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eMERLIN

e-MERLIN – The Next Leap Forward
Simon Garrington

1950’s-70’s
- single baselines
- radio links ->100km
- phase coherent

1980’s
- MERLIN – radio-linked
- 110km, 10 MHz

1990’s-2000’s
- MERLIN-2: 32-m at Cambridge
- 217km, 2x15 MHz, new rx, correlator…

2010-2020
- e-MERLIN
- fibre network; 2x2 GHz

2020+ JBNA
- full freq coverage
- 2x8 GHz
- Lovell Tel PAF

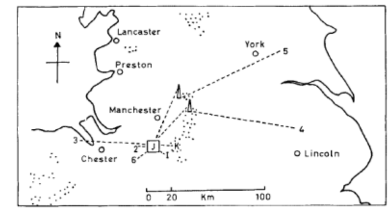
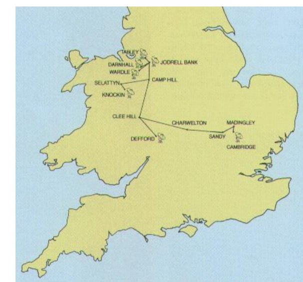


Fig. 2. An outline map of northern England, showing the positions of radio telescopes



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Northwest Regional Development Agency
University of Cambridge
Science & Technology Facilities Council
Liverpool JMU

Radio astronomy in transition

- SKA will be different
- Transition period: MeerKAT, ASKAP, LOFAR, MWA
- E-MERLIN provides resolution for key science

galaxy assembly/evolution; star/planet formation

MeerKAT:	5 arcsec
VLA:	1.5 arcsec
e-MERLIN	**0.15 arcsec**
VLBI	0.015 arcsec

1 kpc @ z=1 (1.5 GHz)
5AU @ Taurus (8 GHz)

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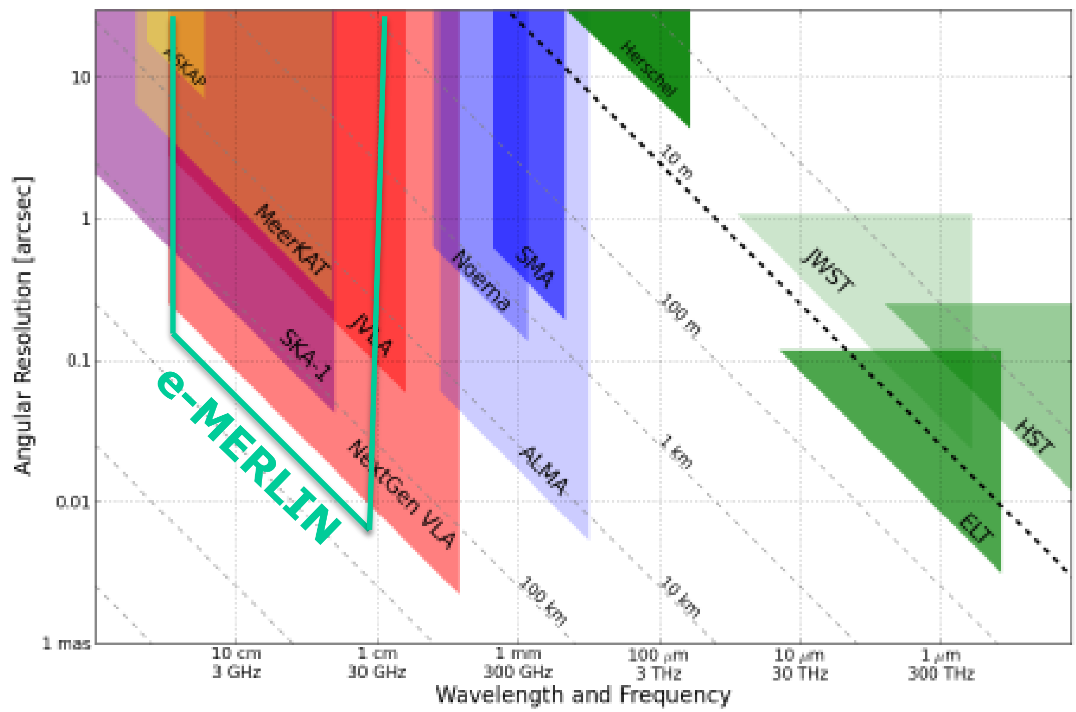
e-MERLIN

Next Gen VLA

- 200km
  250x 18m antennas
- 1-100 GHz
- Planet formation;
  galaxy assembly
- PI-driven, pointed

… $x bn, 2030?



Slide adapted from M McKinnon

JBA
Jodrell Bank Array

- Full integration of Lovell Telescope
  - Programmatic, financial, technical
  - PAF to match e-MERLIN FOV
- Full Frequency coverage ~1-30 GHz
- Full bandwidth – 8 GHz/pol
- SKA and COTS technologies
  - Data acquisition & sampling, network,correlator
- SKA-like operations
  - Phasing-up; sub-arrays
  - SDP, Pipelines, transients,…

Competitive & Compatible

World-class instrument on UK soil; Test-bed & training ground for UK SKA community

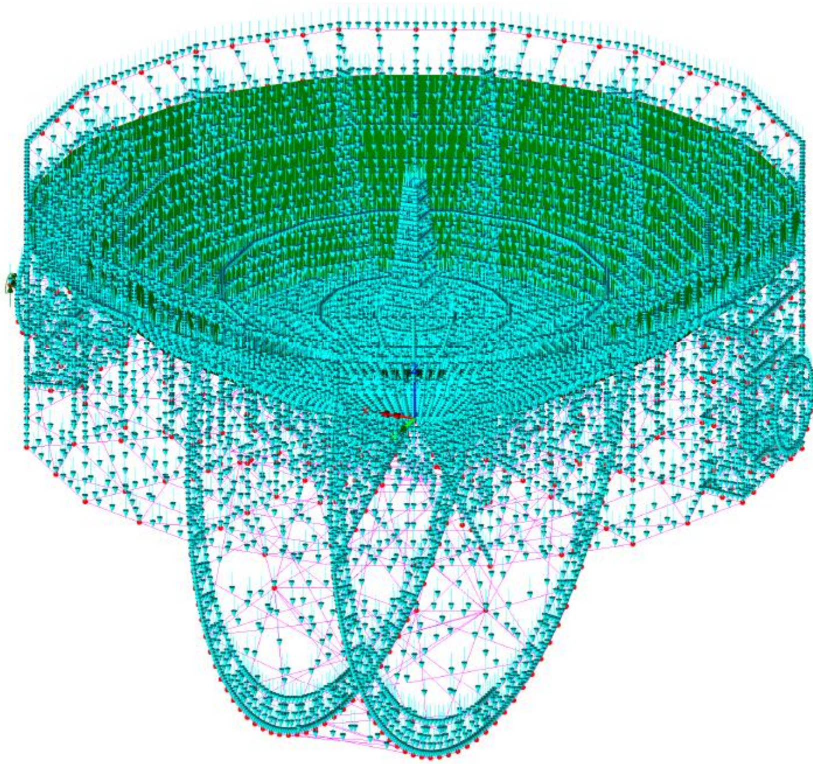
Same resolution & frequency range as SKA1-mid

Lovell Telescope Refurbishment + Upgrades

- Lovell Telescope Structural refurbishment

  (UoM: £6M)
  - (old) surface, foundations, structure
- Lovell Telescope PAF

  (UoM £0.6M)
  - 96 elements, 36 beams
  - Expand Lovell Telescope FOV X10



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Upgrade paths

- Frequencies
- Data acquisition, transport, correlator

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SKA-1 Bands

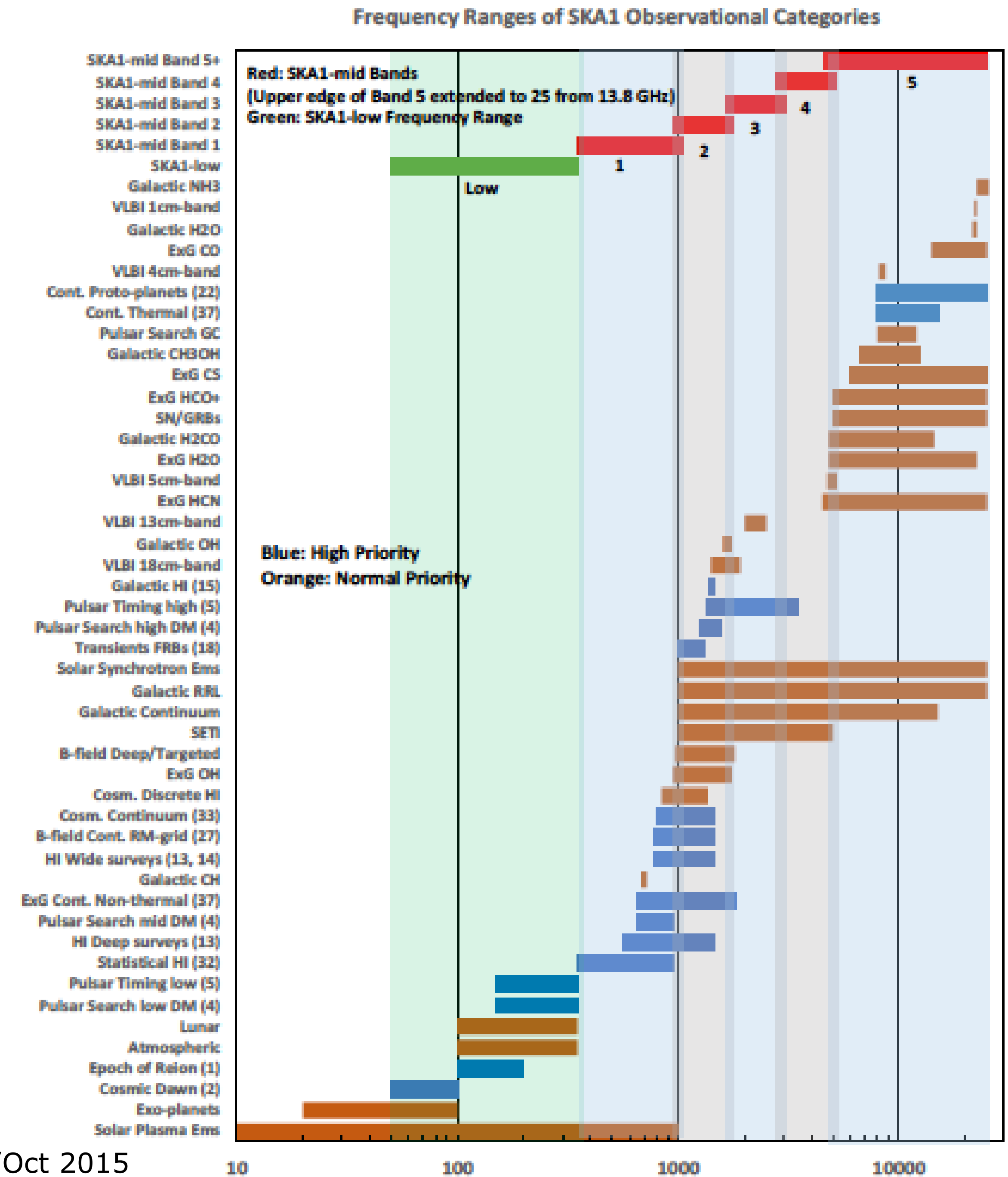
1: 0.35-1GHz

2: 1 – 1.8

3: 1.8 – 3.0

4: 3.0 - 5

5: 5 – 13.8(25?)



SKA Baseline Design v2 /Oct 2015

Band Plan

Octave

L: 1.3-1.75 GHz
S: 2.2- 4
C: 4 – 8
X: 8 – 16 ← 5b?
K: 16 – 26 ← 5c?

SKA Band 5/5+
5 – 13/26 GHz

WBSPF

(L:1.3-1.75)
BRAND (RadioNet)
1.5 – 15 GHz
K: 16-26

Significant penalty in efficiency/Tsys
Fewer Rx to operate
Simultaneous coverage

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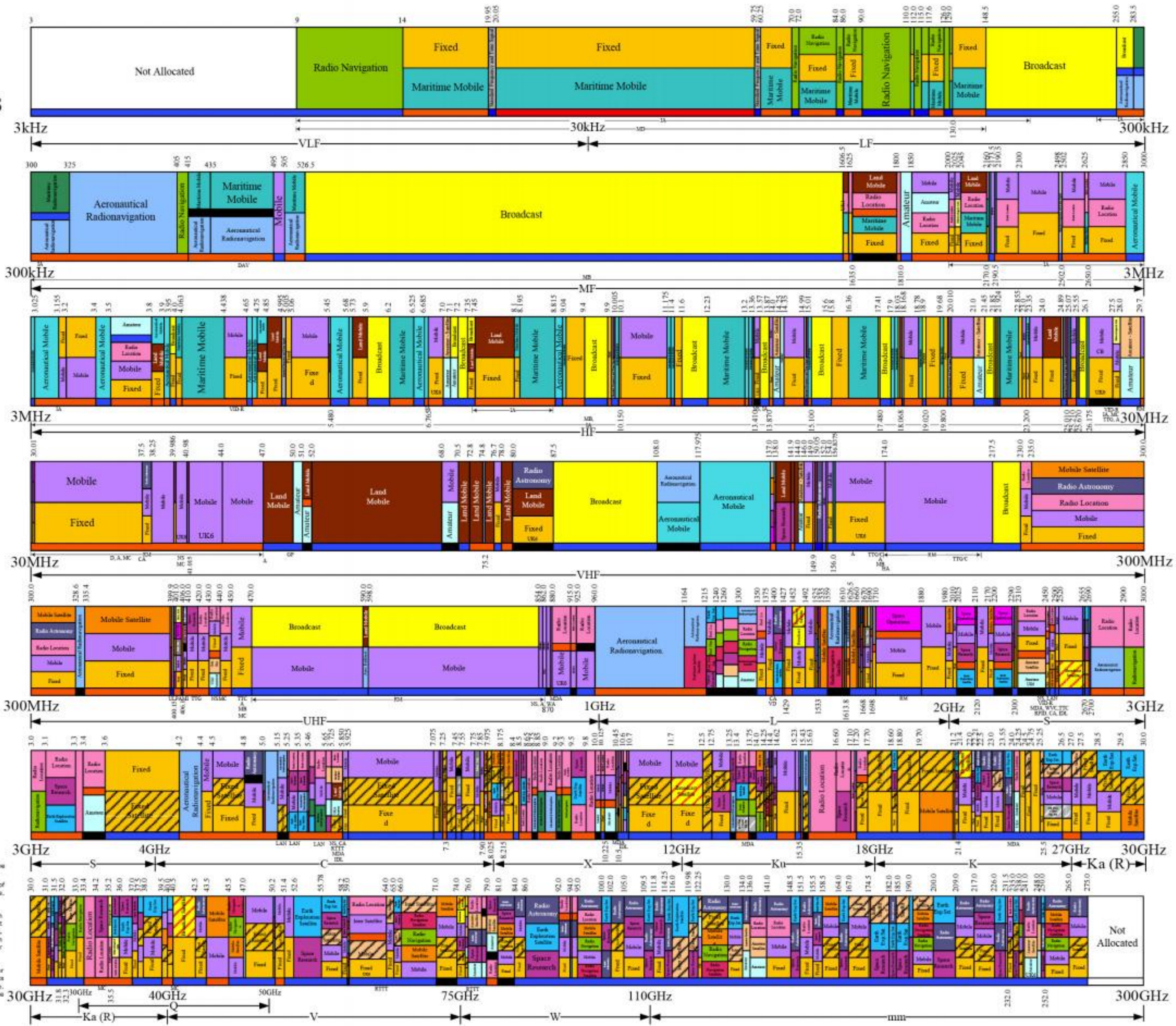
roke

The UK Frequency Allocations



Short Range Devices (SRDs) Shared Allocations Acronyms

A - Alarms
CA - Cordless Audio
D - Databuoys
DAV - Detection of Avalanche Victims
GP - General Purpose SRDs
HA - Hearing Aids
IA - Induction Applications
IDL - Indoor Data Links
LAN - Local Area Network
MB - Medical and Biological
MC - Model Control
MD - Metal Detectors
MDA - Movement Detection or Alert
NS - Non Specified including Telemetry and Telecommand
RFID - Radio Frequency ID
RM - Radio Microphones
RTTT- Road Transport and Traffic Telematics
TTC - Telemetry and Telecommand Commercial
TTG - Telemetry and Telecommand General
VID-R - Vehicle ID - Railways
VD - Video Distribution
ULPAMI - Ultra-low Power Active Medical Implants
WA - Wireless Audio
WVC- Wireless Video Cameras

Radio Service Legend

- Civil and Military Use
- Civil Use
- Military Use
- Radio Astronomy
- Aeronautical Radionavigation
- Earth Exploration - Satellite
- Amateur
- Aeronautical Mobile
- Maritime Mobile
- Maritime Radionavigation
- Radio Navigation
- Meteorological Aids
- Broadcasting
- Broadcasting - Satellite
- Fixed
- Fixed Satellite Service
- Amateur - Satellite
- Inter - Satellite
- Mobile Satellite
- Land Mobile
- Radio Location
- Space Research
- Space Operation
- Mobile
- Standard Frequency and Time Signal
- Standard Frequency and Time Signal Satellite
- Meteorological Satellite
- Radionavigation Satellite

Notes

UK6 ISM applications are designated for use within this band

UHFs include bandings S and L

SHFs include bandings S, C, X, Ku, K, Ka and R

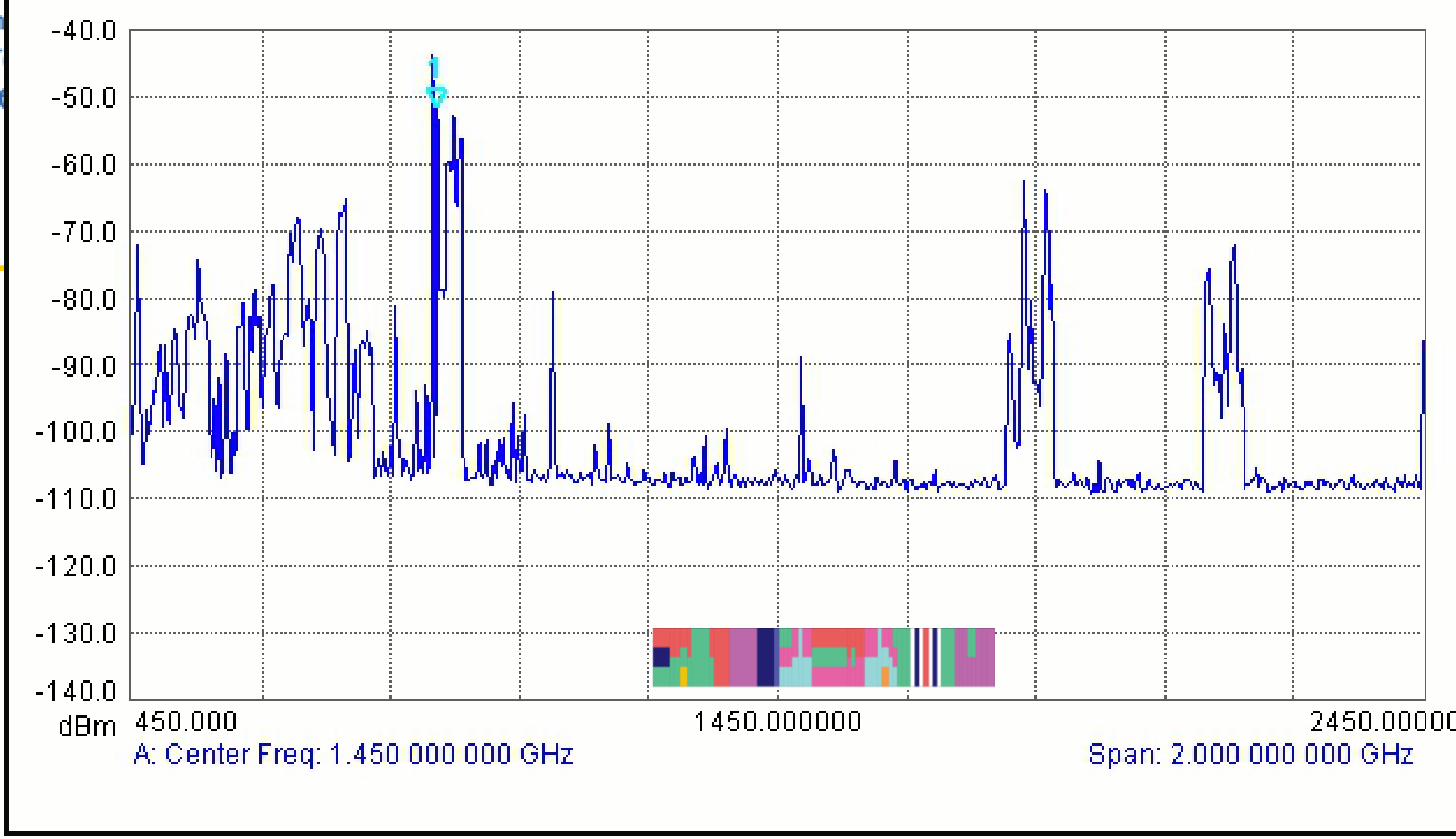
EHFs include bandings Ka, R, Q, V, W and millimeter (mm)

This chart does not differentiate between primary and secondary allocations. Details may be found in the UK FAT.

Frequencies for distress and safety, search and rescue and emergencies and the protection of frequencies for Radioastronomy are protected bands and should be avoided wherever possible. Details may be found in the UK FAT Annexes H and D.

The authoritative document for spectrum allocations for the UK is the UK Frequency Allocation Table (UK FAT), published by Ofcom (www.ofcom.org.uk). This UK Frequency Allocation Chart was developed by Roke Manor Research in accordance with the latest version of this table, published by the Ofcom in 2007. UK spectrum allocations may change over time in accordance with decisions of the ITU, CEPT, European Commission, the UK Government or Ofcom.

The Allocations table does not necessarily imply that the frequencies indicated are available for the use for the purposes allocated. Ofcom publishes a frequency authorisation plan on its website which shows the frequencies for particular licence classes or for licence-exempt use. Ofcom also publishes the UK Spectrum Strategy, which contains guidance on future use on the spectrum in the UK.



Measurement Parameters

		Stop Frequency	2.450 000 000 GHz
Trace Mode	Normal	Frequency Span	2.000 000 000 GHz
Preamp	ON	Reference Level	-40.000 dBm
Min Sweep Time	2 S	Scale	10.0 dB/div
Reference Level Offset	0 dB	Serial Number	1324070
Input Attenuation	10.0 dB	Base Ver.	V4.88
RBW	10.0 kHz	App Ver.	V6.30
VBW	3.0 kHz	Model	MS2720T
Detection	Peak	Options	720
Center Frequency	1.450 000 000 GHz		
Start Frequency	450.000 000 MHz		

Band priorities & comments

- L:1.25-1.75 – maintain & improve
- S: 2 – 4 GHz – new Rx
  - Easy design, good performance, optics?
  - Can use full current 2 GHz bandwidth: sensitivity+res'n
  - Prime JVLA survey band: JBNA+JVLA
- C: 4 – 8 GHz – maintain & improve
  - Already building new Rx: T_rx = 10K (LNA, new cold head)
  - Upgrade to 4 GHz bw
- X: 8 – 16: new Rx
  - Looking at designs
  - Aim for 8 GHz bw; can start with current 2 GHz
- K: 16 – 26: new Rx
  - Improved 20-24 GHz Rx being installed now (T_rx = 30K)
  - New HEMT design, 8 GHz bw

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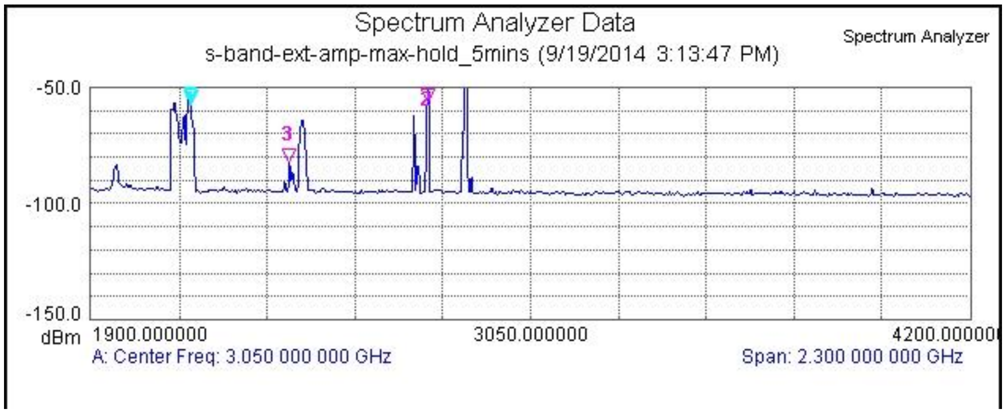
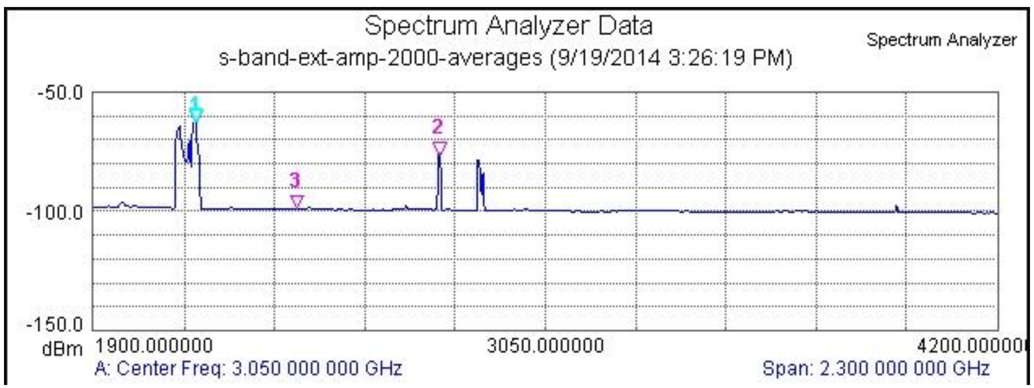
S-band RF environment





Mobile

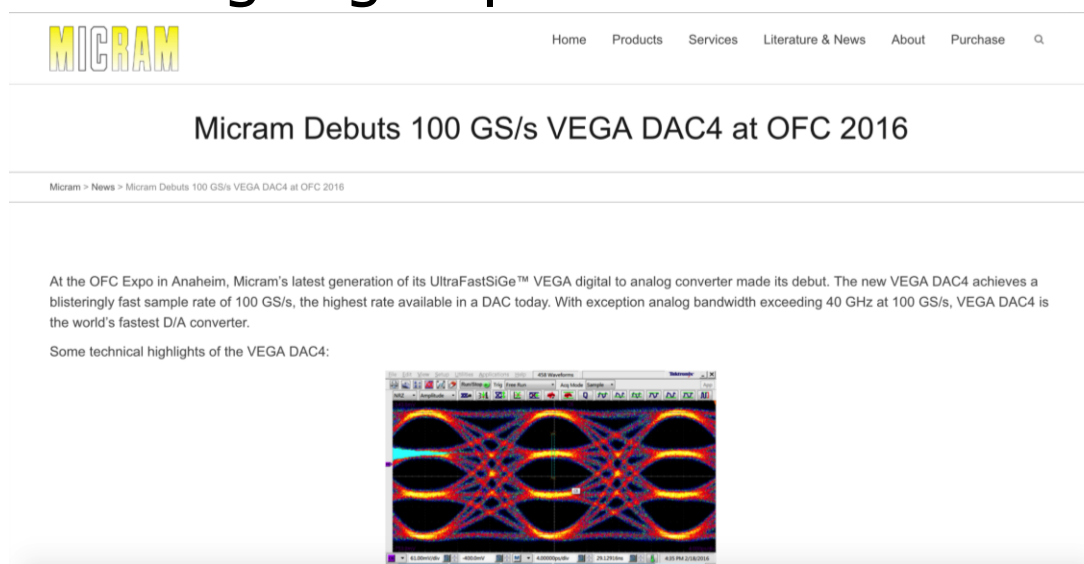
Wifi etc

Mobile
MOD?

Some pressure for further public sector release in this area

Digital Rx & transmission

- Current 4 Gs/s devices (Teledyne)
  Difficult for JVLA & e-MERLIN…
- TI & e2v 4-5 Gs/s 12b devices look better
- 26 Gs/s 3 bit chip from Analog Devices
- 100G transmission driving high speed ADCs

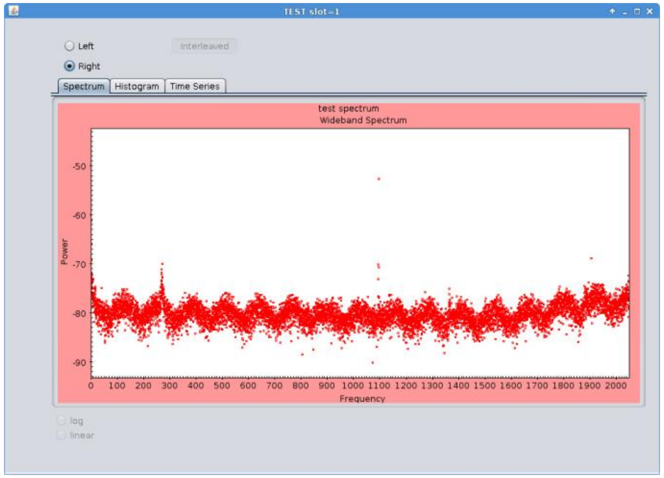


4 Gs/s sampler update

- Long story of using 4 Gs/s Teledyne devices at NRAO and JBO
- Design change; poor performance (median 10% down, but long tail); requires good performance across band
- JLVA: partial replacement with Hittite devices
- e-MERLIN implementation delayed & hit further problems: firmware & significant board rework
- Finally fully integrated &

  running end-end

  Now tuning
- On-sky tests & early obs Oct/Nov



Digital Options

- Next steps are 4 & 8 GHz/pol

  N x 2 GHz IF blocks

  single wideband RF processor (16+ Gs/s)
- Follow SKA?
- Follow DiVA?, watch ~ 20 Gs/s developments?

- Data Transmission
  - Fibre Network in place
  - Move to 100 Gb/s COTS

    8 GHz/pol @ 3b is 96 Gb/s

Correlator

- No additional capacity for > 2 GHz in existing WIDAR correlator (FPGA+ASICs)
- Many options:

  FPGA: PowerMX,Uniboard,Redback,AASL

  GPU: LOFAR, MIT, ATCA (6 x 8 GHz)
- Worth considering GPU route

  1 GPU board ~ 25 Gb/s

  4 boards/host with 100 Gb/s NIC

  Total ingest is ~ 0.8-1.2 Tb/s for 8 GHz/pol

  Topology depends on data organisation

  IF Chunks, or coarse channelisation at telescope
- Flexible, expandable, shareable with PSR, PAF processing

Upgrade sequence

- LT PAF
- S-band Rx
  - No digital dev required: immediate new sci with JVLA sensitivity & resolution for high-z starformation/AGN
- X-band Rx
  - First science with 2 GHz bw sensitivity & resolution for star/planet formation
- 100 Gb/s network upgrade
  - Interface to existing correlator
- Sampler & correlator upgrades
  - 4 GHz & 8 GHz
- K-band Rx
  - New Rx: 8 GHz b/w

Rough guide to performance…

Band	BW/GHz	FOV/arcmin	Resolution/mas	Rms/uJy
L	0.5	15	150	5-10
L-PAF (Lovell PAF)	0.4	30	150	7-15
S	2	10	75	~ 2
C	4	5	40	~ 1.5
X	8	2.5	20	~ 2
K	8	1	10	~ 4

Additional Telescopes

- Network, correlator & digital upgrades make it much easier to add new antennas
  - Goonhilly
  - Defford replacement
  - Others in UK
- Including European antennas
  - For imaging & PSR (LEAP)
  - Onsala, Westerbork,Effelsberg,…
- And to fully integrate e-MERLIN + EVN
  - 10 – 10,000km baseline range
  - Better spatial DR than VLA A+B+C+D+

Operations

- Full integration with Lovell and single dish operations
  - Phasing-up, sub-arrays, transient & PSR processing, spectroscopy & continuum for any single dish,+…
- Higher reliability with more COTS & SKA equip
- Receiver operations and mounting
  - Telescope optics
  - 3 -> 5 rx/telescope
  - PAF + multiple single beam Rx on Lovell

Summary & Discussion

- Plausible & v cost-effective route to

  New science bands, better performance, more flexibility, higher reliability

  Provides a UK facility which is competitive & compatible in SKA era

  Test-bed for science & instrumentation

Wrap-up points

- SKA + National facilities
  - Community support ('VLBA problem'- Phil)
  - Piloting, feasibility, SDP-tuning (1 chance – Anna)
  - Too much to follow up (Evan)
  - Demand now (Jane)
  - Counting effort towards SKA (Danielle)
- Competitive & compatible…
- Strong case for e-MERLIN resolution: 'Goldilocks' across a wide range of science areas
- Sensitivity with 2-8 GHz b/w is competitive (Paul)
- Exciting possibilities for PSR and transients
  - 110m equivalent, FRB localisation,…

Upgrade path

- Non-disruptive
- Strong support for
  - LT integration
  - S-band – extragalactic – sensitivity & resolution
  - X-band – stars/planets – spectrum & resolution
  - Additional telescopes – esp to S; EVN integration
  - Full bandwidth for max sensitivity
- Processing bottleneck
  - Need to speed things up!
  - Comprehensive approach to 'RFI' (incl raw voltage data)
  - Make early use of SDP pipelines
- Use of SKA technologies
  - 'Few extra in the production run' (Mike J)
  - Timescales are a key issue

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Discussion points

- Technical alignment with SKA
- Technical contributions from UK groups … return
- Strategic alliances
- Develop & prioritise science case
  - Upgrade sequence/priorities
- Frequencies < 1 GHz
- Scientific (and processing) alignment with SKA
- Big vs small projects

Next steps

This is just the start of the process…

Immediate/short-term (days/weeks):

- please pass/send me your talks – we will places these on-line (next week)
- comments on plans – keep the coming
- I will send a brief questionnaire/email to attendees for comment and wide ranging input

Medium term (coming months):

- This is first of series of potential meetings. Future meetings:
  - Inc Focussed topic (science or technical) or more wide ranging
  - JBCA/e-MERLIN staff happy to come to institutes to summarise talks/plans
- Distil plans → develop science case (w/t community input) & project plans
- *Oversight/input (essential):* as a national facility will engage key community members & relevant steering committees (e-MERLIN… etc)
- *Stakeholder oversight:* Set up a standing consultation/review committee – (incorporating members of steering committees but broadening to encompass the whole 'JBNA' concepts..)(?)