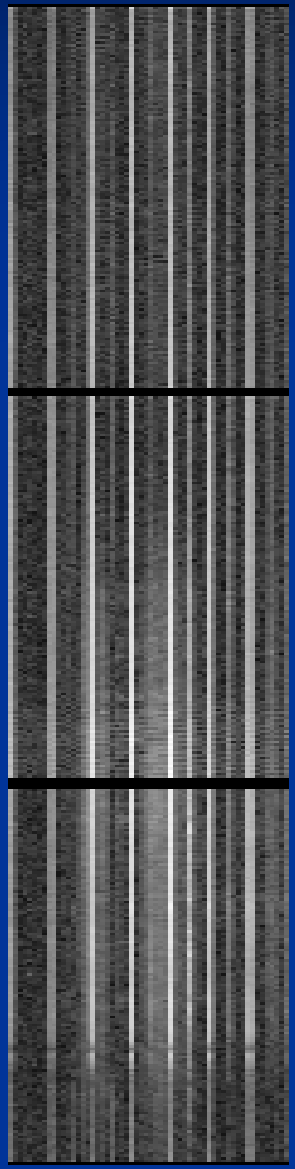
Post-Correlation RFI-Excision at Low Radio Frequencies

W. Lane (NRL)
A. Cohen, N. Kassim, J. Lazio (NRL)
R. Perley, B. Cotton, E. Greisen (NRAO)

The Problem

- Existing radio telescope systems do not routinely mitigate interference.
- There is a lot of RFI at low radio frequencies!
- Much of this RFI is generated by the radio telescopes or their supporting systems.
- As a user, it becomes necessary to devote a large amount of time to editing, or flagging, this interference.

RFI Gallery: VLA 74 MHz



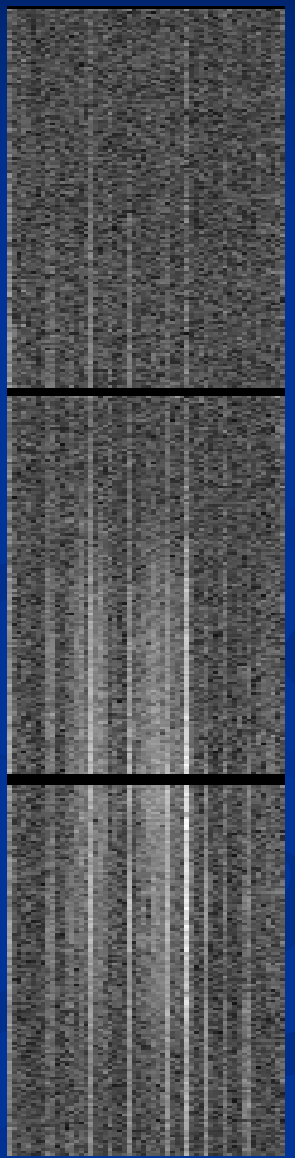
Time

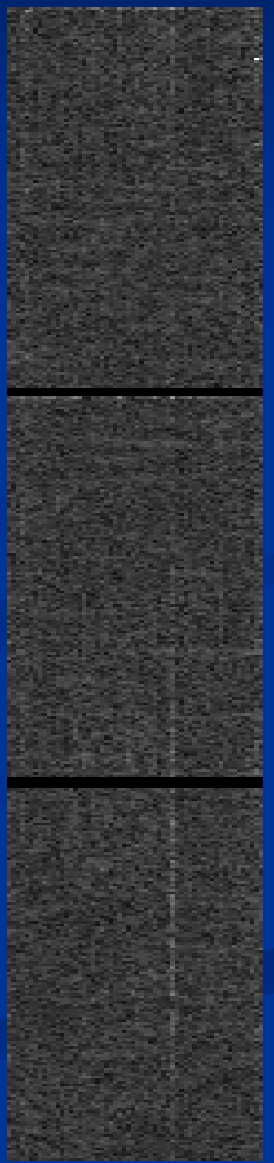
Channel

Internally generated rfi “comb” at 100 kHz

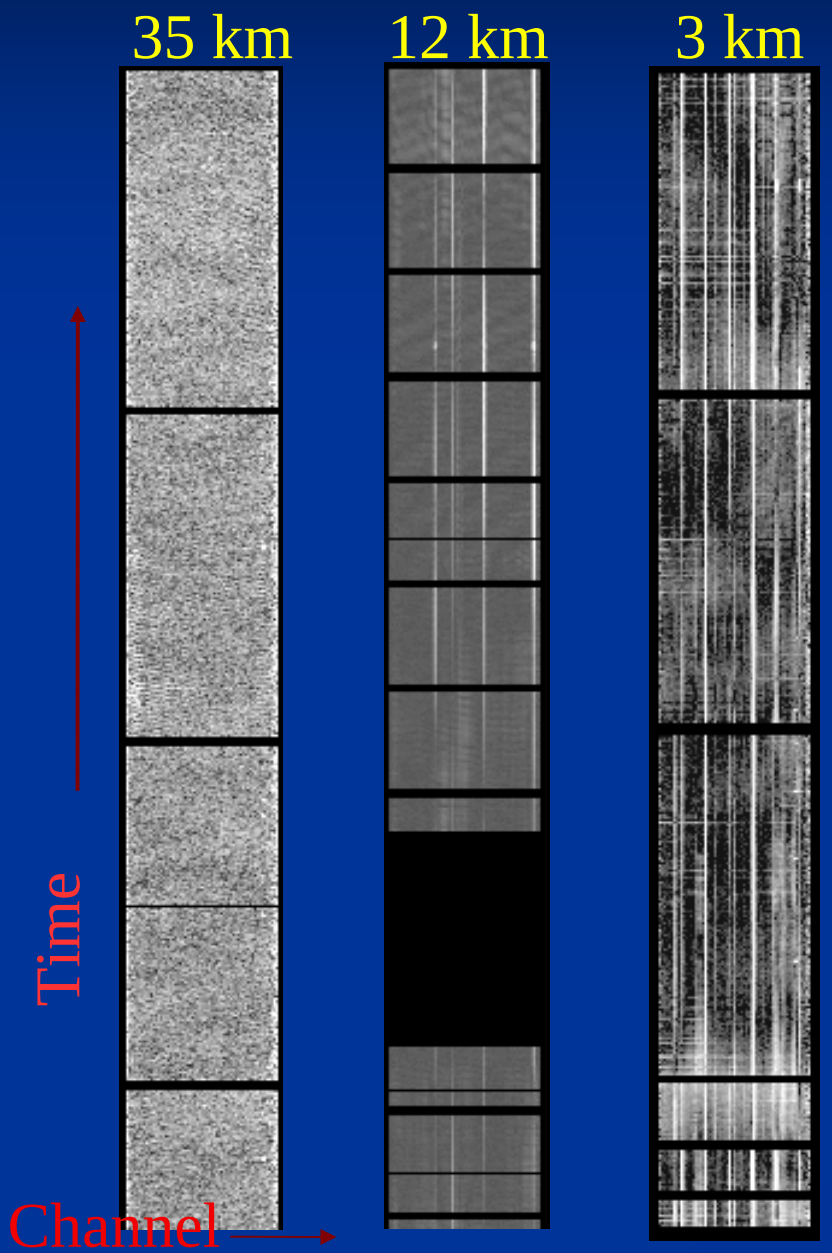
Narrow, isolated signals, easy to identify and remove

Presence varies from baseline to baseline, and depends on the antennas involved as well as the baseline length.



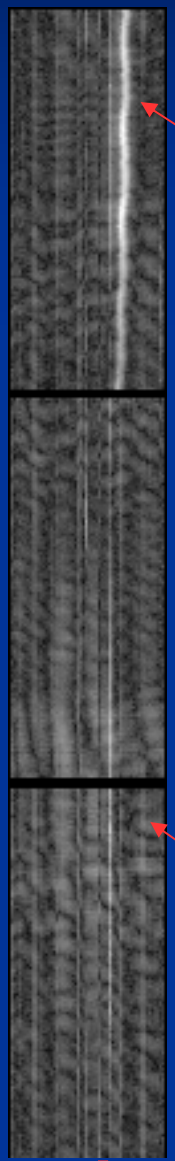


RFI Gallery: 74 MHz



- The RFI environment is usually worse on shorter baselines.
- Some antenna pairs ‘resonate’ strongly, no matter where they are.
- Particularly difficult is the ‘wideband’ interference, commonly seen on short spacings.

RFI Gallery: VLA 74 MHz



wanders

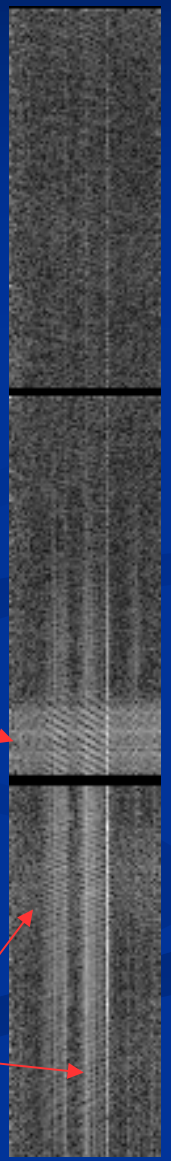
Externally generated signals are seen, even at 74 MHz, which is considered "relatively clean".

These can be any bandwidth and even wander in frequency, and are not necessarily constant over time.

Time

Channel

Low-level rumble



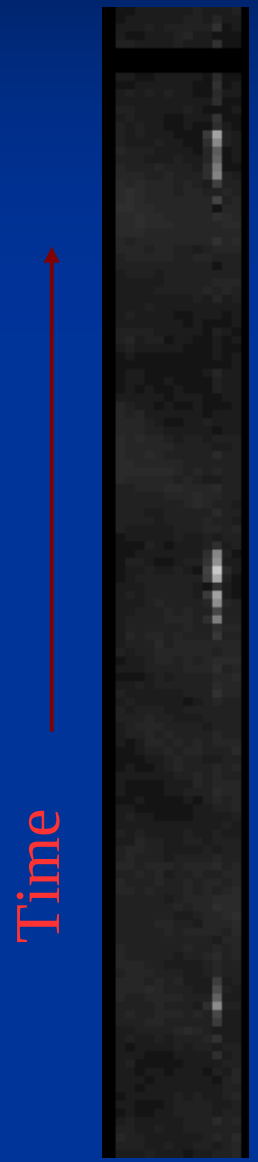
Entire band

Moderately broad

Time

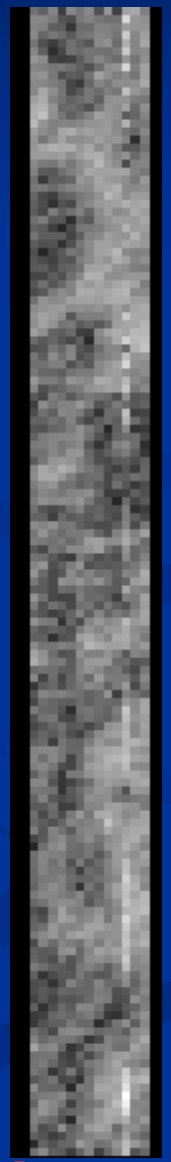
Channel

RFI Gallery: VLA 330 MHz



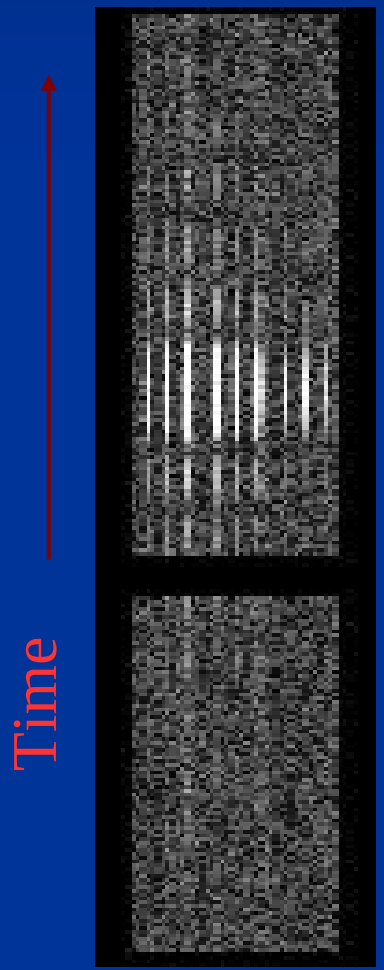
At 330 MHz, the majority of the RFI is externally generated.

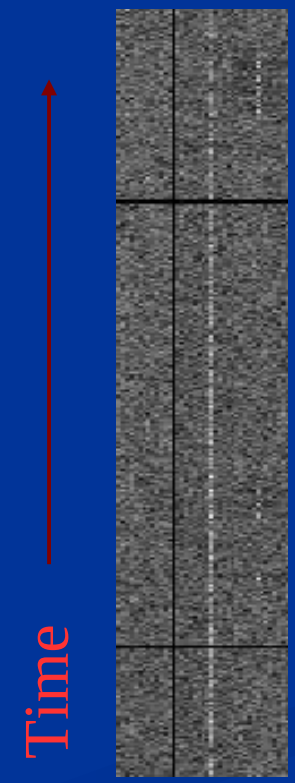
Observing in multi-channel “pseudo-continuum” mode allows much of it to be removed, as it is often narrow-band.

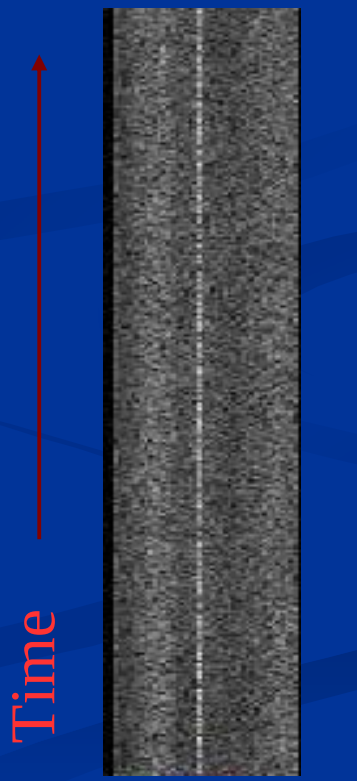


RFI Gallery: VLBA 330 MHz

Even long baselines, such as those from the VLBA are not enough to prevent RFI at low frequencies.







Solutions

- Careful planning
  - Observe in multi-channel “pseudo-continuum” mode to allow excision of RFI with minimal data loss.
  - Try to avoid known strong emitters in the observed band.
- Data Editing
- Patience!

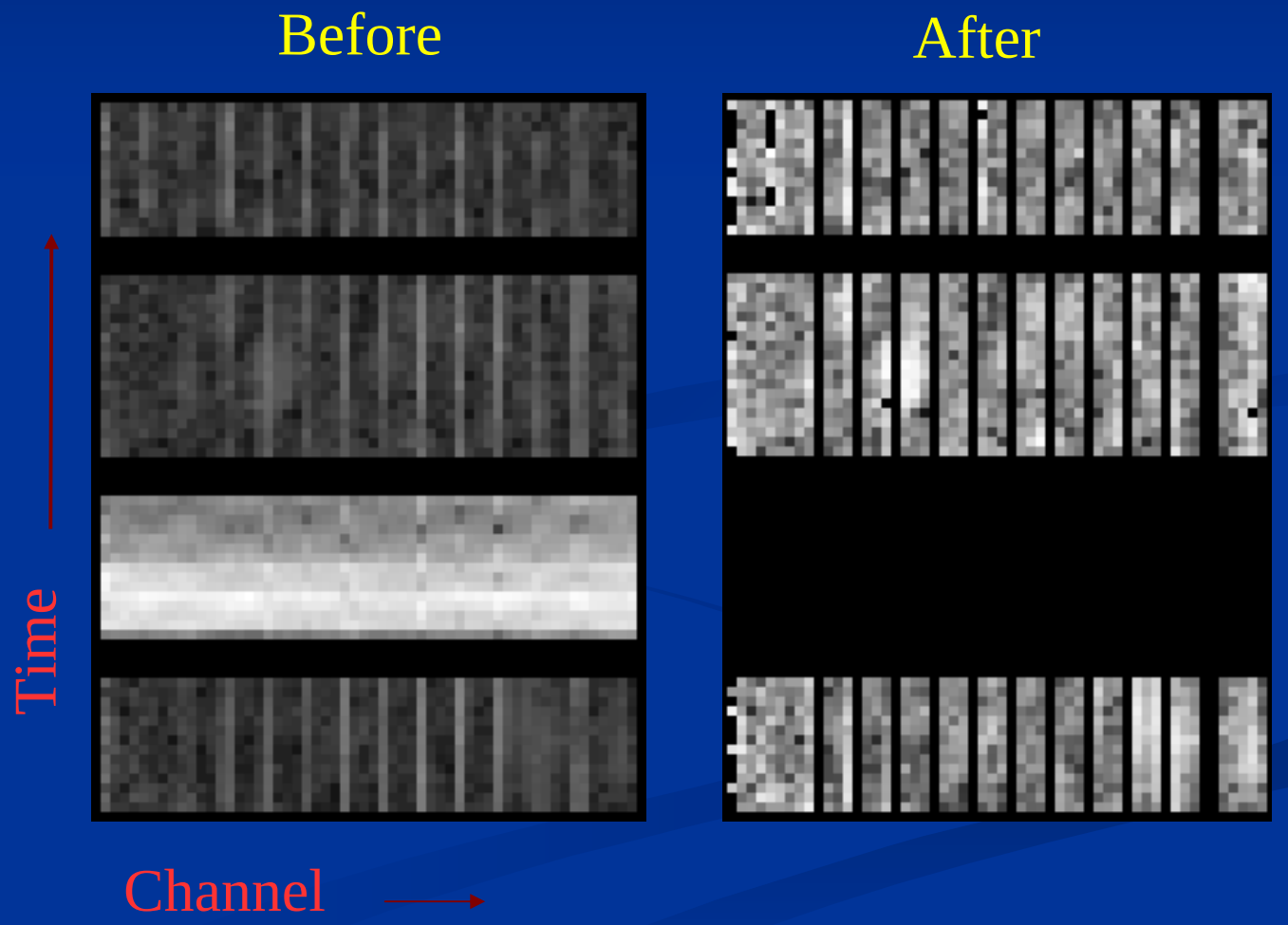
Data Editing (Flagging)

- Automated Flagging Software
  - Tends to work best on narrow band, constant signals
  - Useful for large, homogeneous projects (e.g. Surveys)
  - Rarely the best choice for individual projects
- Hand Editing
  - Is usually both tedious and time-consuming
  - Requires some care and knowledge of the data
  - Should give better results!

Automated Flagging

At 74 Mhz, removing the known “comb” channels and running a high-level “clip” of the data can remove a significant fraction of the RFI.

It is frequently also helpful to simply remove the inner portion of the UV-plane.

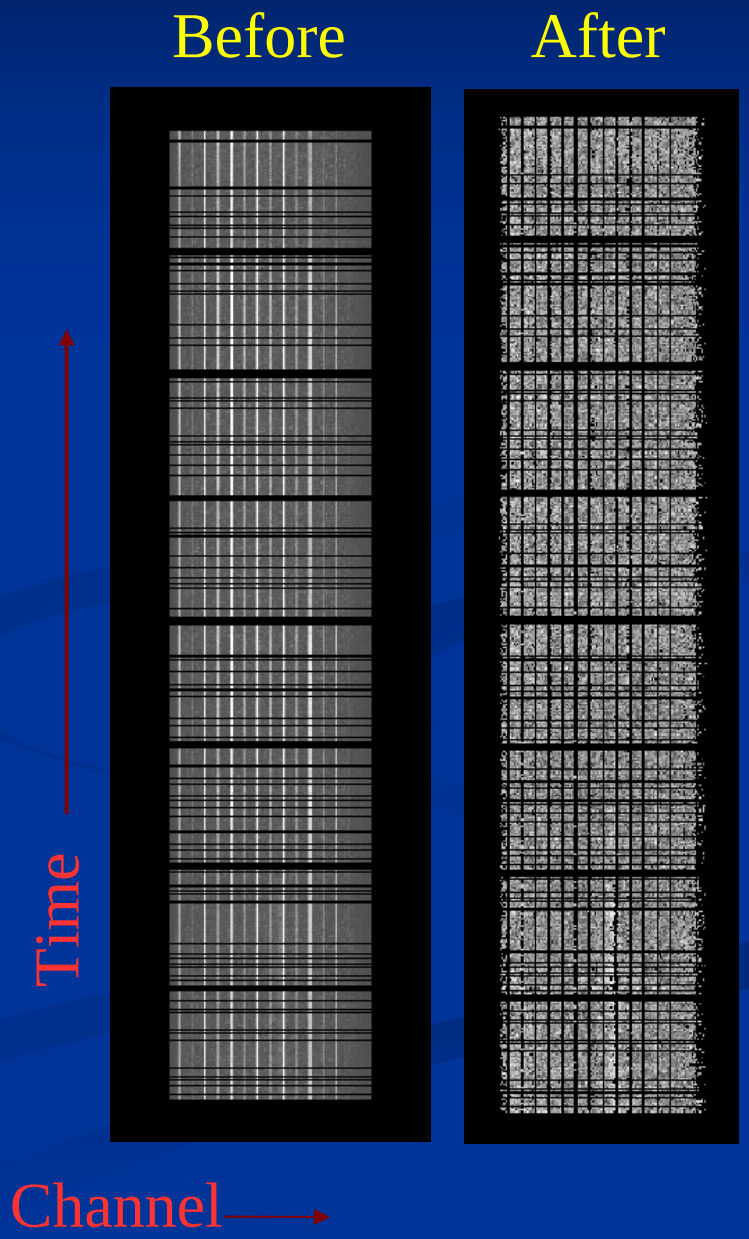


The AIPS Program FLGIT

The best automated flagging routines attempt to identify RFI by checking for deviation from an average data value.

In AIPS this is implemented by the task FLGIT.

This works best on narrow-band RFI that is constant in frequency and time. Care must be taken not to clip off the top of broad-band features making them more difficult to identify.



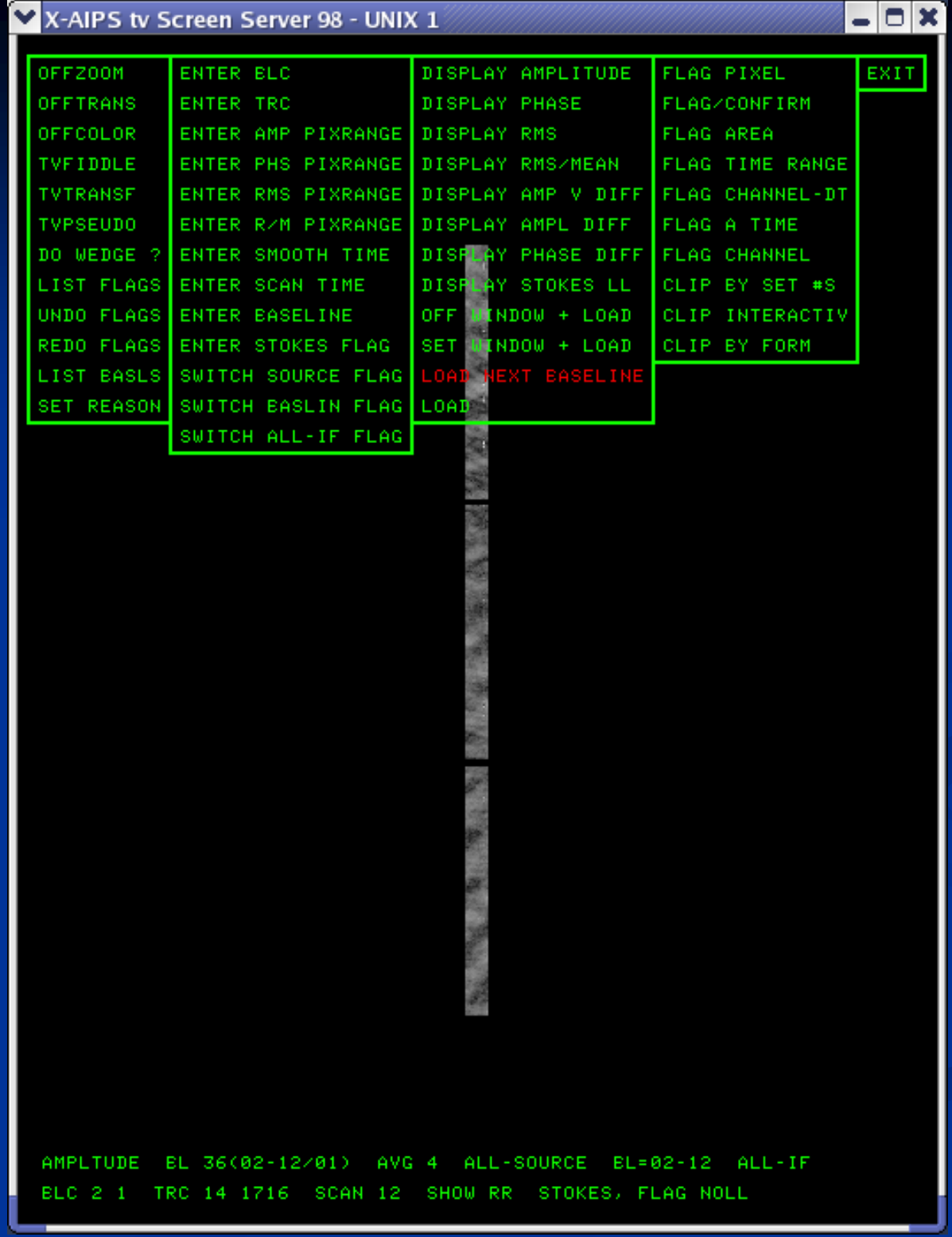
Hand-Flagging: SPFLG

One of the most effective ways to flag low-frequency data is to flag time and channel in each baseline separately.

In AIPS this is done by the task 'SPFLG'.

A wide variety of menu options allow great flexibility.

It is, however, tedious for an average observation at the VLA which has 351 baselines and frequently 2 polarizations!

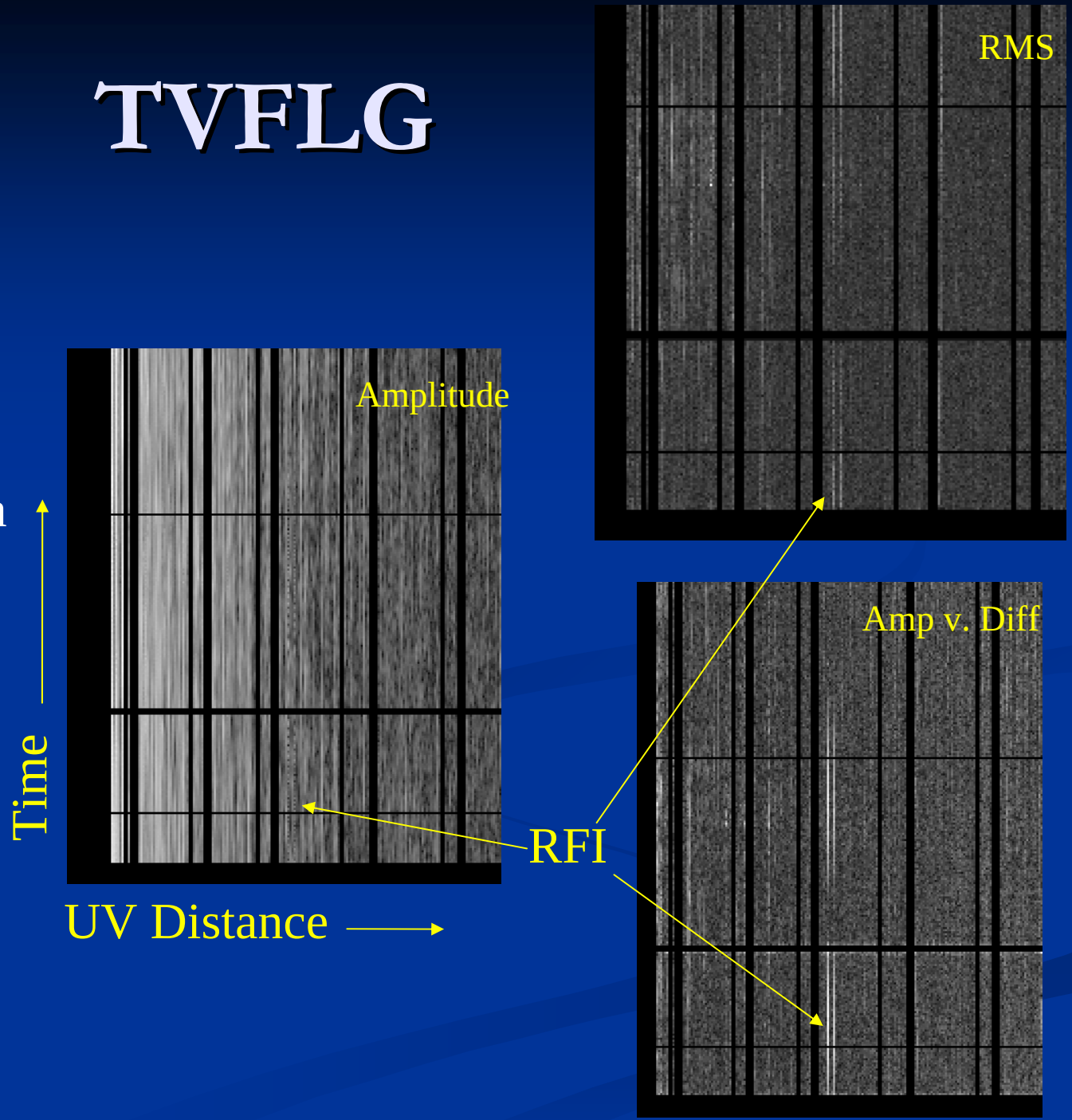

X-AIPS tv Screen Server 98 - UNIX 1
OFFZOOM
OFFTRANS
OFFCOLOR
TVFIDDLE
TVTRANSF
TVPSEUDO
DO WEDGE ?
LIST FLAGS
UNDO FLAGS
REDO FLAGS
LIST BASLS
SET REASON
ENTER BLC
ENTER TRC
ENTER AMP PIXRANGE
ENTER PHS PIXRANGE
ENTER RMS PIXRANGE
ENTER R/M PIXRANGE
ENTER SMOOTH TIME
ENTER SCAN TIME
ENTER BASELINE
ENTER STOKES FLAG
SWITCH SOURCE FLAG
SWITCH BASLIN FLAG
SWITCH ALL-IF FLAG
DISPLAY AMPLITUDE
DISPLAY PHASE
DISPLAY RMS
DISPLAY RMS/MEAN
DISPLAY AMP V DIFF
DISPLAY AMPL DIFF
DISPLAY PHASE DIFF
DISPLAY STOKES LL
OFF WINDOW + LOAD
SET WINDOW + LOAD
LOAD NEXT BASELINE
LOAD
FLAG PIXEL
FLAG/CONFIRM
FLAG AREA
FLAG TIME RANGE
FLAG CHANNEL-DT
FLAG A TIME
FLAG CHANNEL
CLIP BY SET #S
CLIP INTERACTIV
CLIP BY FORM
EXIT
AMPLTUDE BL 36(02-12/01) AVG 4 ALL-SOURCE BL=02-12 ALL-IF
BLC 2 1 TRC 14 1716 SCAN 12 SHOW RR STOKES, FLAG NOLL

TVFLG

After SPFLG it is useful to continue flagging on a smaller, frequency-averaged dataset.

Displays all baselines as a function of time.

Options such as "Amplitude vector Difference" and "RMS" to view the data make it easier to identify RFI. Flagging Stokes V is another useful option.

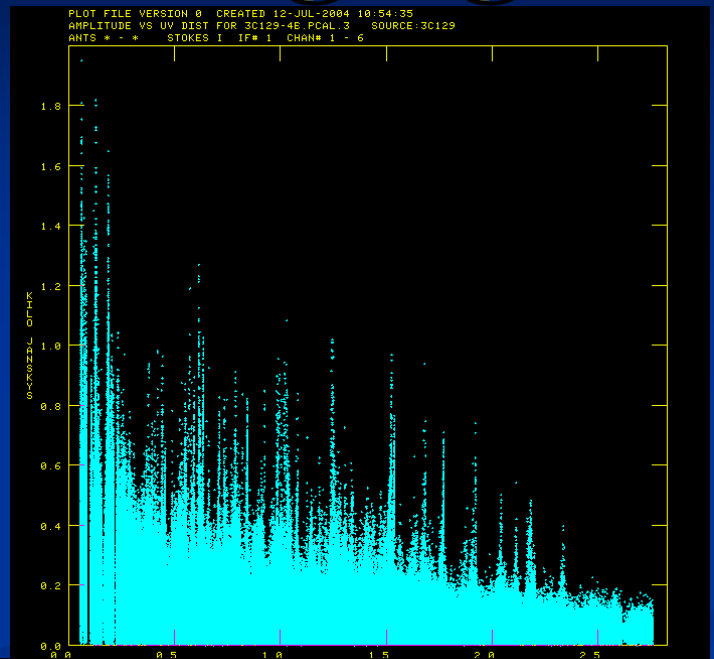


Time & Frequency Averaging

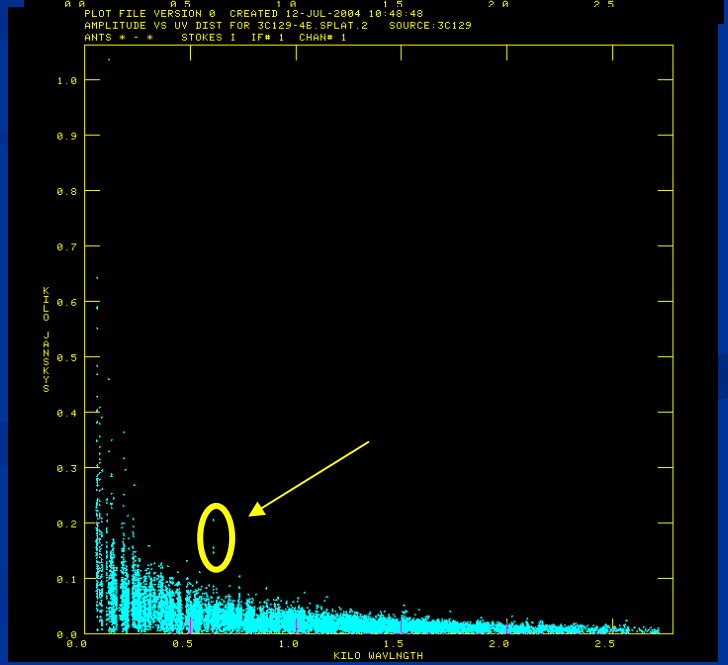
Averaging in time and/or frequency makes it easier to isolate RFI, which can average coherently, from gaussian noise, which does not.

Once identified, the affected times/baselines can be flagged in the un-averaged dataset.

before



after



Comparison to Model

Once a very good model of the observed source is derived, it can be compared to the visibilities and discrepant baselines flagged.

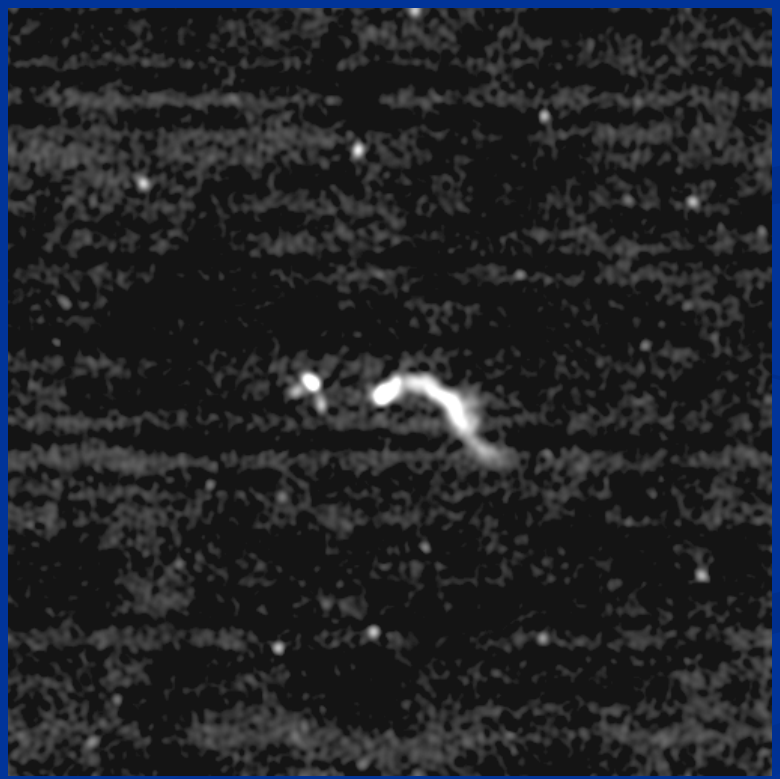
In AIPS the typical implementation is to divide or subtract the model from the data, and then clip the data at a reasonable amplitude.

The Last Bits

Although the methods described can find most of the RFI in a dataset, there is frequently a small amount remaining.

One typical example reveals itself as so-called “polar rings”.

These are the sidelobes of a source ‘located’ at the NCP, and are in fact due to stationary, low-level, probably broad-band RFI.



Summary

On individual fields, hand-flagging remains the best way to remove most RFI

However it requires a substantial commitment of time for a large-N array.

Preventing self-pollution, and techniques to mitigate or blank known strong signals will become increasingly necessary on future instruments as the RFI environment continues to worsen, the number of antennas continues to increase, and thus the amount of time needed to properly flag data also increases.