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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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1 Introduction

The training activity of RadioNet is devoted to equipping radio astronomers and engineers with the skills, which are essential to take full advantage of the present and future radio astronomical infrastructures by offering a focussed set of schools and forums.

Spectrum management is critical for the future of radio astronomy. It is also interesting and even challenging, as it requires a combination of scientific motivation, technical background, legal knowledge and diplomatic skills. These skills are normally not taught as part of science curricula. The Spectrum Management School trains the next generation of Scientists, Engineers and Administrators in the skills enabling discoveries via observations using the radio spectrum.

The 5th IUCAF 5th School on Spectrum Management for Radio Astronomy was held in Stellenbosch in South Africa from March 2nd to March 6th 2020. The event website is at http://www.iucaf.org/sms2020/

2 Spectrum Management School

Over 80 years ago K. G. Jansky first detected radio emission from the Galaxy, while searching for the origin of the weak static that was causing interference to communications. Since then, radio astronomy has revolutionized our view of the Universe through the discovery of quasars, pulsars, the Cosmic Microwave Background, surveys of our Galaxy in the 21-cm hydrogen line, molecular lines, and many other phenomena. The radio window was the first non-optical window in the electromagnetic spectrum explored by astronomers, and radio techniques continue to be a prime tool in the exploration of the Universe. At the same time, radio astronomy retains close ties to the world of radio communications, adopting some of its leading technologies, and sometimes giving rise to technologies of its own adopted by radio engineers for commercial applications.

During the 20th century, radio astronomers enjoyed relatively easy and interference free access to large portions of the spectrum, by locating telescopes far from potential sources of man-made noise. A small number of specialists took care of regulatory issues that arose in national and international fora that rarely required attention from the broader astronomy community. This state of affairs has been changing rapidly in the 21st century.

The IUCAF School in Spectrum Management was an opportunity for rising spectrum managers to profit from the experience of colleagues. The purpose being to train the next generation of scientists, engineers and administrators in the skills necessary to protect the scientific use of the radio spectrum. Ever increasing availability of wireless applications (mobile phones, Wireless LANs, etc.), communication satellites and marketing of new technologies, such as ultra-wide band systems, power line telecommunication systems, cognitive radio systems and dynamic spectrum access (DSA) put pressure on the scientific use of the spectrum. The development of radio astronomy depends critically on astronomers' continued access to the radio spectrum, and this in turn demands that astronomers and particularly radio observatories pay closer attention to the technical and regulatory issues that arise in relation to managing the radio spectrum, particularly as they relate to radio astronomy.

Spectrum management is an important component in the successful operation of any radio astronomy facility.

IUCAF spectrum management schools were previously held in 2002 (Green Bank, USA), 2005 (Castel San Pietro Terme, Italy), 2010 (Mitaka, Japan) and 2014 (Santiago, Chile). The meeting presentations are available at

https://www.atnf.csiro.au/people/Tasso.Tzioumis/sms2020/presentations/

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2.1 Programme

Monday, 2 March 2020

09:00 Introduction

Greetings from the SOC	T. Tzioumis
Welcome from the sponsors	
SARAO	Adrian Tiplady (SARAO)
CRAF, RadioNet	Michael Lindqvist (Chalmers)
IUCA	Harvey Liszt (NRAO)
Introduction of participants	All

11:00 Radio Astronomy in South Africa

SARAO, SKA & Radio Astronomy in South Africa	A. Tiplady (SARAO)
Engineering Aspects of MeerKAT & the SKA	J. Jonas (SARAO)
Science with MeerKAT	F. Camilo (SARAO)

14:00 Radio Science & Technology

Radio science and engineering basics	A. Clegg (Google)

16:00: Radio Science & Propagation

Radio astronomy and radio telescopes	T. Tzioumis (CSIRO)
Radiowave propagation	C.Wilson (CSIRO)

Tuesday, 3 March 2020 – Spectrum Management

09:00 Spectrum Management

History and Principles of RF spectrum management	S. Cruz-Pol (NSF)

11:00 Spectrum Management -The International Regulatory Structure

International spectrum management, basics and implications for Radio astronomy	V. Nozdrin (ITU)
The role of WP 7D	T. Tzioumis (CSIRO)
IUCAF and radio astronomy spectrum management at 60	H. Liszt (NRAO)

14:00 National and Regional Regulatory Structures and how they feed into the International structure

South Africa, African region	B. Sethole (SA)
USA	A. Zauderer (NSF)
Americas, CITEL	A. Zauderer (NSF)
Europe, CEPT, CRAF	W. Madkour (CRAF)
Asia-Pacific Region, APT, RAFCAP	M. Ohishi (NAOJ)

16:00 The Regulatory Structure in Practice

ITU-R Recommendations, RA series	M. Ohishi (NAOJ)
ITU-R Reports, RA series	M. Ohishi (NAOJ)
The ITU-R Radio Astronomy Handbook	T. Tzioumis (CSIRO)

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Wednesday, 4 March 2020 – Meerkat or free day

Thursday, 5 March 2020

Quiet Zones, Coordination & Knowing Your Antagonists, Pycraf

09:00 Radio Quiet Zones in theory and practice	T. Tzioumis
RQZ around the world and ITU-R Report RA.2259	F. Di Vruno (SKA)
External management of RQZ	A. Tiplady (SARAO)
Internal management of the Karoo RQZ	B. Otto/C. van der Merwe (SARAO)
Internal management of Murchinson Shire RQZ	C. Wilson (CSIRO)
11:00 Satellite coordination; radar systems and their coordination	
Satellite coordination-I: Iridium, radar	H. Liszt (NRAO)
Satellite coordination: SpaceX	A. Zauderer (NSF)
Active sensors: Radar system bandwidth requirements	J. Colom-Ustáriz (NSF)
PR TARS coordination example	S. Cruz-Pol (NSF)
14:00 Pycraf afternoon - I	
Introduction to Pycraf	F. Di Vruno (SKA)
Basic exercise	F. Di Vruno (SKA)

Friday, 6 March 2020

RFI Detection, Measurement, Mitigation

09:00 RFI detection and mitigation	A. Clegg (Google)
AI Techniques for RFI Discrimination	B. Bassett (SARAO)
RFI Mitigation	G. Hellbourg (CIT)
11:00 Measurement & Instrumentation	
Measurement and Analysis Tools & Techniques	B. Otto (SARAO)
A 4G/5G cell detection & monitoring setup for MRO	B. Indermuehle (CSIRO)
Measurement Infrastructure & Instrumentation	B. Otto (SARAO)
14:00 Views from the outside looking in and the inside looking out	
An industry perspective	A. Clegg (Google)
Development of spectrum management system	V. Nozdrin (ITU-R)
15:00 Wrap up	

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2.2 Attendance

The school attracted 55 participants from Europe, Asia, the USA, Australia and South Africa. Almost 20% of the attendees were female. The event was also attended by up to 5 local students.

A number of experts including from areas outside radio astronomy have been invited to present at the school. These include:

- Sandra Cruz-Pol (NSF) - University course in Spectrum management
- Andrew Clegg (Google) - An industry perspective (see also previous schools)
- Vadim Nozdrin (ITU-R) - the ITU perspective
- John Zuzek (NASA) and SG 7 chair
- Paulette Woody (NRAO) - RQZ expert

Figure 1 – Global distribution of participants.

Figure 2 – SMS 2020 participants in the grounds of STIAS, Stellenbosch. © Dineo Mahab

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	Last Name	Affiliation	Country
1	Baloye Musa	SARAO	South Africa
2	Bautista-Duran Marta	Yebes Observatory, IGN	Spain
3	Botha Antheun	SARAO	South Africa
4	Bothma Aneshka	SARAO	South Africa
5	Clegg Andrew	Google	USA
6	Colom-Ustariz Jose	NSF	USA
7	Cruz-Pol Sandra	NSF (National Science Foundation)	USA
8	Dineo Mahabo	SARAO	South Africa
9	Di Vruno Federico	SKAO	UK
10	Drew David	ICASA	South Africa
11	Dube Busisiwe	SARAO	South Africa
12	Eiman Duocasius	SARAO	South Africa
13	Fynn Jason	SARAO	South Africa
14	Hase Hayo	Bundesamt für Kartographie und Geodäsie	Germany
15	Havenga Johan	SARAO	South Africa
16	Hellbourg Gregory	California Institute of Technology	USA
17	Helmy Islam	National Research Institute of Astronomy and Geophysics	Egypt
18	Indermuehle Balthasar	CSIRO Astronomy and Space Science	Australia
19	Isaac Sihlangu	SARAO	South Africa
20	Jaroenjittichai Phrudth	National Astronomical Research Institute of Thailand	Thailand
21	Lindqvist Michael	Onsala Space Observatory	Sweden
22	Harvey	National Radio Astronomy Observatory & IUCAF	USA
23	Liu Qi	Xinjiang Astronomical Observatory, CAS	China
24	Lopez-Perez Jose A.	Yebes Observatory, IGN	Spain
25	Mabusha Kabo Onesmo	SARAO	South Africa
26	Madkour Waleed	CRAF/JIVE	Netherlands
27	Matabane Thomas	South African Civil Aviation Authority	South Africa
28	Mazibuko Brandon	SARAO	South Africa
29	McCauley Joe	DIAS	Ireland
30	Melhuish Simon	University of Manchester	UK
31	Mere Kgampe	Department of Science and Innovation	South Africa
32	Mojela Doreen	ICASA	South Africa
33	Monyepao Ntebaleng	ICASA	South Africa
34	Moroka Kaizer	Science and Technology	South Africa
35	Motsepe Khomotso	ICASA	South Africa
36	Msani Nduduzo	SKA SARAO	South Africa
37	Nametshego Gumbi	Department of Science and Innovation	South Africa
38	Nozdrin Vadim	ITU	Switzerland
39	Ntuli Nosipho	ICASA	South Africa
40	Ohishi Masatoshi	National Astronomical Observatory of Japan	Japan
41	Otto Braam	SARAO	South Africa
42	Pakade Ntuthuzelo	SARAO	South Africa

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	Last Name	Affiliation	Country
43	Punyawarin Songklod	National Astronomical Research Institute of Thailand	Thailand
44	Sethole Busang	SARAO	South Africa
45	Subrayen Firdosia	ICASA	South Africa
46	Tóth L. Viktor	Eötvös Loránd University	Hungary
47	Thomas Yvan	Paris Observatory / CRAF	France
48	Thupana Machoene	ICASA	South Africa
49	Tiplady Adrian	SARAO	South Africa
50	Tornatore Vincenza	Politecnico di Milano DICA	Italy
51	Tshongweni Siyabulela	SKA	South Africa
52	Tzioumis Tasso	CSIRO	Australia
53	van der Merwe Carel	SARAO	South Africa
54	Wilson Carol	CSIRO Astronomy and Space Science	Australia
55	Zauderer Bevin	National Science Foundation	USA

3 Impact

The radio spectrum is a limited resource, under ever increasing pressure for frequency allocations by active (= emitting) users. Users need to share the radio spectrum, while providing sufficient protection of the passive (= receive only) Radio Astronomy Service (RAS). Spectrum management is the use of regulatory means to achieve this goal.

There are no formal, regular courses for our intended participants to learn about spectrum management specifically for radio astronomy, it is mainly on-the-job training, with a long learning curve. This Summer School will provide a thorough introduction to the many aspects involved.

This summer school attracted the largest number of participants to date for the IUCAF spectrum management summer school. Some of these participants are experienced spectrum managers, but the majority were not. This represents a significant transfer of knowledge to a wider group at a time when scientific use of the radio spectrum is under pressure from commercial interests.

At least nine RadioNet beneficiaries were directly represented, plus staff/students from telescopes currently involved or planning participation in EVN/Global VLBI. The situation in 2020 is becoming ever more urgent, as the number of planned communication satellite launches is increasing exponentially. A number of mitigation strategies are under discussion, such as switching off transmission whilst above major telescopes. The radio astronomy community needs to have well-informed representatives going in to such negotiations, both technically and in terms of understanding potential impacts on the local communities (e.g. the economic benefits of building and operating radio astronomy infrastructure v. a specific form of communication). This school was a vital and rare opportunity for radio astronomers and regulators to meet with industry representatives e.g. SpaceX, Google.

The school also demonstrated, and provided training in, how observatory spectrum management experts can help the radio astronomy community. The pycraf software package is used to calculate the impact of ground- or space-based emitters with known characteristics, on antennas with various response patterns. Various other tools for interference mitigation or excision were also introduced. All students received a copy of the most recent (and one of the only) textbooks, RF Spectrum management (Sandra Cruz-Pol).

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4 RadioNet financial support

The RadioNet contribution was used to support the travel costs of individual trainees (12000 €):

- Vincenza Tornatore – Politecnico di Milano/IT
- Viktor Toth – Loránd Eötvös University/HU
- Marta Bautista – Centro de Desarrollos Tecnológicos/ES
- Joe McCuauley – TCD/IR
- Phrudth Jaroenjittichai – National Astronomical Research Institute of Thailand/TH
- Songklod Punyawarin – National Astronomical Research Institute of Thailand/TH
- Ivan Thomas – Nançay Radio Observatory/FR
- Simon Melhuish – UMAN/UK
- Islam Helmy – National research institute of astronomy/EG

5 Acronyms

IUCAF	International Council of Science
RAS	Radio Astronomy Service
EVN	European VLBI Network
VLBI	Very Long Baseline Interferometry

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