreover, nine new sulphur-bearing species, nine cations, several hydrocarbon radicals, anions and a couple of O-bearing species are among the detected molecular species. It is clear that these results require an in depth revision of the chemical models and new laboratory experiments to understand how these complex molecules are being formed. All these relevant discoveries in Q-band were possible because of the high-sensitivity of the receiver and its large instantaneous bandwidth, which, above all, was unaffected by humanity generated interfering signals. It is of the utmost importance for radio astronomers to keep the K, Ka and Q bands free from harmful, non-natural radio signals. Otherwise it would be impossible to detect these very weak, molecular lines such as the ones shown here (note that the lines of indene (coloured red) are indeed very weak, of the order of 1 mK, see Figure 13). Some improvement in QUIJOTE sensitivity should be possible to enable the detection of lines of 0.4 mK at the 5 sigma level, resulting in many more new discoveries, which will show the complexity of the chemistry of a cold starless core. To achieve this purpose, these not so low frequency bands require protection. The sensitivity level required for an understanding of the chemical evolution of the Universe needs a complete lack of spectral contamination at a very low intensity level.

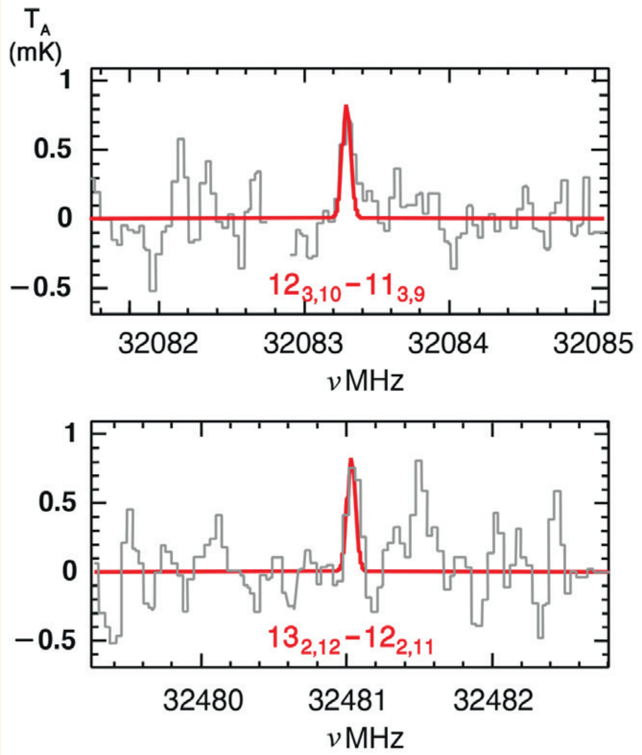

Figure 13.
Examples of spectra obtained. Lines assigned to Indene highlighted in red.

It is clear that the frequency management work of CRAF, i.e. its group of expert members, is critical for the achievement of new discoveries in radio astronomy and, therefore, has to be recognised and valued by the radio astronomy community.

José Cernicharo; José Antonio López-Perez

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- COAlition S
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- The European Astrobiology Institute (EAI)
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Committee on Radio Astronomy Frequencies (CRAF)

CRAF is an Expert Committee of the European Science Foundation. Established in 1988, it represents all the major radio astronomical observatories in Europe. Its mission is to coordinate activities to keep the frequency bands used by radio astronomers in Europe free from interference.

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