The MITRA as a solar and ionospheric instrument
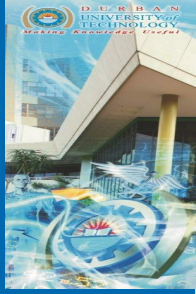
Girish Kumar Beeharry[1]

Mauritius Radio Telescope

Department of Physics

Faculty of Science

University of Mauritius

gkb@uom.ac.mu

Stuart MacPherson[1] & Gary van Vuuren[1]

Department of Electronic Engineering

Faculty of Engineering &

the Built environment

Durban University of Technology

1: Principal investigators

Outline

-Radio astronomy in Africa

-Motivation

-Overall description

-Station outline

- Sensitivity & Resolution

- Science & Technology

- Preliminary work

- People

- Ministerial visits

Multifrequency Interferometry Telescope for Radio Astronomy: MITRA

मित्रं हुवे पूतदक्षं वरुणं च रिशादसम ।

(Rg veda mandala 1 suukta 2 paada 7)

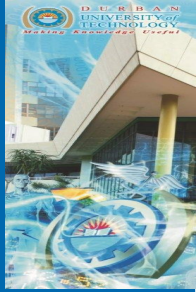mitra, of holy strength, I call, and foe-destroying varuNa, who make the oil-fed rite complete[1].

-Vedic god of contracts, meetings; modern meaning friend.
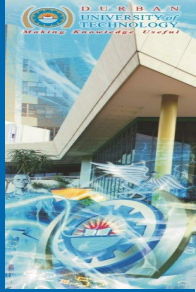
- Friend telescope.

1: http://en.wikisource.org/wiki/The_Rig_Veda/Mandala_1/Hymn_2

Radio Astronomy in Africa

- Pre African SKA bid (2004): South Africa & Mauritius only

- Post bid (2015): Botswana, Ghana,, Kenya, Madagascar, Mozambique, Namibia, Zambia and other countries

- Training: students, technicians & engineers RSA HCD programme

- African VLBI Network AVN

Motivation

· Developing an base in astronomy, engineering and technology.

· Involvement in international scientific collaboration.
  A major boost to research in radio astronomy in Africa.

· Original output in science and technology from Africa.

· Modularity and cost compared to large dishes

MITRA: Overall description

- A sensitive high resolution multi-frequency dual polarity

- Frequency range 200 to 800 MHz

- Multiple independent stations of low-cost dipoles

- Baselines: ~metres, ~1-250-500-1000-3000 km-

- Instrument & station: modular & subsets

- Technical specifications function of number of stations
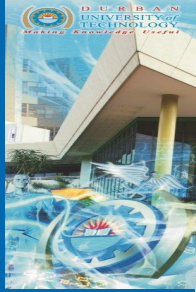
MITRA: Station outline

- Each station: sufficient sensitivity and resolution built in.

- Front-end & the back-end integrates with data acquisition.

- Local system synchronised, centrally, with other stations.

- The data pipeline: intra-station & inter-station correlation.

- Intra & inter station hub management

- Inaging & spectroscopy

Sensitivity 1

- Sky noise ~300-1000 K Galaxy@150MHz (Golap 1998)

- No cooling of field electronics: science & cost factor

- Mauritius Radio Telescope~250 mJy point source sensitivity per station for 1024 antennas. (Golap 1998, Pandey 2006, Daiboo 2012). 1 MHz BW, 16 s integration, area ~4000 m^2

- MITRA 2nd stage ~128 antennas: aim for < 2.5 Jy

Sensitivity 2

-The w term

-Convolution & Gridding

-Primary beam

-Phasing

-Bandwidth decorrelation

-Ionospheric effects

   ►Problem in ~low frequency imaging

   ►Used to advantage here

Resolution

ν	λ	Resolution						
MHz		10m	100m	1km	500 km	2500km	5000km	
		<---------------------------- arcseconds-------------------->						
50	6.0	123758.9	12375.9	1237.6	5.0	2.5	1.24	0.495 0.248
100	3.0	61879.4	6187.9	618.8	2.5	1.2	0.62	0.248 0.124
200	1.5	30939.7	3094.0	309.4	1.2	0.6	0.31	0.124 0.062
300	1.0	20626.5	2062.6	206.3	0.8	0.4	0.21	0.083 0.041
400	0.8	15469.9	1547.0	154.7	0.6	0.3	0.15	0.062 0.031
500	0.6	12375.9	1237.6	123.8	0.5	0.2	0.12	0.050 0.025
600	0.5	10313.2	1031.3	103.1	0.4	0.2	0.10	0.041 0.021
700	0.4	8839.9	884.0	88.4	0.4	0.2	0.09	0.035 0.018
800	0.4	7734.9	773.5	77.3	0.3	0.2	0.08	0.031 0.015
900	0.3	6875.5	687.5	68.8	0.3	0.1	0.07	0.028 0.014

uv coverage
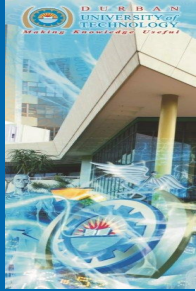
$$u = x_\lambda \sin H + y_\lambda \cos H$$

$$v = - x_\lambda \sin \delta \cos H + y_\lambda \sin \delta \sin H + z_\lambda \cos \delta$$

$$w = x_\lambda \cos \delta \cos H - y_\lambda \cos \delta \sin H + z_\lambda \sin \delta$$

-The w term becomes important for non local baselines.

uv coverage 2 stations

uv coverage 14 stations

Connectivity

http://manypossibilities.net/africa-undersea-cables

RFI levels 45-870 MHz

Christian Monstein 2013

RFI levels 45-870 MHz

Christian Monstein 2013

Extremely wide field imaging with heterogeneous non coplanar arrays

- Short spacing
- w/n term, sampling & visibility
- Primary beams: size and dependence on position
- Bandwidth decorrelation
- Imaging & CLEANing etc
- Future problem for the SKA
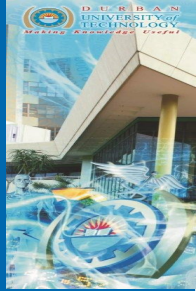
MITRA: Science I

- **<u>Solar: flares, coronal mass ejections</u>** (de Pontieu et al 2011, Zaarashvili et al 2013)

- The Milky Way, Galactic centre star forming regions(Yusef-Zadeh et al 2013)
- Galaxies and clusters of galaxies (van Weeren et al 2011)
- Pulsars & Supernova remnants (Stappers et al 2011, Han et al 2013)

MITRA: Science II

- Low brightness wide sources (Dodson 1997)
- Transient sources (Nithyanasdan et al 2011, Bannister et al 2011, Schmidt et al 2013)
- Spectral and recombination line observations (De Pree et al 1997)
- Spectral indices of sources(Miley et al 2008)
- Interstellar scintillation, Jupiter (Rickett et al 2002, Zarka et al 2005, de Pater et al 2003)

- **<u>Ionospheric and Space Weather</u>** (Judd et al 1987)

MITRA: Technology I

- Receiver system design (Ginourie 2009, Lutchumon 2011, Mahadu 2011, Bhoyrub 2012, Chataroo 2012, Armoogum 2013)

- Data acquisition system design (N. Pirthee 2013)

- Radio Frequency(RF) Electronics
(UOM & DUT projects with collaboration)

- Networking (Conhyea 2007, Armoogum 2013)

MITRA: Technology II

- Data Management (Brunner et al 2001, Morgan et al 2013, Grange et al 2012)

- High Capacity Multi-Parallel-Correlation (Begeman et al 2011, Jheengut 2008, Platel 2010, Mondon 2011, N. Pirthee 2013)

- Antenna design (Muthoor 2005, Ramdohee 2007, Mohur 2007, Boyjpnauth 2008, Nursimhulu 2009, Nunkoo 2009, Prayag 2011, Shibchurn 2013)
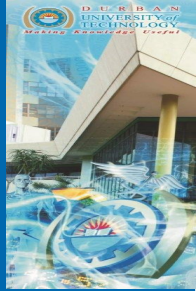
- VLBI and e-VLBI (e.g EVN)

MITRA Preliminary work:
Antenna design Version 1

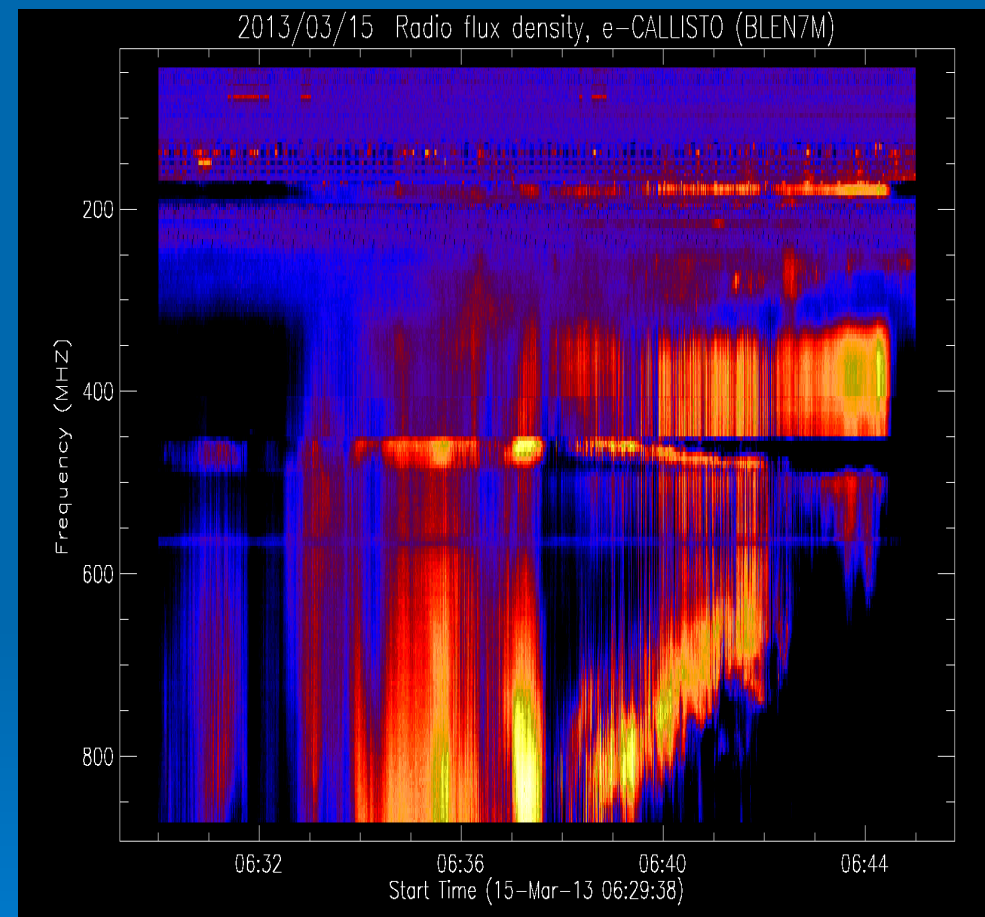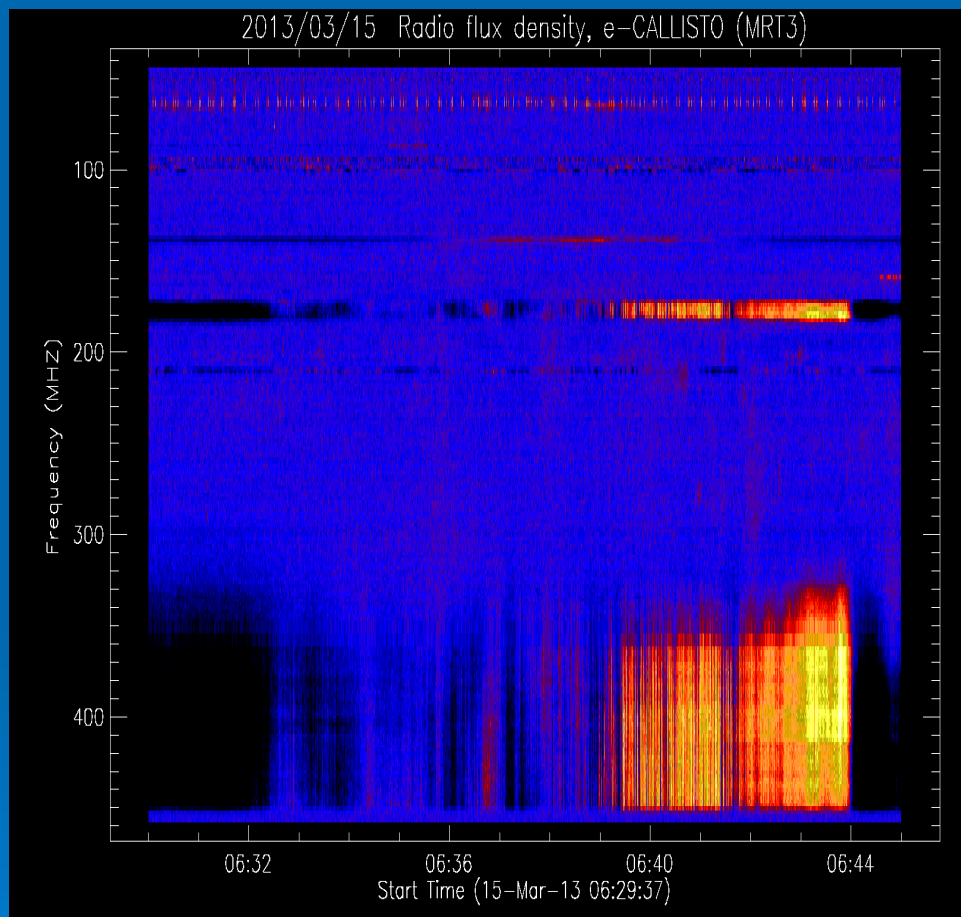Prayag, Lallbarry & Beeharry @ Bras d'Eau, Mauritius

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015

MITRA Preliminary work:1st antenna 100-850 MHz

MRT
Bras d'Eau
Mauritius

GK Beeharry

DUT
Durban
RSA &
Students
from Kenya
& Zambia

G Van Vuuren

MITRA Preliminary work:
Solar flare with antenna 1 20.4.2011
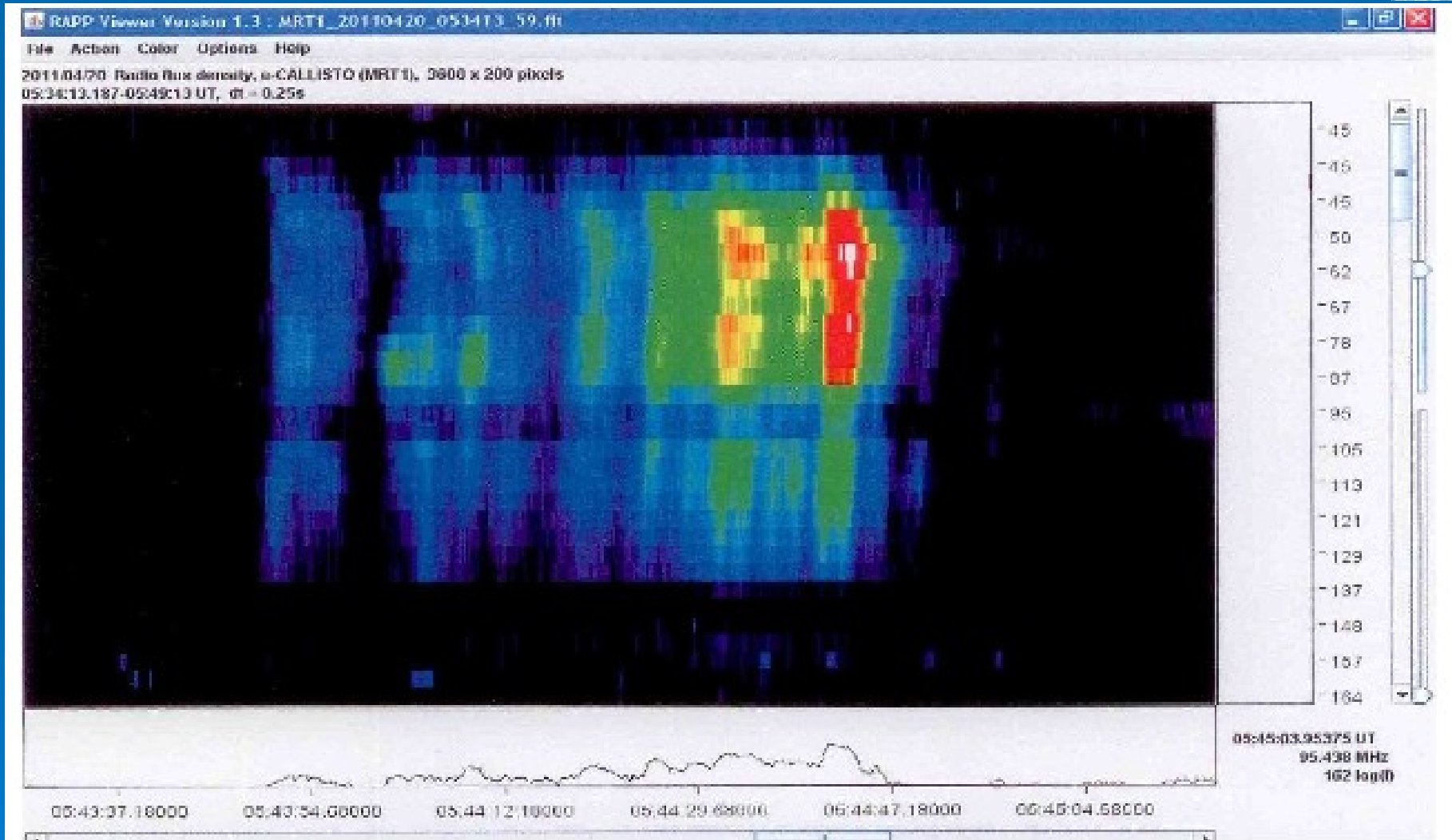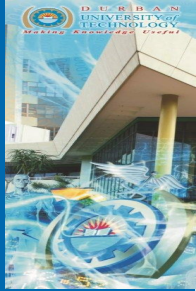
MITRA 1.:
new antenna design 200-800 MHz
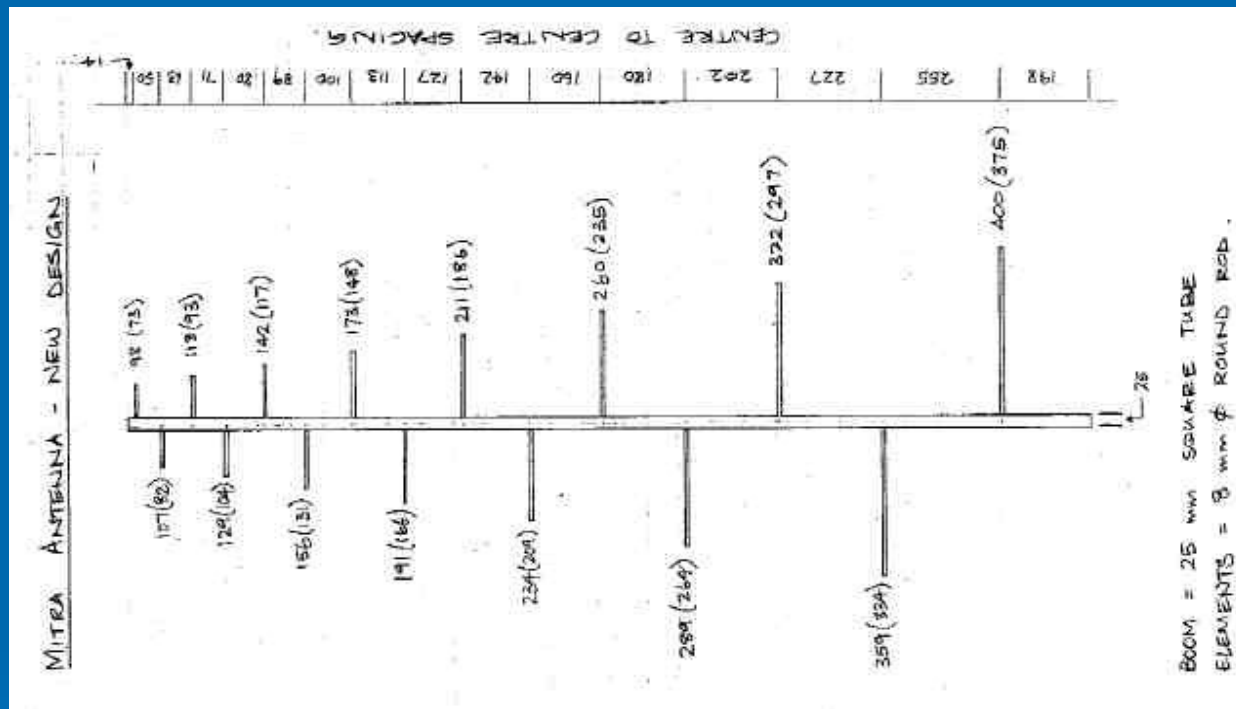
New Antenna design@DUT, Durban, RSA

Antenna@MRT Bras d'Eau, Mauritius

MITRA 1.0: simple model new antenna design 200-800 MHz.
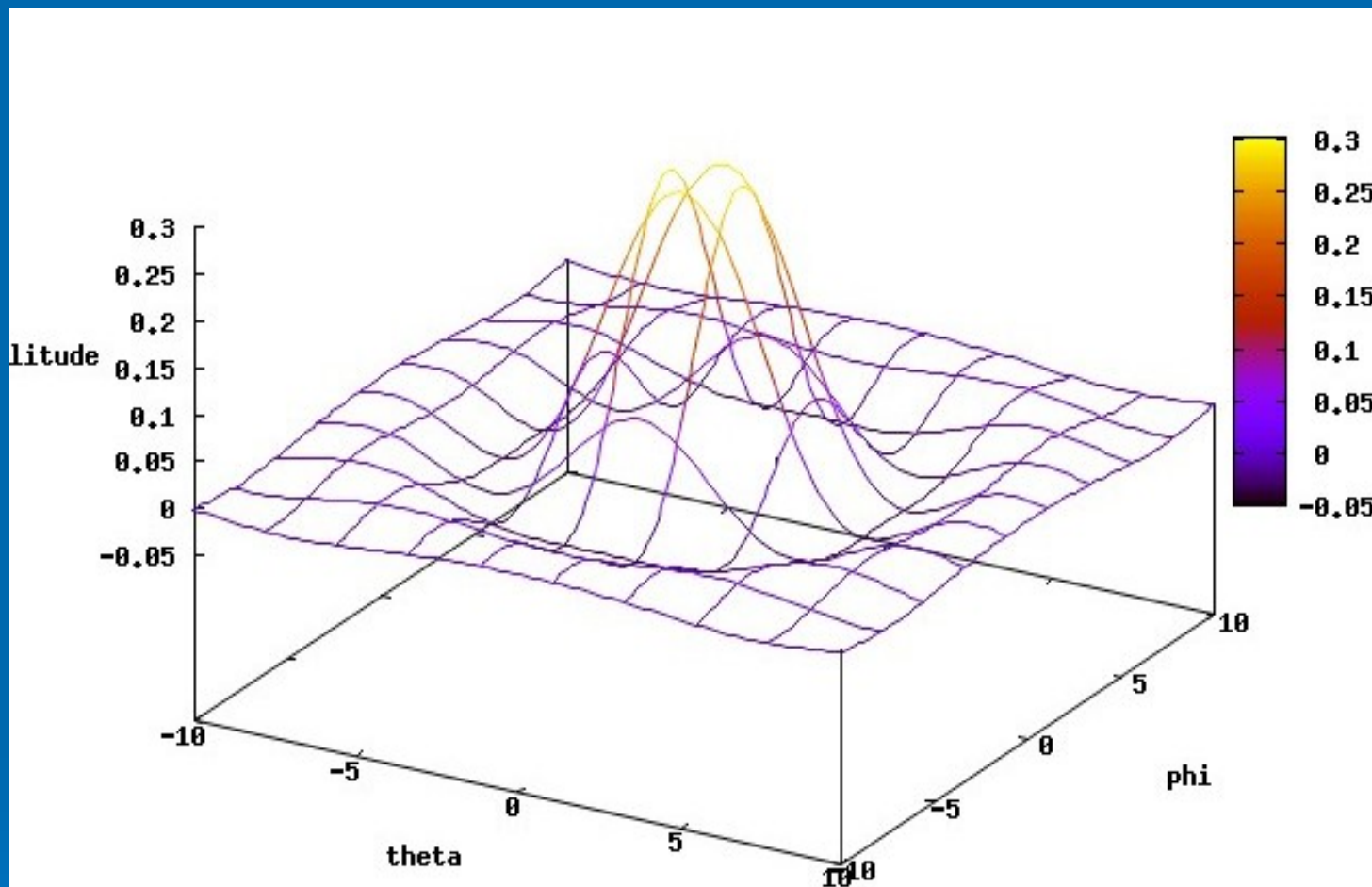
K Bhoyrub & A Chataroo 2012 Bras d'Eau, Mauritius

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015
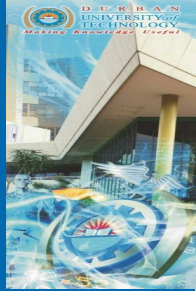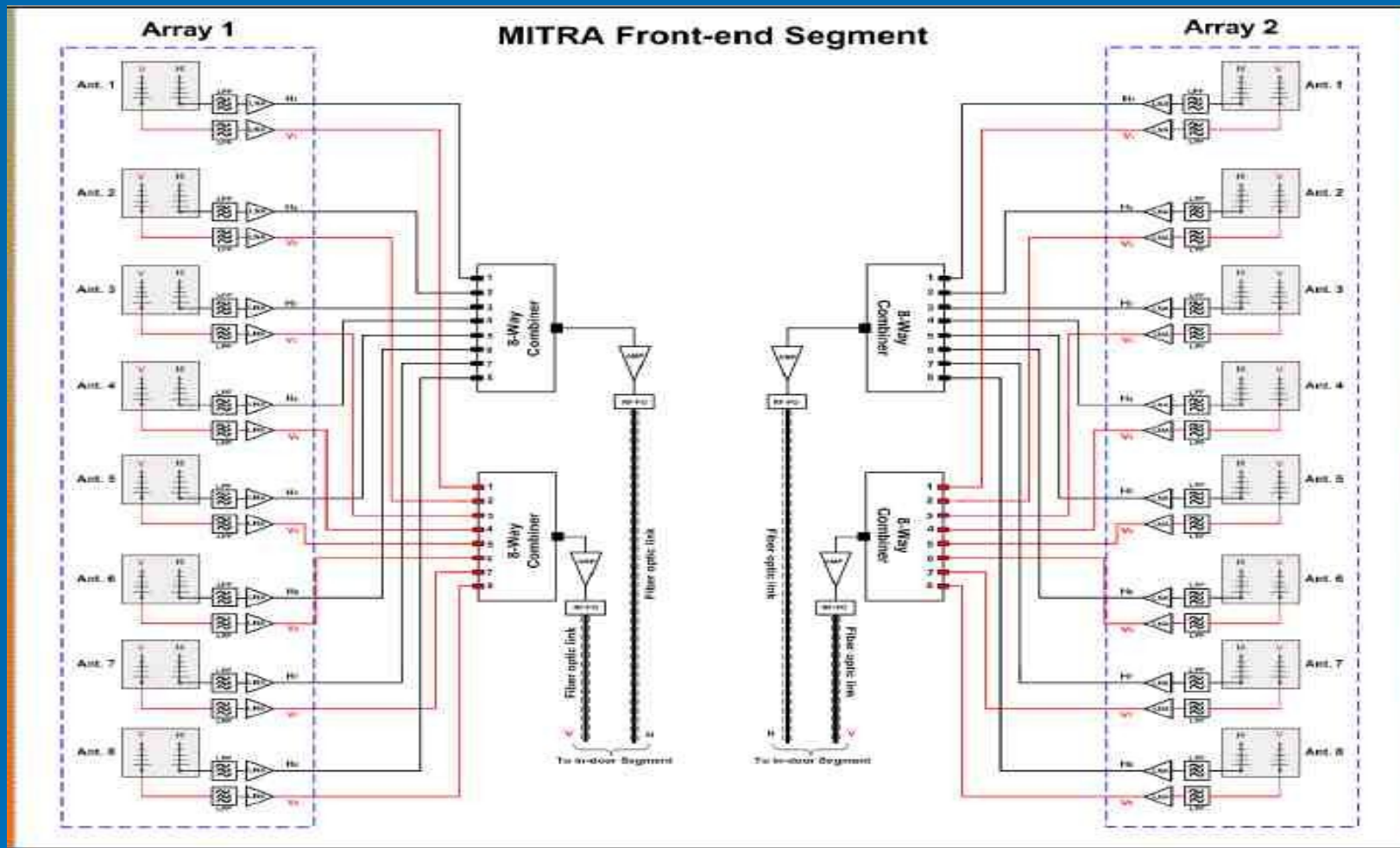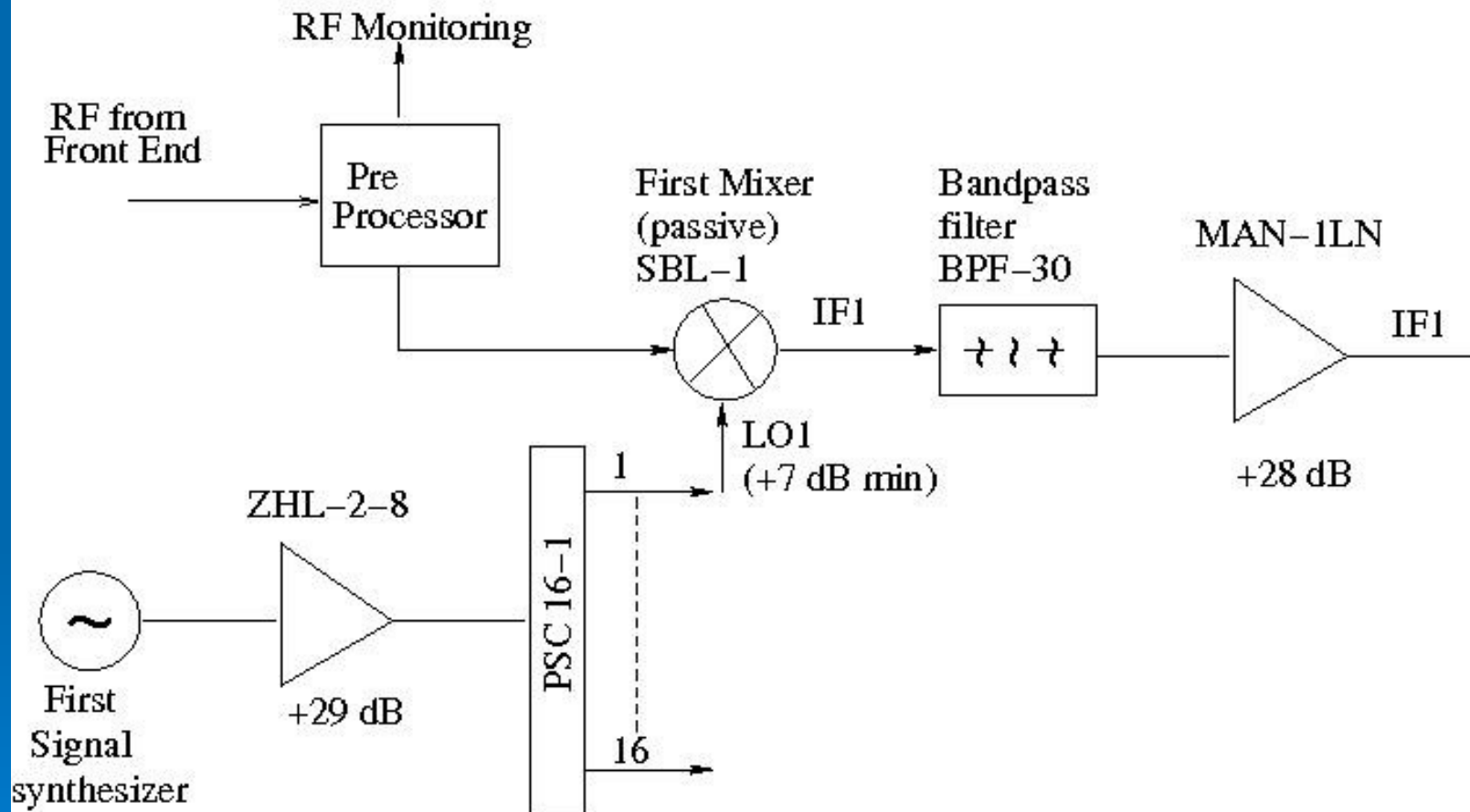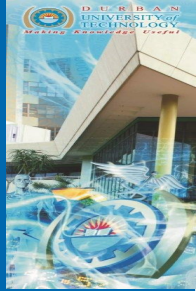
MITRA 1.0:New Antenna design 200-800MHz
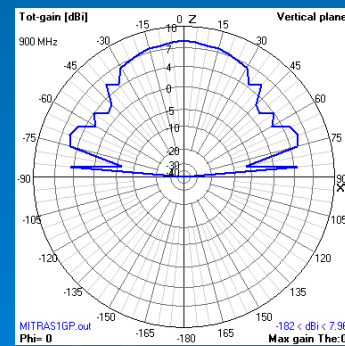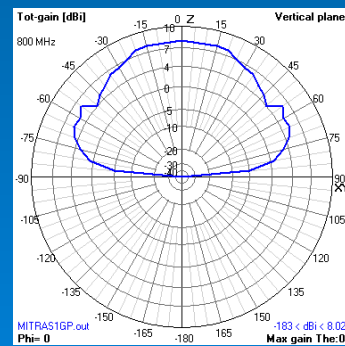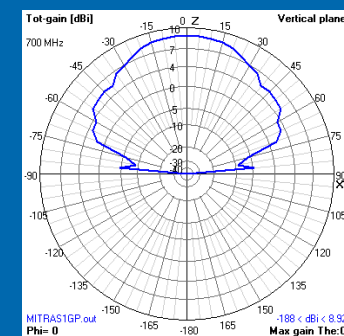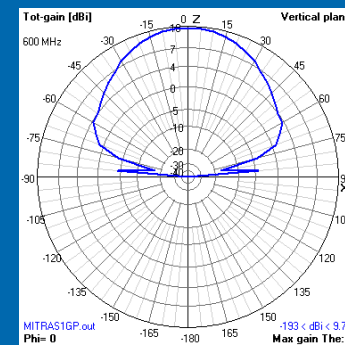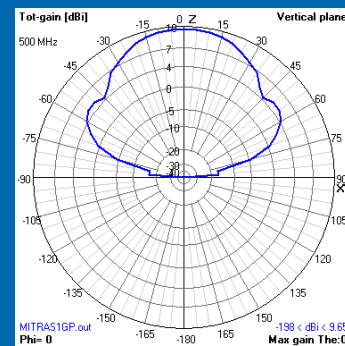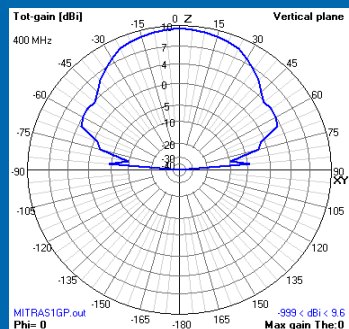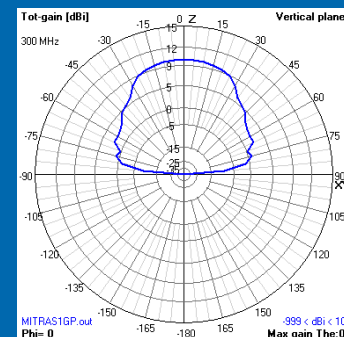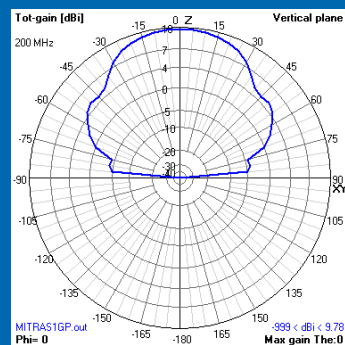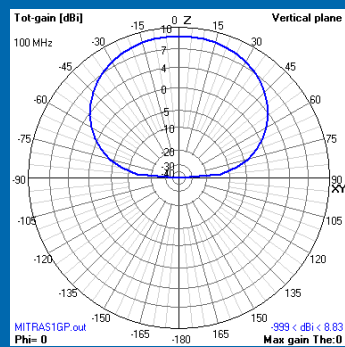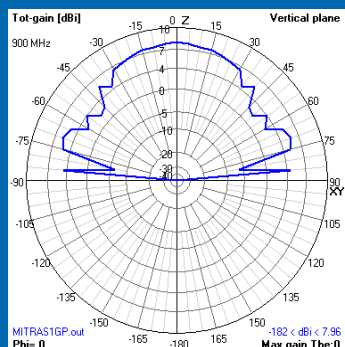
Ground plane 14: from last element with shorting bar.
SMacPherson@DUT
Model fit needed

MITRA Preliminary work:
Antenna design Version 2

Shibchurn, Lallbaree, Beeharry   @ Bras d'Eau, Mauritius 2012-13

MITRA Preliminary work:
CME observed with e-CALLISTO MRT 3 (antenna 2(&Bldinrn 15.03.2013

MITRA Preliminary work: antenna 2 VSWR

D. Ingala,S MacPherson & G. Van Vuuren, Durban

MITRA Preliminary work:antenna2 Return loss
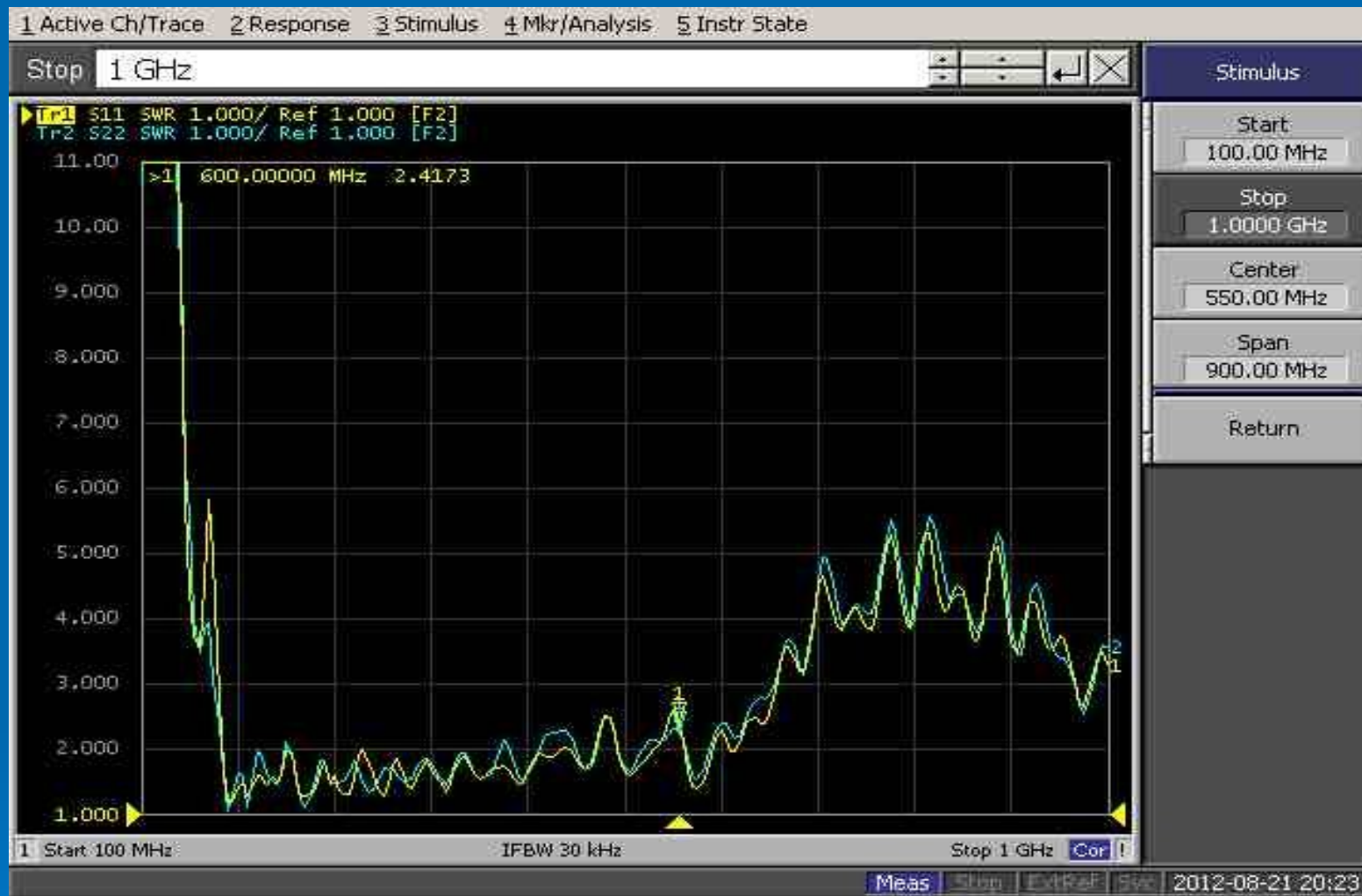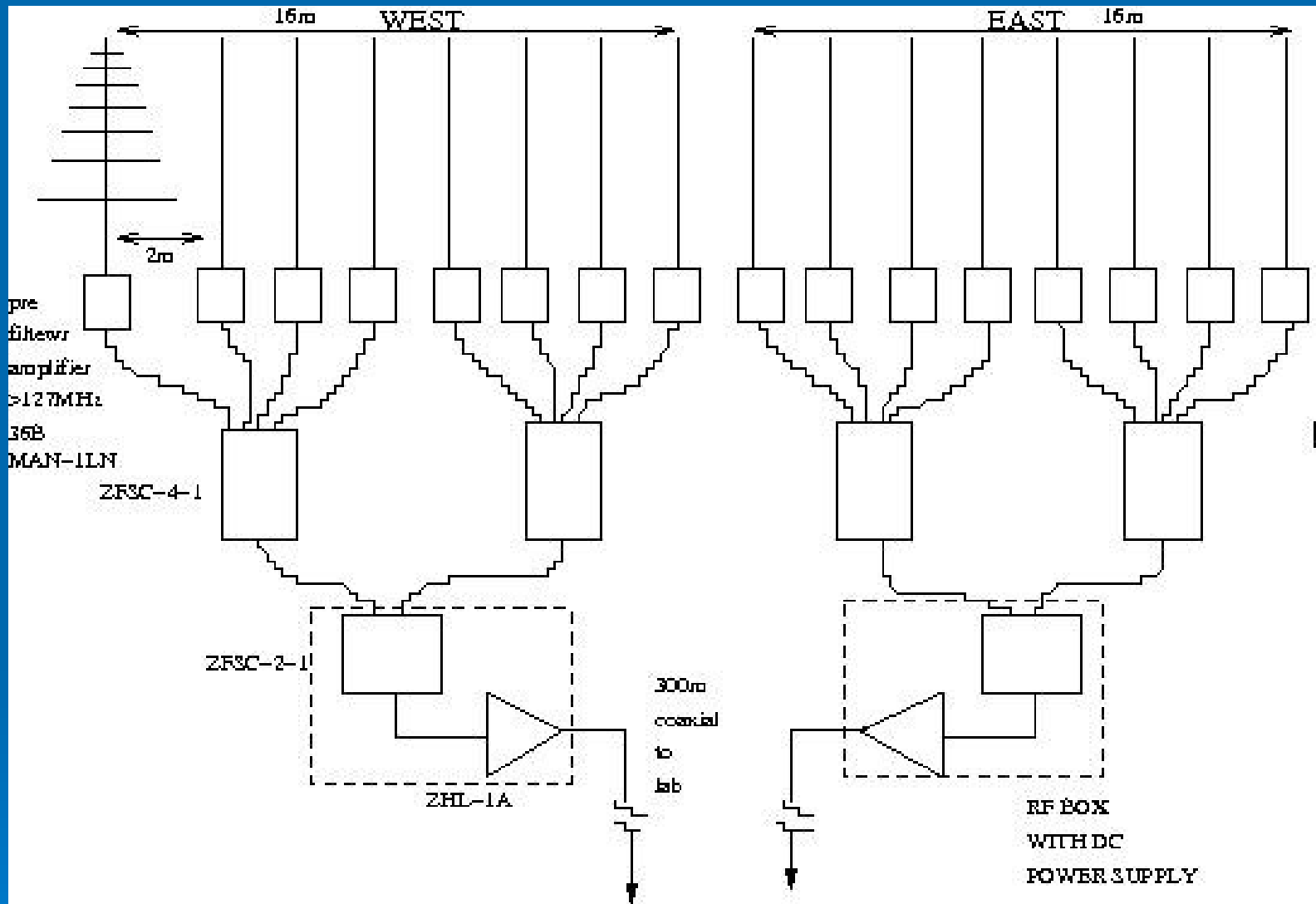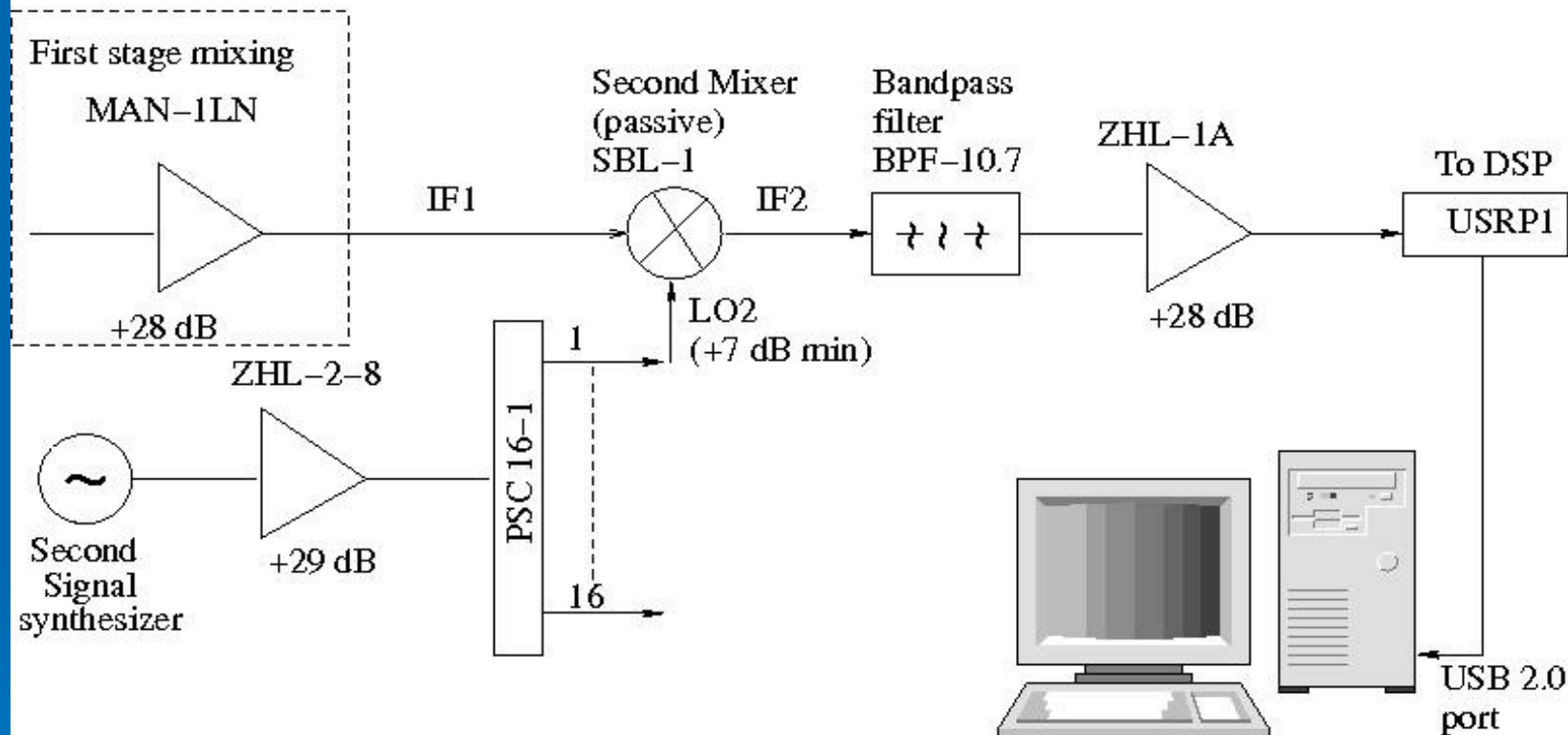

D. Ingala, S MacPherson & G. Van Vuuren, Durban

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University, Fukuoka, Japan 2-6 March 2015

N Vydelingum & GK Beeharry Mauritius

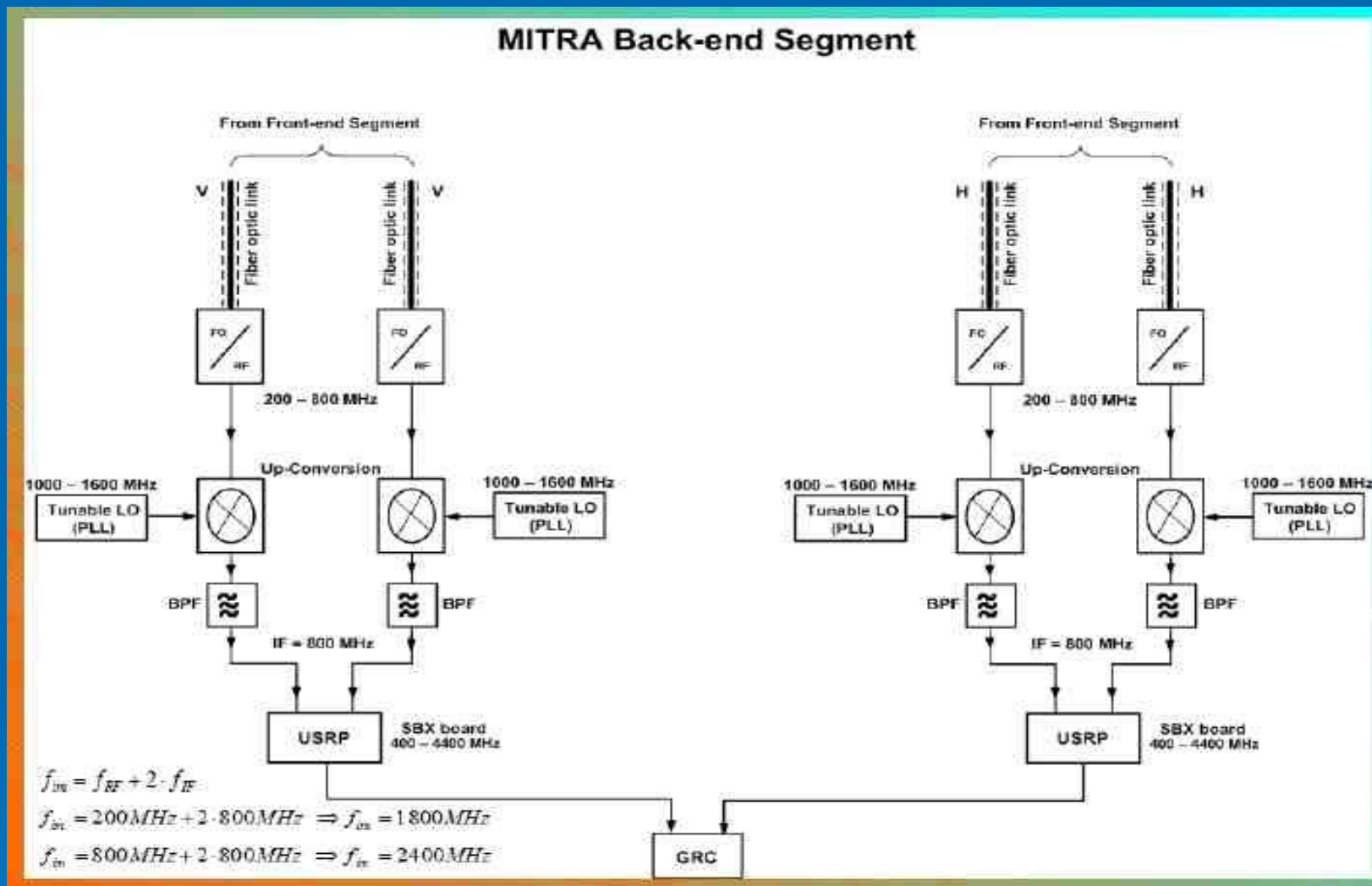gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015

Dominique Ingala @DUT

Back End in Lab: first stage mixing

K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

Back End in Lab: second stage mixing

K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

MITRA Back-end Segment

Dominique Ingala @DUT
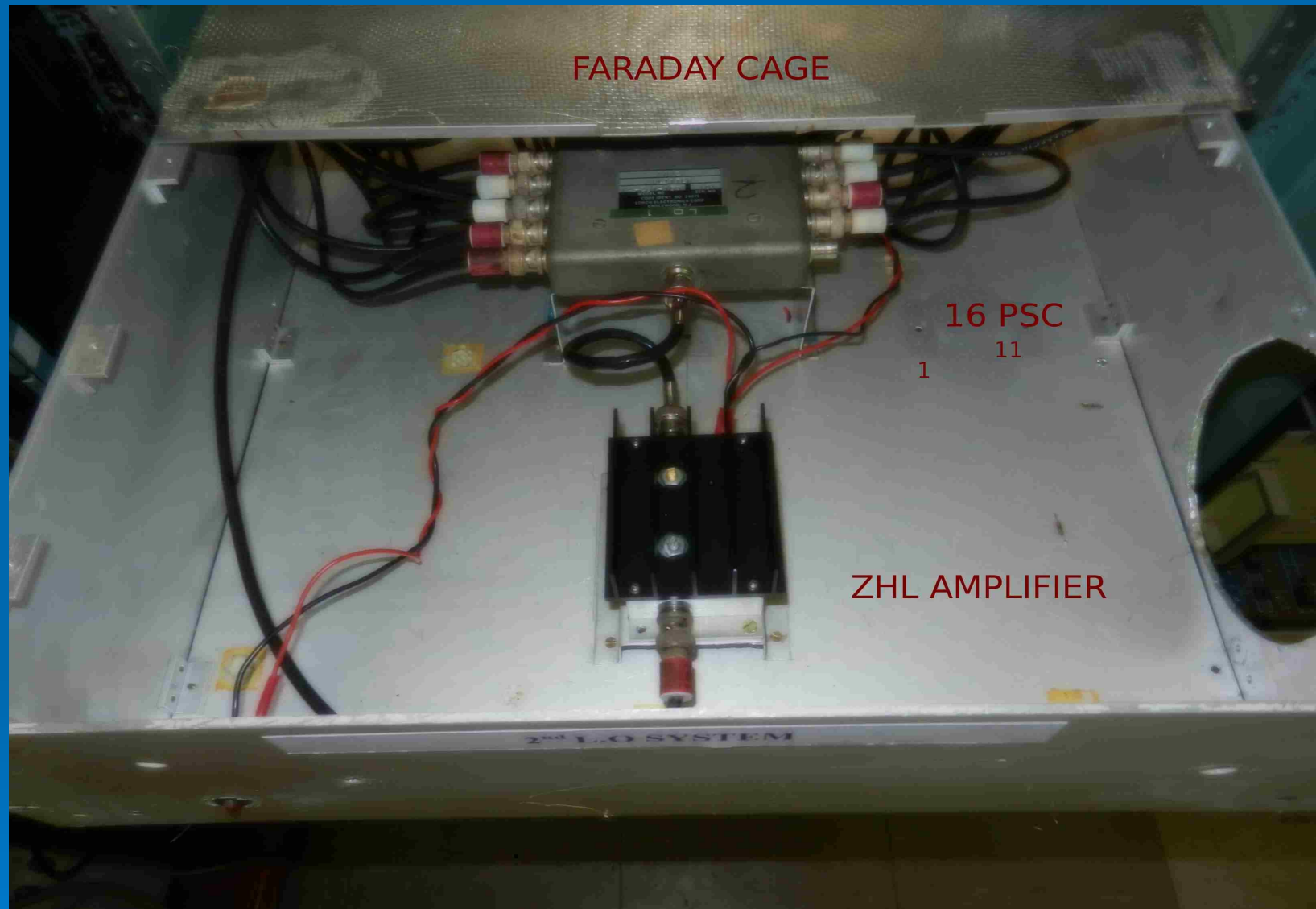
MITRA Preliminary work: students at work

K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015
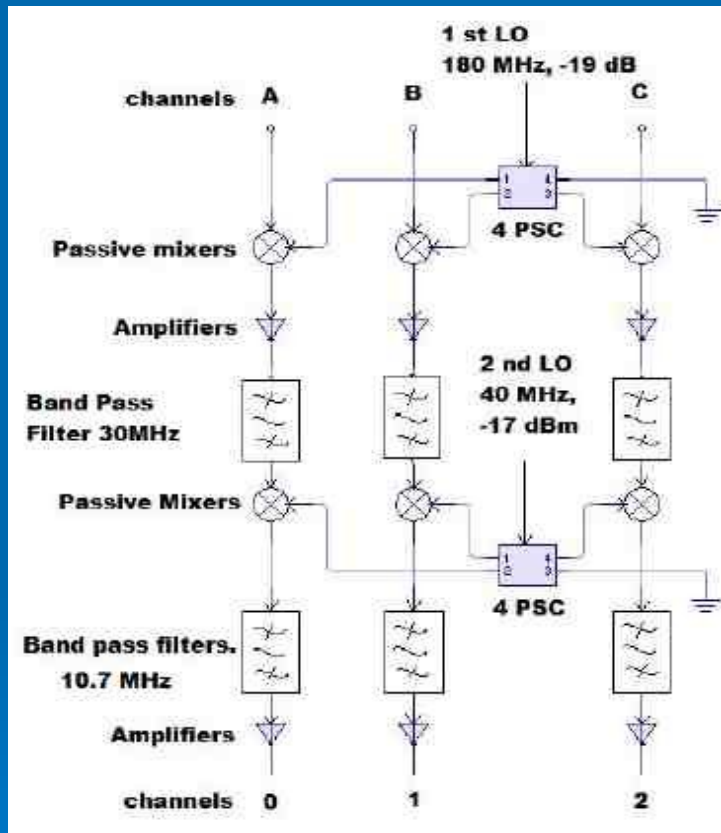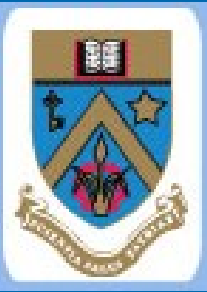
Figure 6.5: New back-end receiver system

Muthoor, Ramdohee, Nursihmhulu, Nunkoo, Ginourie, Lutchumon, Mahadu, Chataroo, Bhoyrub
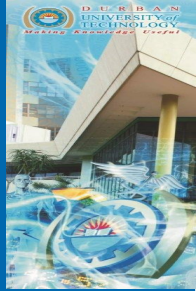
MITRA Preliminary work:
4 channel receiver (4->16)

Figure F.34: Receiver system

Figure F.29: PCI-ADC card

Muthoor, Ramdohee, Nursihmhulu
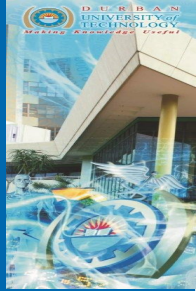Nunkoo, Ginourie, Lutchumon, Mahadu,
Bhoyrub, Chataroo

K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products
from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015

VITRA Preliminary work:16 channel receiver first mixer

SBL-1 MIXER BOARD

BAND PASS FILTER 30MHZ-6BDTH

K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015

K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

MITRA Preliminary work:16 channel complete receiver

K Bhoyrub & A Chataroo Bras d'Eau, Mauritius

Now 2x16 channels

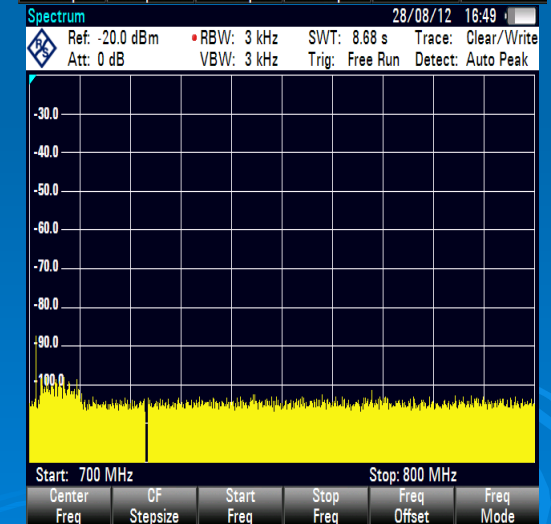# MITRA Preliminary work:DUT receiver room
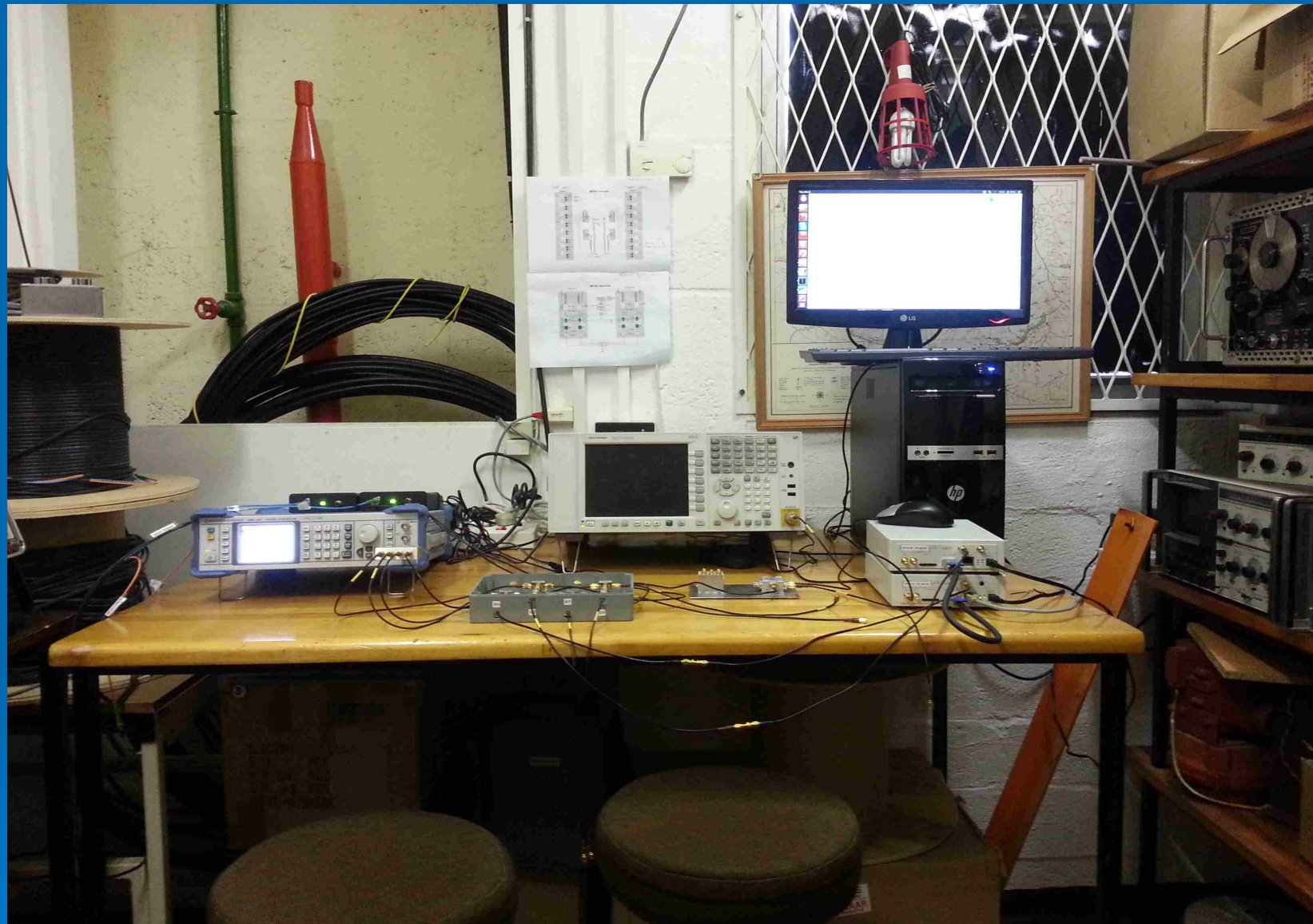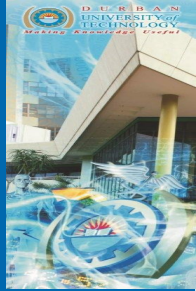
S.MacPherson, G. van Vuuren, D Ingala DUT 2013
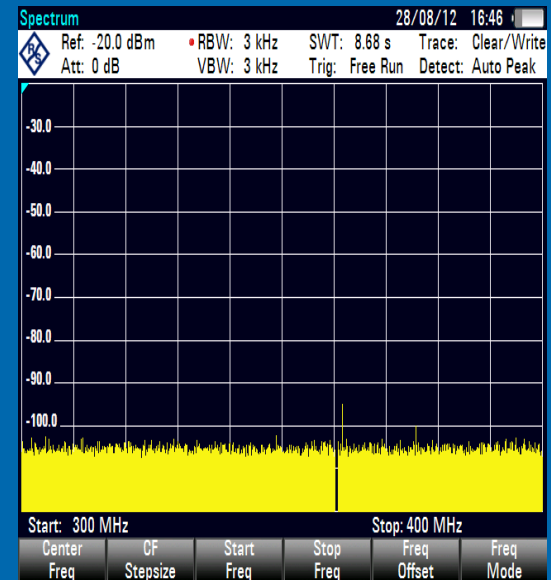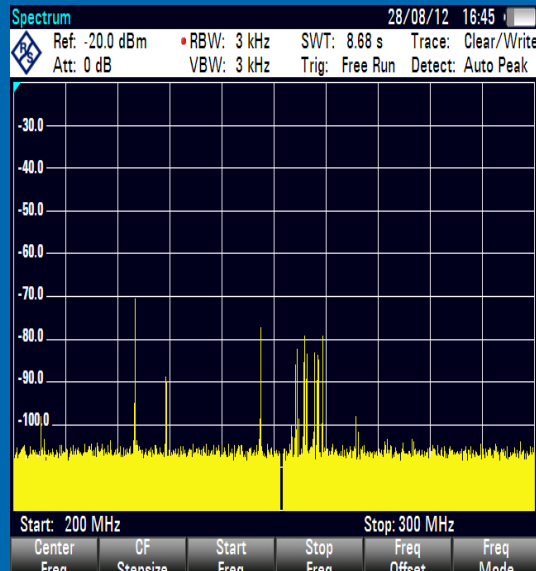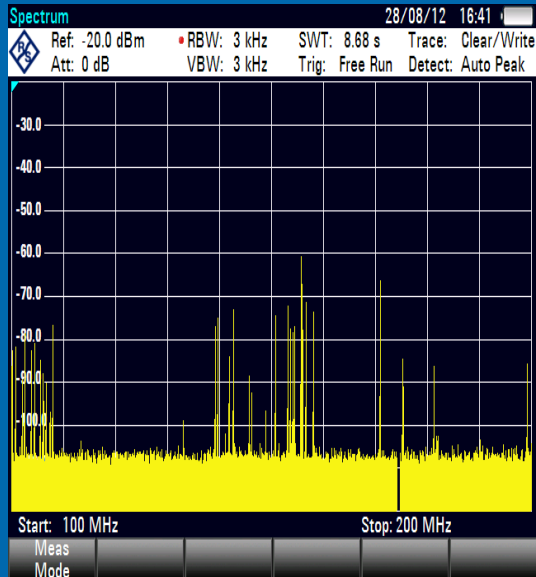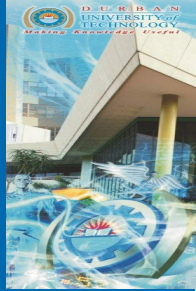
gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015
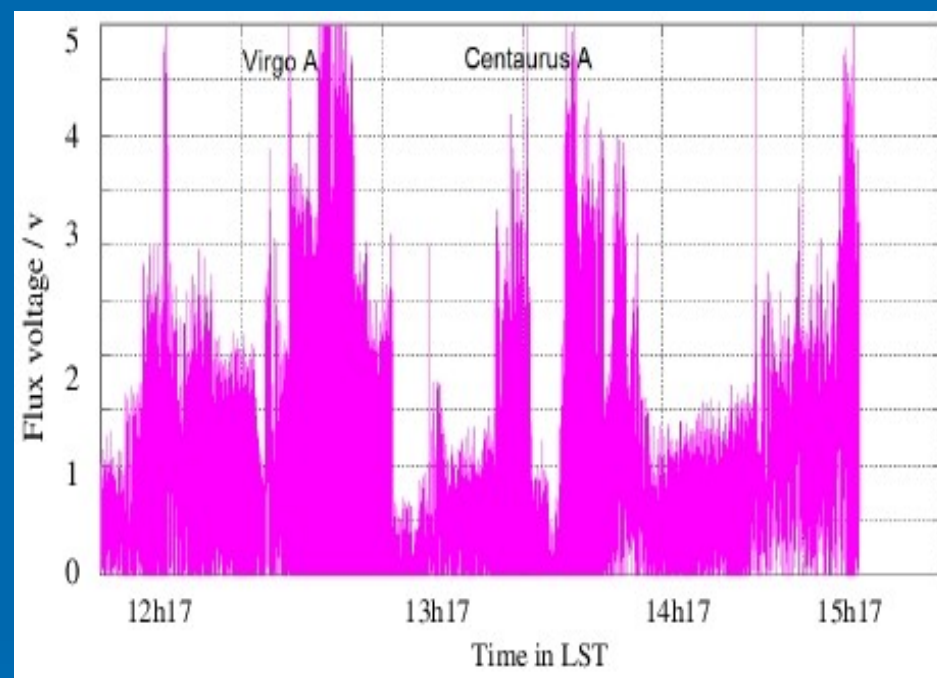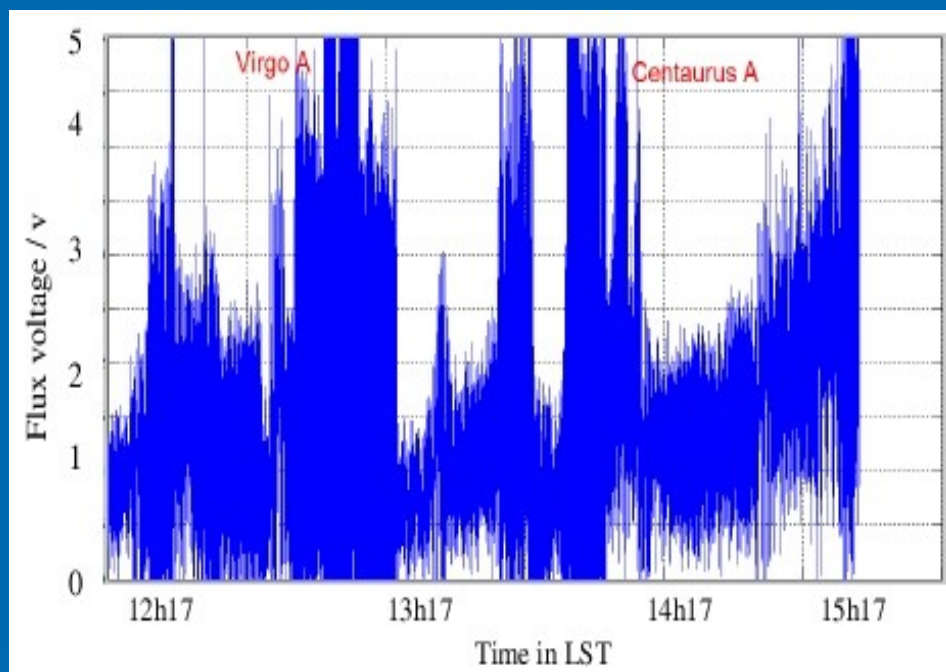
MITRA Preliminary work: back end Durban
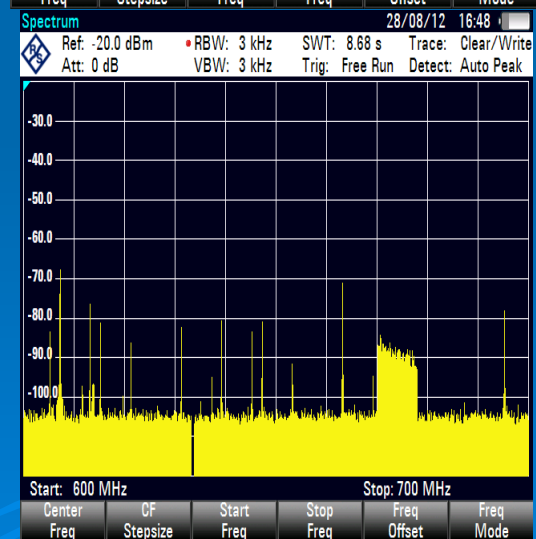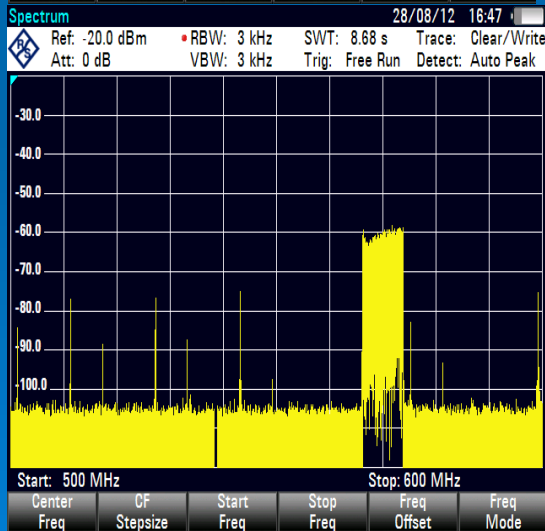
Dominique Ingala @DUT

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015
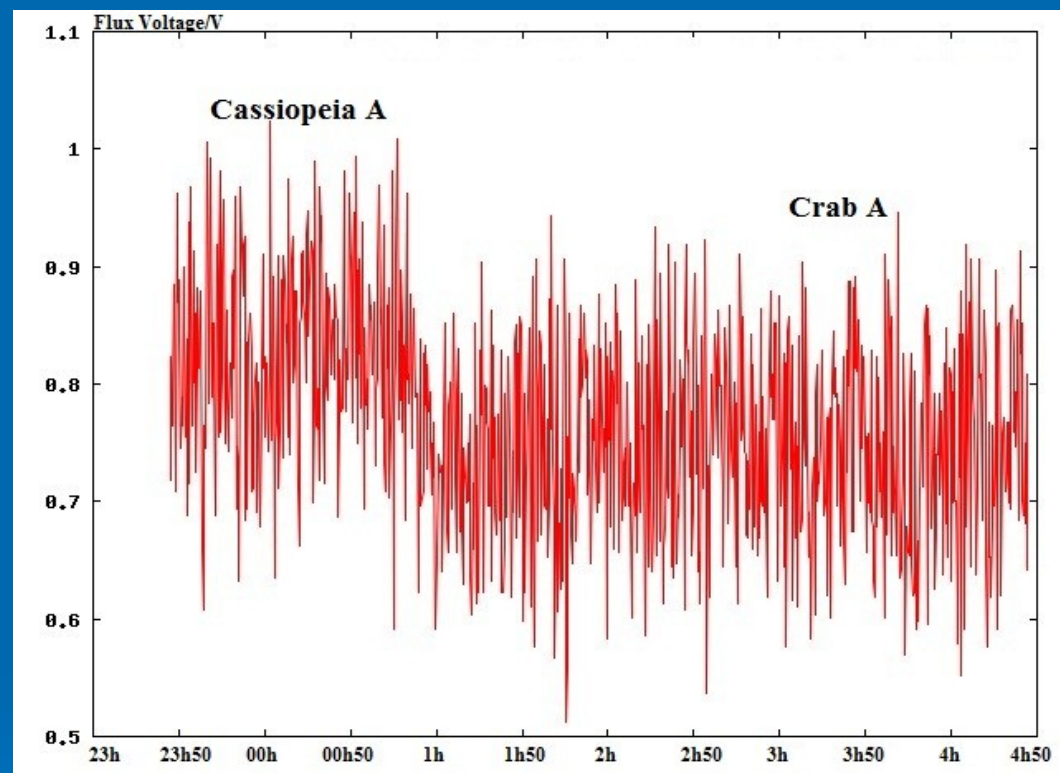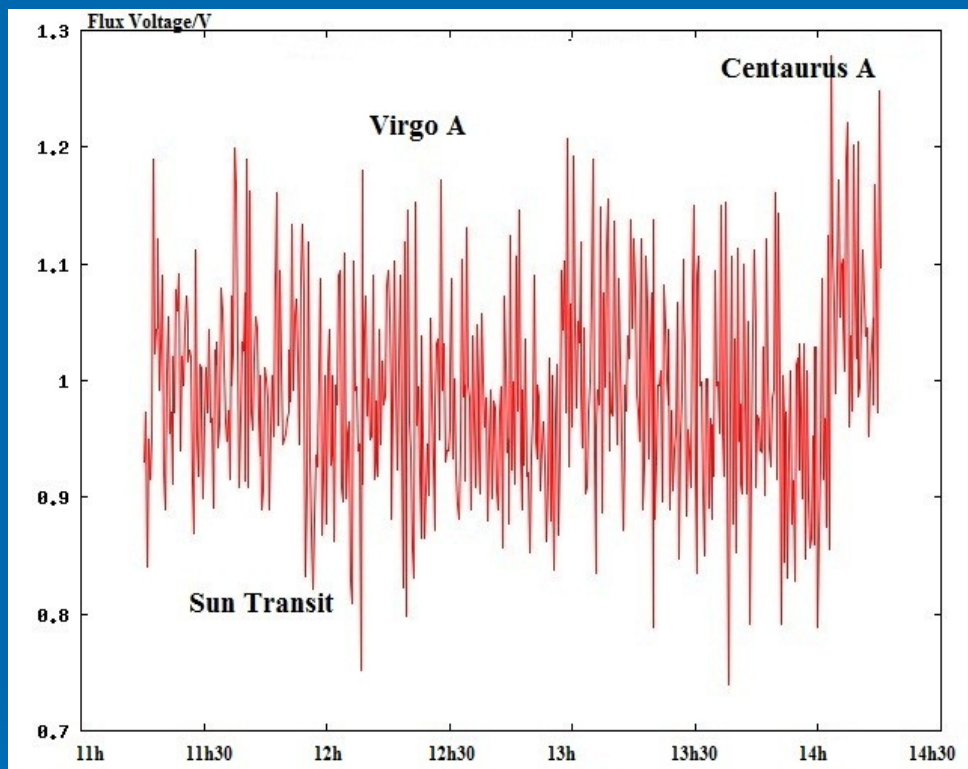
MITRA Preliminary work 4 channel receiver

1 D dirty scan (8 antennas) Cos(left) and Sin(right)
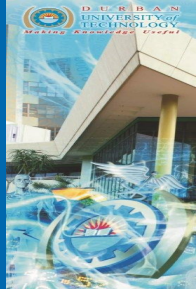150 MHz RF 2-channel correlator ADC card Mahadu & Lutchmon

MITRA Preliminary work 16 channel receiver

1 D dirty smoothed scan (8 antennas) 150 MHz RF 2-channel correlator ADC card Bhoyrum & Chataroo April 2012

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015
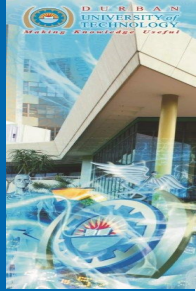
MITRA Preliminary work 16 antenna array Durban
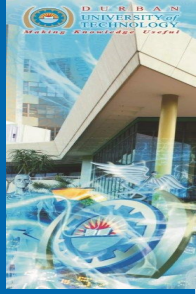

S.MacPherson, G. van Vuuren, D Ingala DUT 2013

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015

MRT 2013

- Ettus Research

- Open source design

- Programmable FPGA

- PC-USRP USB link

- Daughter boards available: WBX transceiver

- PC initial data processing

MITRA Preliminary work:
Universal Software Radio Peripheral Software
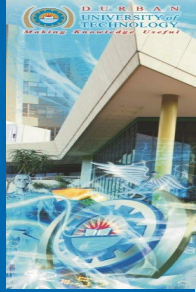
- Software Defined radio

- Open source GNU Radio

- Processing defined by flow graphs in Python

- Primitives in C++

- Programmes for the FPGA

MITRA Preliminary work: USRP1Mainboard

C Mondon, N Vydelingum & GK Beeharry Mauritius

MITRA Preliminary work:
USRP control using GNU Radio Companion

D Ingala Mtech DUT 2015

gkb@uom.ac.mu United Nations / Japan Workshop on Space Weather"Science and Data Products from ISWI Instruments" ICSWSE, Kyushu University,Fukuoka, Japan 2-6 March 2015
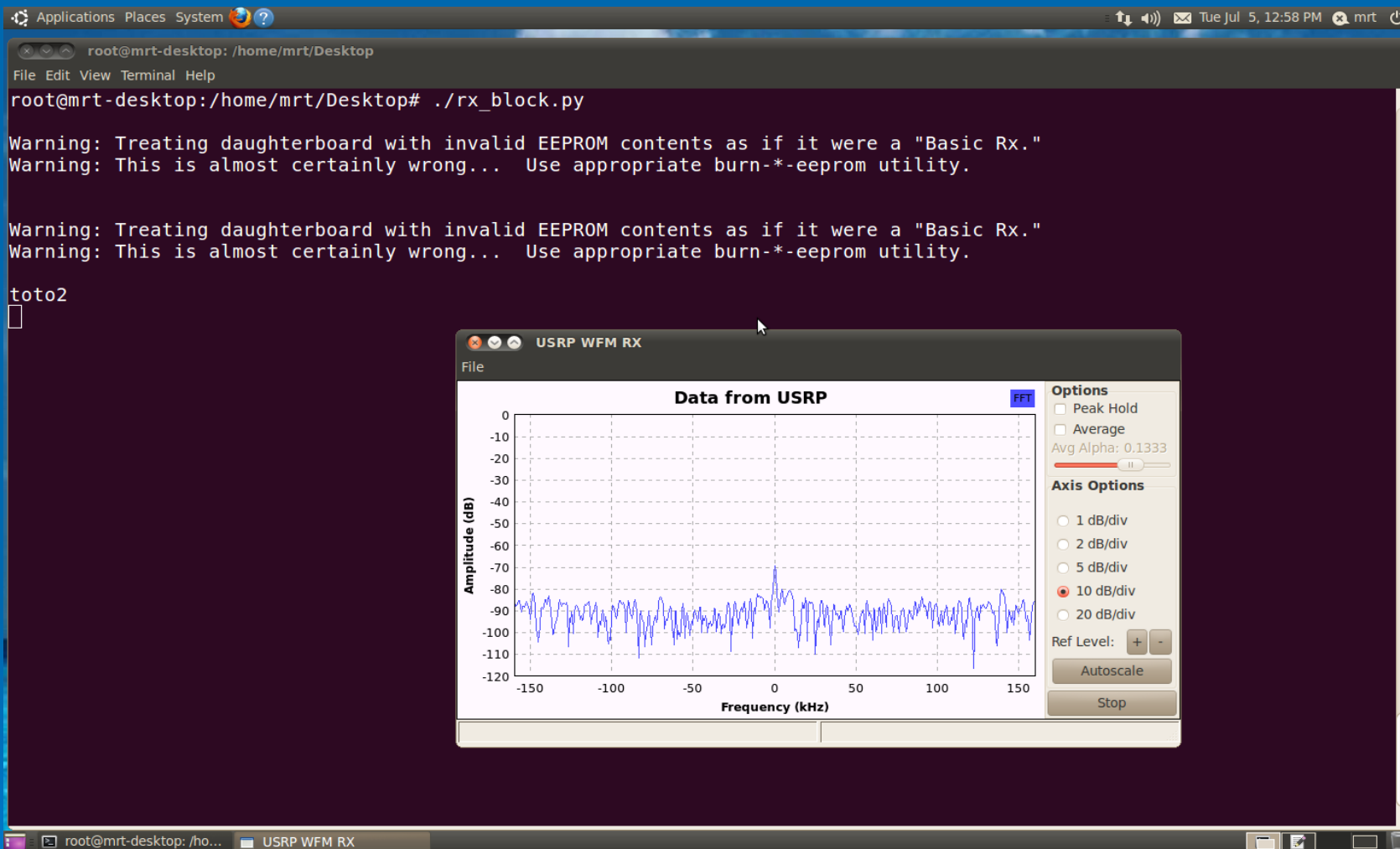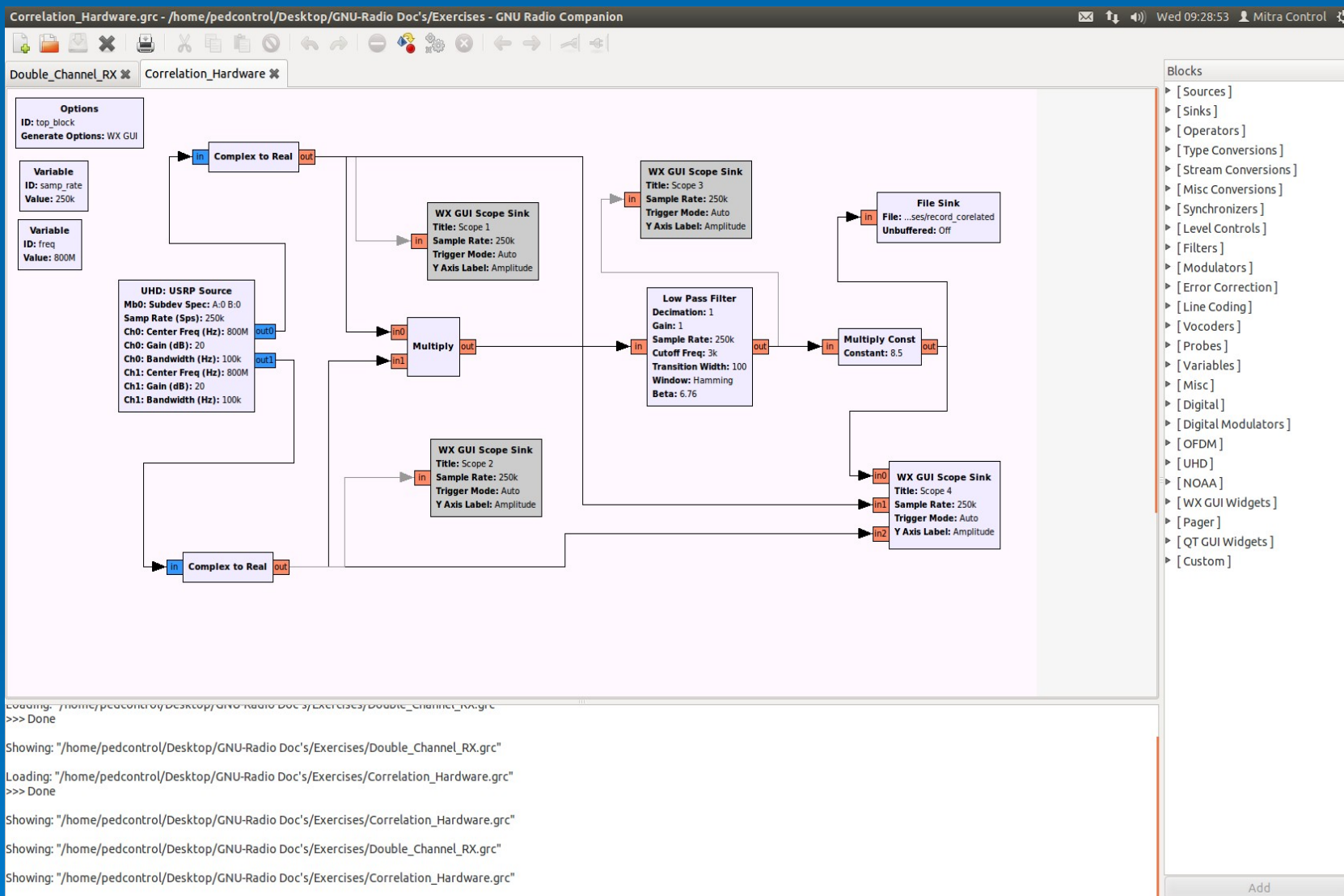
MITRA Preliminary work: 2 USRP detection using GNU Radio Companion

D Ingala Durban

- GNU Radio free open software

- ~1.5-2 months to install in GNU/Linux

- Tried on Slackware, Debian and Ubuntu

- Modified source code "rx_block.py"

C Mondon, N Vydelingum & GK Beeharry Mauritius

N Vydelingum & GK Beeharry Mauritius

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MITRA Preliminary work: ecent relevant software

-Software correlation on CPU (Jheengut)

-ADC card acquisition software CPU (Ginourie)

-ADC card acquisition software GPU (Platel)

-CALLISTO flare detector (Benfifi)

-USRP1 programming (Mondon)

-CPU/GPU FX (Louis)

-PIC programming (Jaulim)

Front end

Construction of 2 groups, with 8 antennas per group (Shibchurn 2012-13)
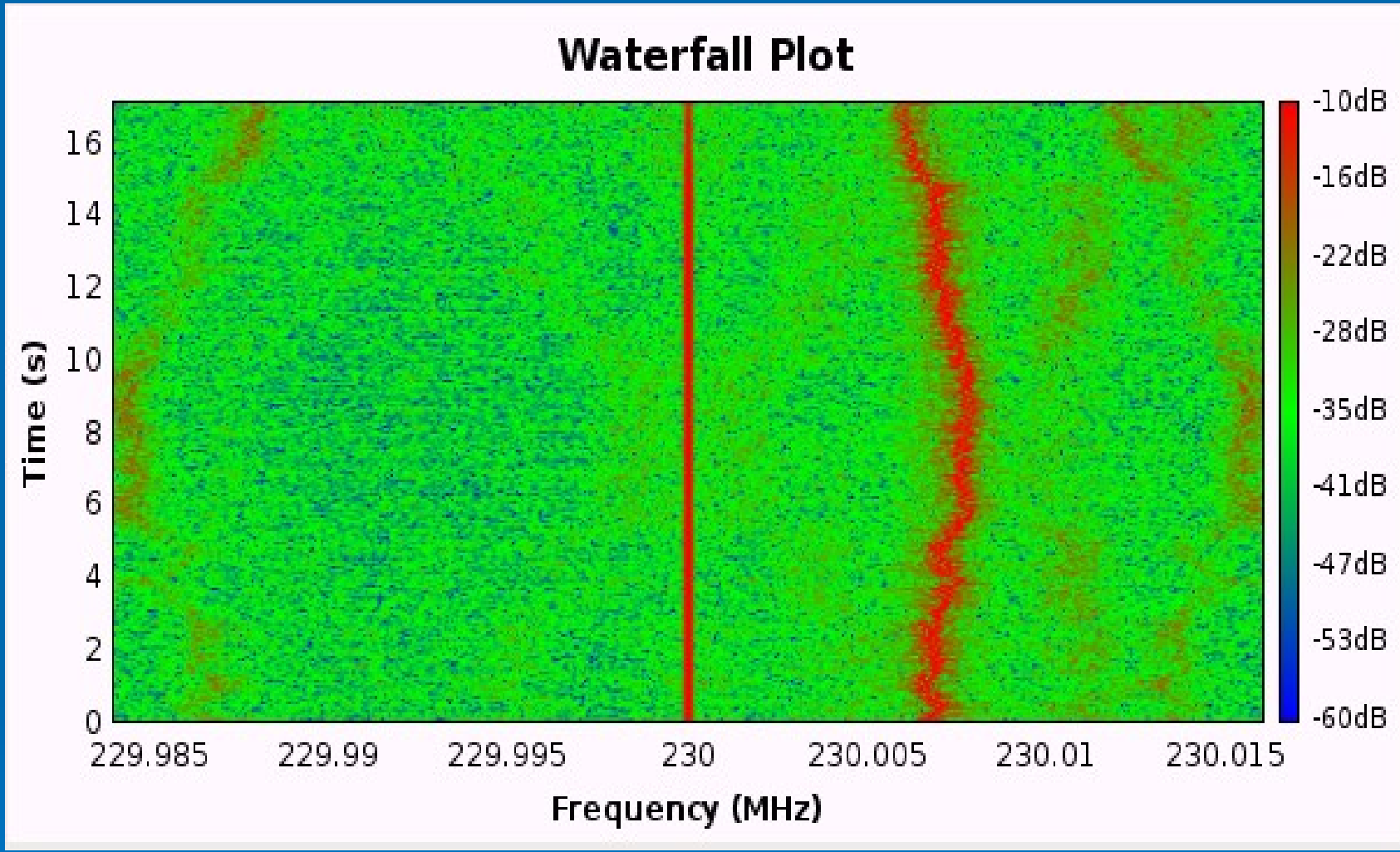
May be extended to 8 x 8.

Set up of optical fibre network (Armoogum 2012-13)

Back end

Integration of receiver & USRP programming using GNU Radio companion (Pirtee 2012-13, Prayag)

Receiver system, USRP1 & 2 programming D. G.Ingala (DUT Mtech 2015)

Design & construction of a 16 channel receiver (Bhoyrub & Chataroo 2011-2012, Ramtohul 2013-2014}

Digital back end Prayag MPhil/PhD 2014-ongoing

GPU FX Ragoomundun Mphil/PhD 2015
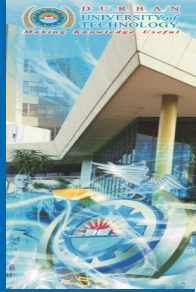
MITRA Preliminary work: RF over optical fibre

Modulator RF opti
cal & Demodulator Optical to RF
Optical fibre 100 MHz to 2.4 GHz
Gain +5 dB
Gain flatness +/- 2 dBover band width
RF input level range -50 to 0 dB
VSWR 2.1
Noise figure < 25 dB
Laser diode 1310 nm
Receiver photodiode operating wavelength 1200-1650 nm
Input & output impedance 50 Ώ
RF input and output connectors SMA
Optical connectors (Trans./ Rec.) FC/APC

FX FPGA Correlator

ROACH board excellent but very expensive

Preliminary work on low cost FPGA on the USRP board

Virtex 6 board

GPU/CPU + hub management

MITRA 1 update

<u>Durban</u>, <u>South Africa</u>

-Completred system end 2014
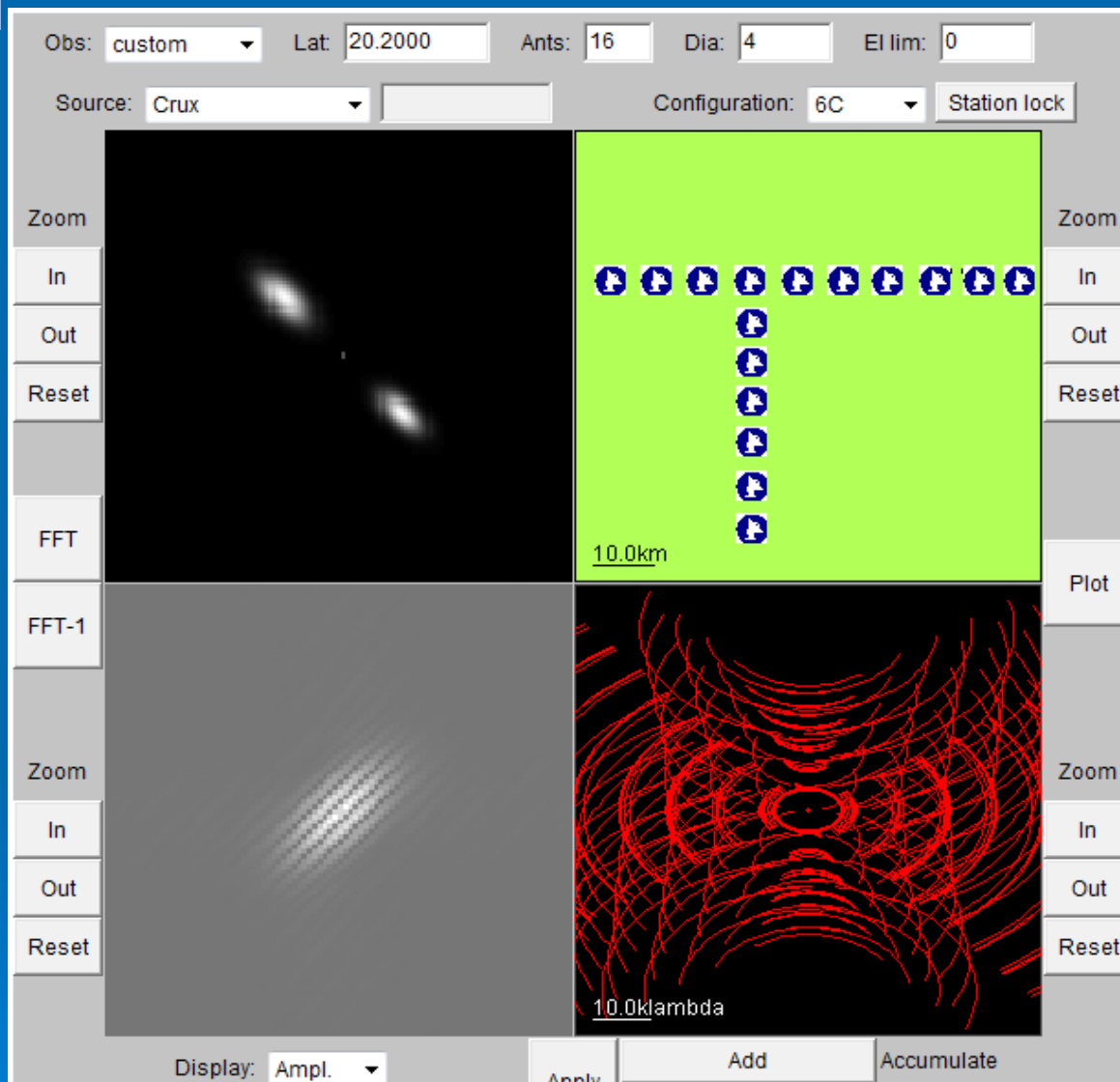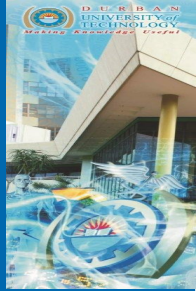-Problem with RFI: shift to Pietermaritzburg?

<u>Mauritius</u>

-To integrate rubidium GPS clock

<u>To do</u>

-Observe,   correlate, imagimg, &spectrography.

MITRA 2 update

At least 8 groups
of 4x4antennas
In Mauritius
2015-2015

At least 8 groups of 4x4antennas .

MITRA 2 update

-At least 8 groups of 4x4antennas in Mauritius 2015-2016

-1 MPhil/PhD on digital back end since Dec 2013

-1 new MPhil/PhD on correlatiom imaging on GPU 2015

-1 Hons on comparing DFX on CPUs & GPUs 2014-2015

-1 Hons on phasing. Beam forming(2 beams) in cognate project 2014-2015

Cost scenarios

	Station 512 antennas	Station 1024 antennas	Relayive ensitivity
Version 1 (MUR)	19M	38M	1
Version 1 (USD)	600K	1.2 M	1
Version 2 (MUR)	12 M	2 4 M	0.7
Version 2 (USD)	400K	800 K	0.7
Relative sensitivity	0.7	1.0	

People in Mauritius

2 M

People in Durban
South Africa

Minister Pandor RSA visit 19.9.2011

Minister Jeetah Mauritius 9.08.2012

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Future of MITRA

Funding crucial for expansion

International help welcome

Expansion to other countries

Thanks

United Nation for Outer Space Affairs
LOC, ICSWSE Kyushu University
MOFA
MEXT
NICT
JSPS
Tohoku University
Nagoya University
Fukuoka City
Government of Japan