Workshop Summary: RFI and its impact on the new generation of HI spectral-line surveys

Lisa Harvey-Smith

19th June 2013

Workshop Rationale

How will RFI impact HI spectral line surveys with the new generation of radio telescopes?


Lane Cove National Park
Terrys Creek Walking Track
Browns Waterhole 1km
No dogs permitted
All flora and fauna protected

Topics

Ron Ekers Overview

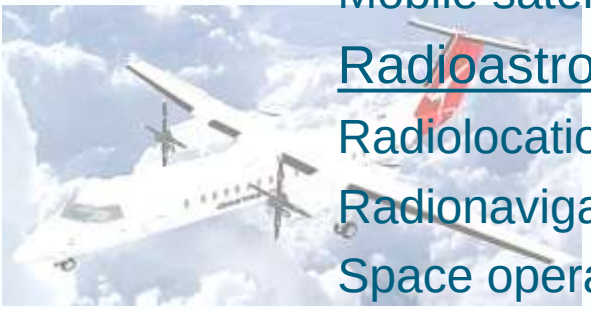
- Wide-Band SPFs increase RFI (more can get in!).
- FPAs can reduce RFI (know what direction it is coming from)

- Most man-made RFI is near-field
- We can remove things that are not at infinity

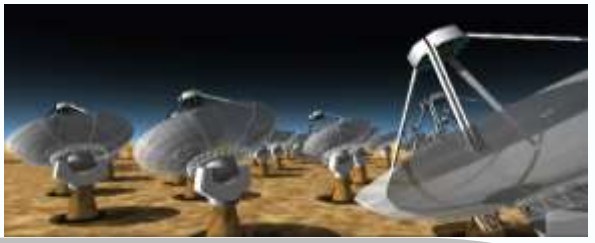
- Astronomers need to be *better informed* about spectrum usage
- Need to establish credibility in mitigation before demanding regulation
- Stop using combative language e.g. ‘harmful interference’

Spectrum Planning – Erik Lensson

Aeronautical mobile
Aeronautical radio navigation
Amateur
Broadcasting
Earth-exploration satellite
Fixed (terrestrial)
Fixed satellite
Inter-satellite
Land mobile
Maritime mobile



Maritime radionavigation
Meteorological aids
Meteorological satellite
Mobile satellite
Radioastronomy
Radiolocation
Radionavigation
Space operations
Space research
Standard frequency and time



Spectrum Management – Summary (Erik Lensson)

- Increasing world-wide demand for spectrum.
- Redshifted HI bands below 1400 MHz under particular pressure
- Regulation alone will not guarantee ongoing spectrum access

What we can do:

- Extend engagement with major national spectrum users
- Develop & implement real-time RFI countermeasures
- Develop RFI data gathering, archiving and analysis systems
- RFI monitoring, identification and EMC testing

Franz Schlagenhaufer

Lab tests on MWA equipment found broadband and narrowband emission.

- Shielding was improved but still not meeting spec at all frequencies.
- Narrowband emission still present at 655 MHz.
- Power line filter, A/C unit are the main offenders.
- No measurements done in the field – need testing in 'real-life' situation.

Aaron Chippendale RFI measurements and metrics

- Discussed 3 key metrics for comparing sites on RFI:
    - Interference to noise power ratio
    - Time-frequency occupancy
    - Total RFI power

For MRO SKA data:

- 1% of data thrown away if time-frequency plots used
- Otherwise up to 25% discarded if frequency-only plots made!

- Raw high sensitivity data for SKA sites in AU and SA are available here: http://www.skatelescope.org/site-raw-data/

Oleg Smirnov RFI measurements at KAT-7

- KAT-7 initially had self-generated RFI, problems are now fixed in hardware.
- Main offenders now UHF, VHF, FM, GSM
- Provided response is linear, and there is low spectral occupancy, flagging can remove the RFI

ATCA staff conducted a 16cm RFI survey – this is on the ATCA webpage

Aeronautical beacons (960-1210 MHz)
1030 MHz (Aircraft)
1090 MHz (Aircraft)

GPS Satellites
1227.6 MHz (BW 20.46MHz) (GPS L2 precision code)
1240-1252 MHz (1246 + n x 0.4375 where n = -7,7)
(Glonass Satellite positioning - like GPS)
1381.05 MHz (BW 4MHz) (GPS L3 code)

1.5GHz Terrestrial Microwave Link Band (1427-1535 MHz)
1430.5 1448.5 1503 MHz (BW 4MHz)
(Mt Dowe microwave link transmissions)
1440.5 1458.5 1501 1509 MHz (BW 4MHz)
(Other microwave link transmissions)
1437.5 1445.5 1494 MHz (BW 2MHz)
(Other microwave link transmissions)

L-band Satellite band (1525-1660MHz)
1525 - 1560 MHz (Inmarsat sat phone system - downlinks)
1525 - 1560 MHz (Thuraya sat phone system - downlinks)
1545 - 1559 MHz (Optus Mobilesat phone system)
1575.42 MHz (GPS L1 coarse/acquisition code)
1603 - 1615 MHz (Glonass Satellite positioning - like GPS)
1610 - 1621.35 MHz (Globalstar global satellite phone system)
1626 - 1660.5 MHz (Thuraya sat phone system - uplinks)

1.8GHz Terrestrial Microwave Link Band (1700-1900 MHz)
1720.5 1734.5 1748.5 1839.5 1853.5 MHz (BW 14 MHz)
1725.975 MHz (BW 1.95MHz)

2.1GHz Terrestrial Microwave Link Band (1900-2300 MHz)
2236.5 2251 2265.5 2280 MHz (BW 29 MHz)

2.4GHz ISM unlicensed band (2400-2483.5 MHz)
wireless LAN, bluetooth, cordless phones, microwave ovens

S-band Globalstar satellite phone system downlinks
2490.54 MHz (BW 1.23MHz)
2491.77 MHz (BW 1.23MHz)
2495.46 MHz (BW 1.23MHz)

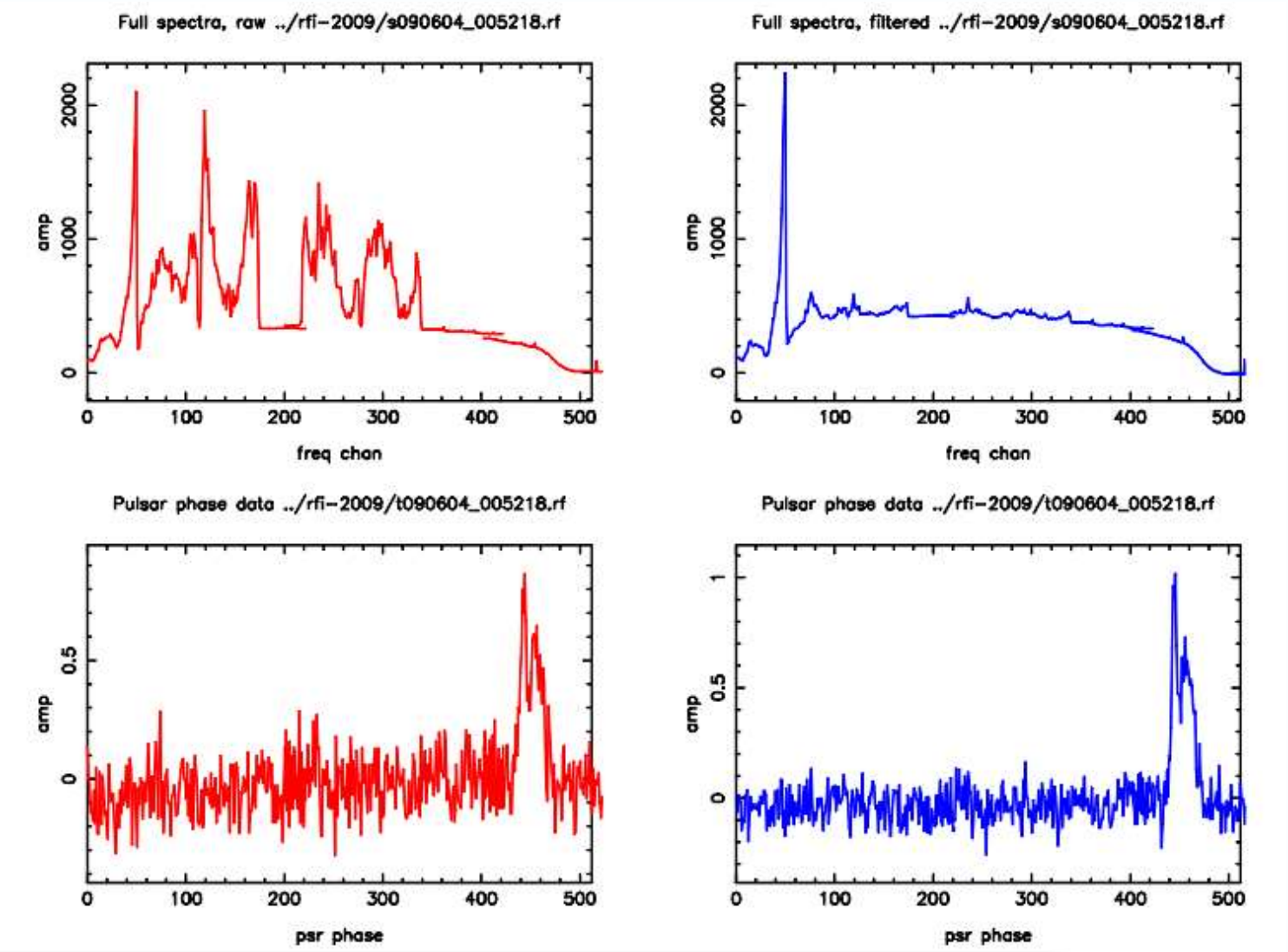
2880MHz Weather Radar - Gunnedah (BW 1MHz)

One particular unnamed bl#$dy aircraft (mid-week RFI)
1265 MHz (BW 10 MHz)
1310 MHz (BW 10 MHz)

ATCA RFI Mitigation strategies

- Being an interferometer helps (good for near-field, non-saturating emissions)
- Design in RFI tolerance (10 bits in digital sampling)
- Develop good flagging tools
- MIRIAD's pgflag has been equipped with LOFAR's AOFlagger algorithm
- Talk to regulators and stakeholders
- Active mitigation techniques (later talks…..)

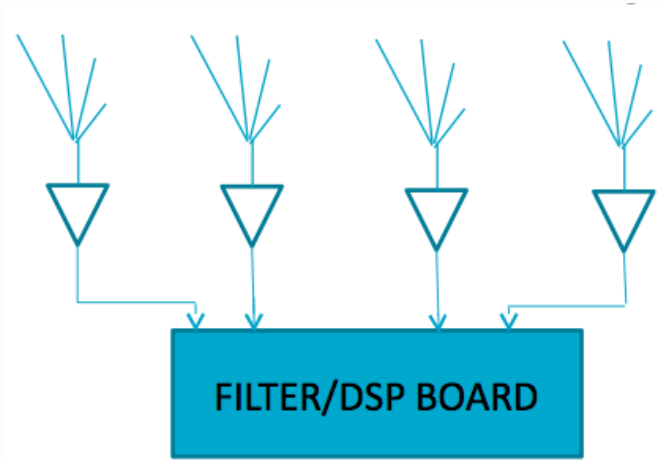
Mike Kesteven: RFI filter that he and Warwick Wilson are close to deploying at ATCA

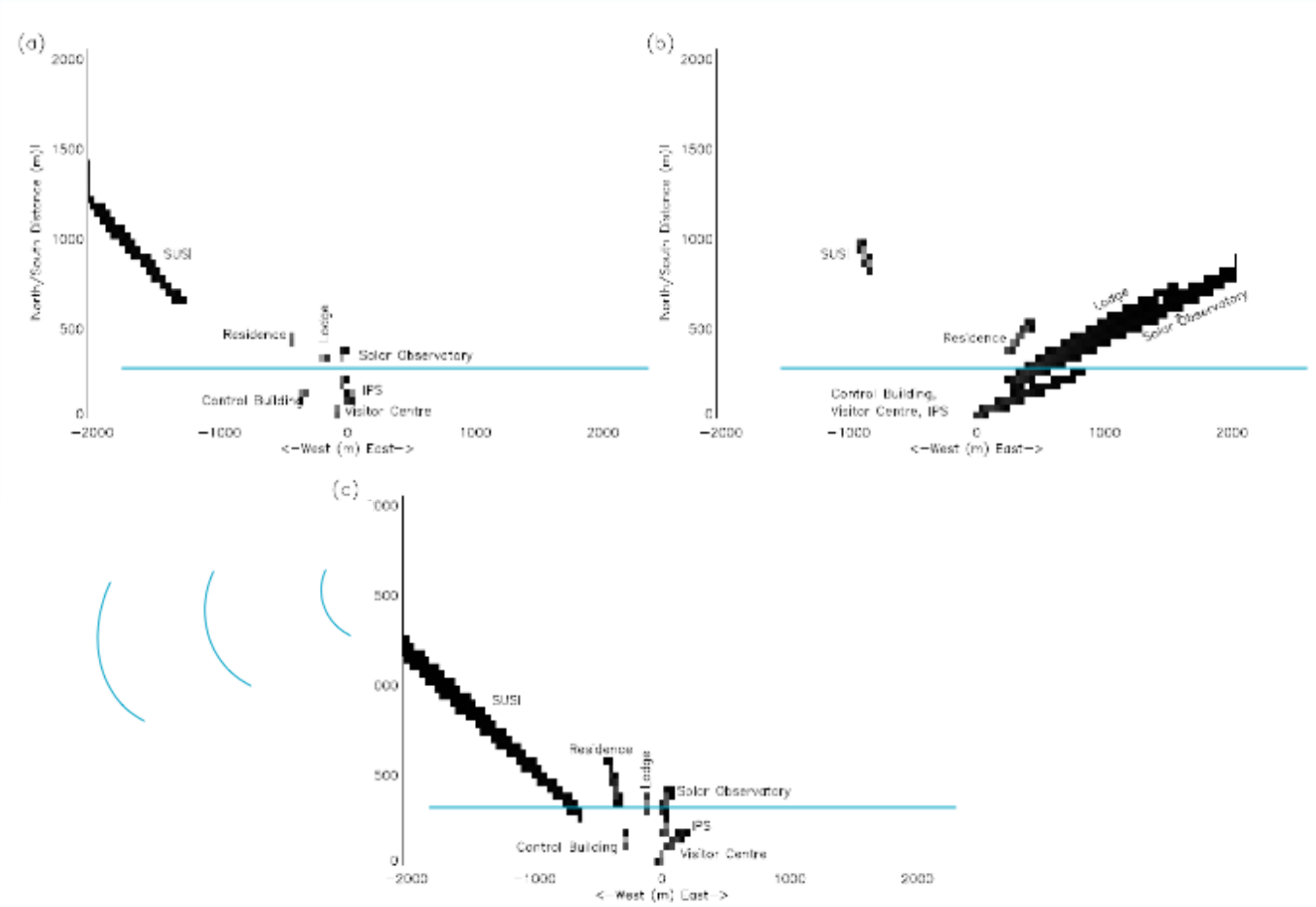


Paul Roberts: A flexible instrument for frequency and time domain RFI and EMC measurement.

3 or 4 antennas

RFI signal location through cross-correlation or timing





Brian Jeffs

PAF spatial filtering – can steer nulls in direction of interferers.

Practical demonstrations have been made at BYU using roof-top Tx and Rx.

The technique works – but there is a lot more work to be done.

Challenges:

- Sidelobe structure can be unpredictable.
- Becomes severe as null approaches the main lobe
- Sidelobe rumble increases confusion noise, hampers on-off subtraction.
- Choose your algorithms carefully if you want to null.
- Algorithms used in wireless comms, radar, sonar etc. do not drive deep enough nulls and distort beam patterns.
- New algorithms have been proposed to address this.

Andre Offringra AOFlagger

"Accurate, fast, tested, flexible"

LOFAR LBA 1.8 % data removed
LOFAR HBA 3% data removed – some small residuals still visible
No residuals seen in image, second stage flagger could be used in future

LOFAR does well because antennas are close to ground (and avoids FM band)*Design has accounted for the anticipated interference*

Recommendations:

- Sample in high time and frequency resolution
- Use a good RFI detection algorithm
- Design a robust signal path
- Always flag before you average data!

How RFI flagging can affect data

Brian Jeffs: For certain z, HI flagging will be problematic in that it removes information from that z range.

Laura Hoppmann: Flagging can create ‘negative flux’ artifacts in her Arecibo data.

Craig Anderson: Flagged sections can affect calibration solutions and the results of spectro-polarimetric measurements.

Tom Oosterloo, Lister Staveley-Smith, Atilla Popping:

RFI mostly affects shorter baselines – therefore removal of RFI biases your beam size.

You need to know your beam for your CLEAN and calibration. Need to store a beam cube next to your image cube.

It can be very difficult to carry around a large amount of beam data. Sometimes software can't deal with this situation.

How RFI flagging can affect data

Jacinta Delhaize:

HI Stacking experiment. Searched $0.04 < z < 0.13$ using Parkes

GPS satellite evident 1265-1270, new satellites evident in later data between 1285-1255, plus broadband RFI.

AOFlagger simply removed everything up to 1310 MHz

Should be able to stack 9000 galaxies, but could only do 3000.

Cannot study evolution of HI in galaxies at $z>0.1$

ATCA observations (CABB zoom modes)
Broadband RFI around 1200-1300 MHz – whole band saturated.

Alternatives to flagging

Ron Ekers: For a moving satellite, there are well documented ways to remove signals. We can't keep flagging 50% of data. We need to model satellite motions. (!!)

Tasso: WSRT had some front-end hardware (an attenuator in front of the amplifiers) but it was never used. Are there plans? No.

Ron E: Information from adjacent beams can tell us about the characteristics of the RFI. We must not write out the possibility of doing this comparison in the correlator design.

Paolo Serra: looking at WSRT data, you actually see RFI varying at ms time resolution. Better to flag at very early stage (don't want to sample in software).

Lister: With ATCA we regularly subtract distant interfering sources. Can be subtracted out in MIRIAD but amplitude is only taken down by factor of a few.

Where do we go from here?

- An international data challenge for flagging software
- Systematic monitoring programs should be standard at all observatories
- User documentation is a priority – existing knowledge must get to the user!

SKA

- Pathfinders will deal with RFI in front-end, software and active techniques.
- During design phase we (SKA representatives) must keep watching brief on pathfinder techniques and their effectiveness.
- Keep RFI on the agenda through presentations at international conferences, SKA engineering meeting, representation in work packages etc.
- Regular international workshops alongside science-focused meetings