Calibration of MeerKAT autocorrelation data for HI Intensity Mapping

SKA Cosmology SWG meeting

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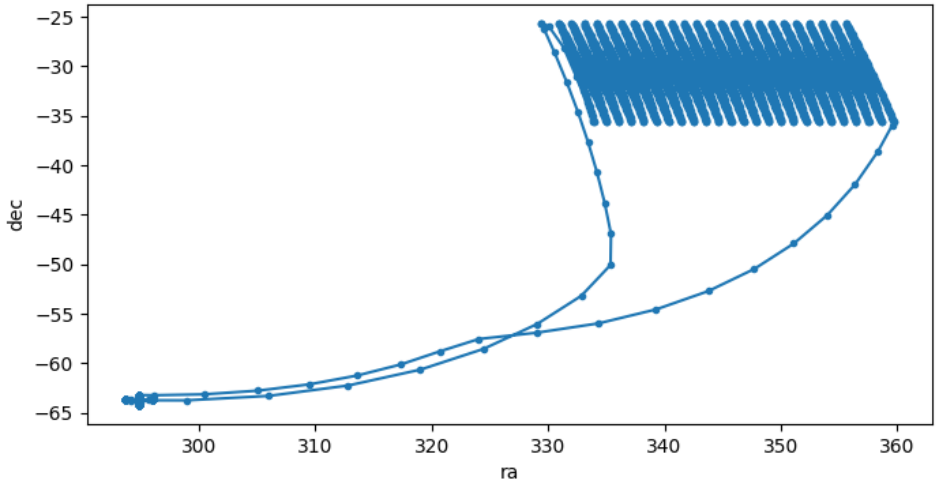
Neutral Hydrogen Intensity Mapping

MeerKAT (Credit SARAO)

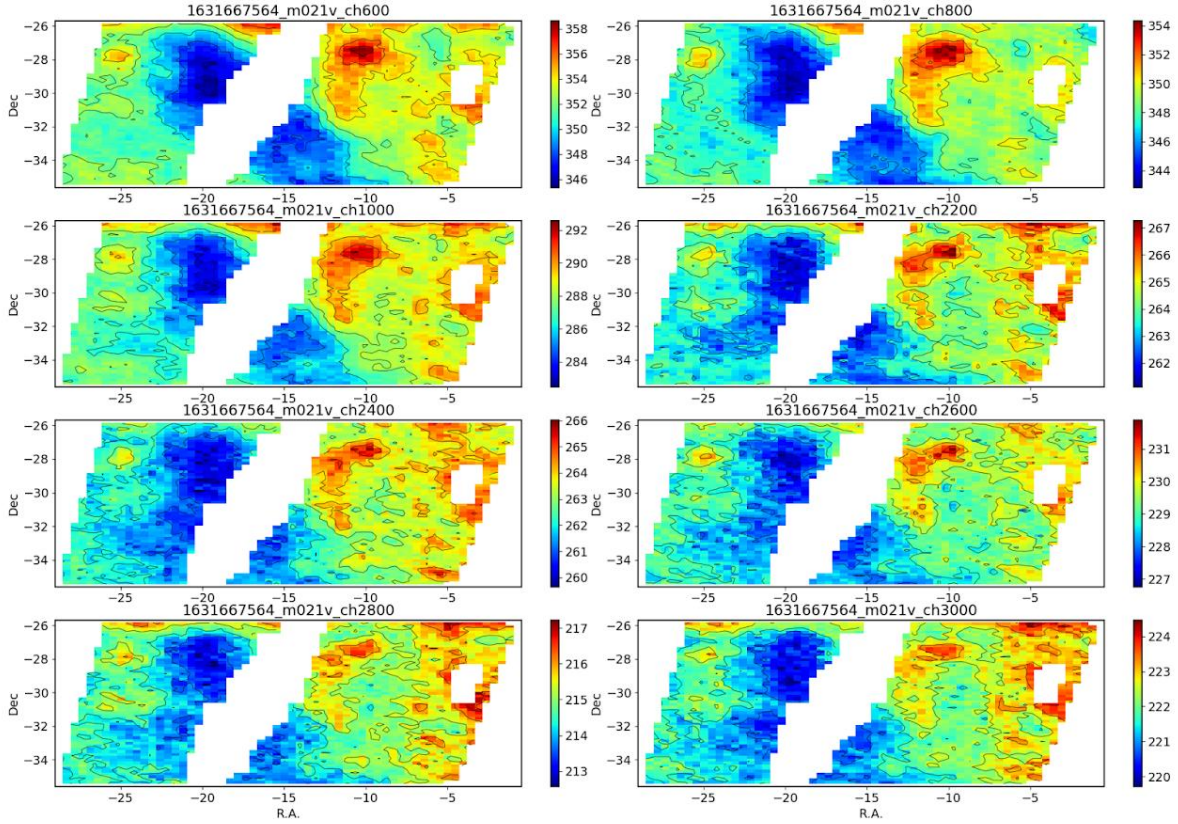
- HI in galaxies is a tracer of mass
- Observe 1.42 GHz HI emission
  - Redshift gives 3D map
- Detect large scale HI
  - Do not resolve individual sources
  - ~Degree+ scale
- Use MeerKAT 13.5-m antennas
  - Baselines resolve out signal
  - Use “single dish” mode
    - Measures total power
- Lose interferometry advantages
  - Systematics rejection

MeerKLASS Scanning Strategy



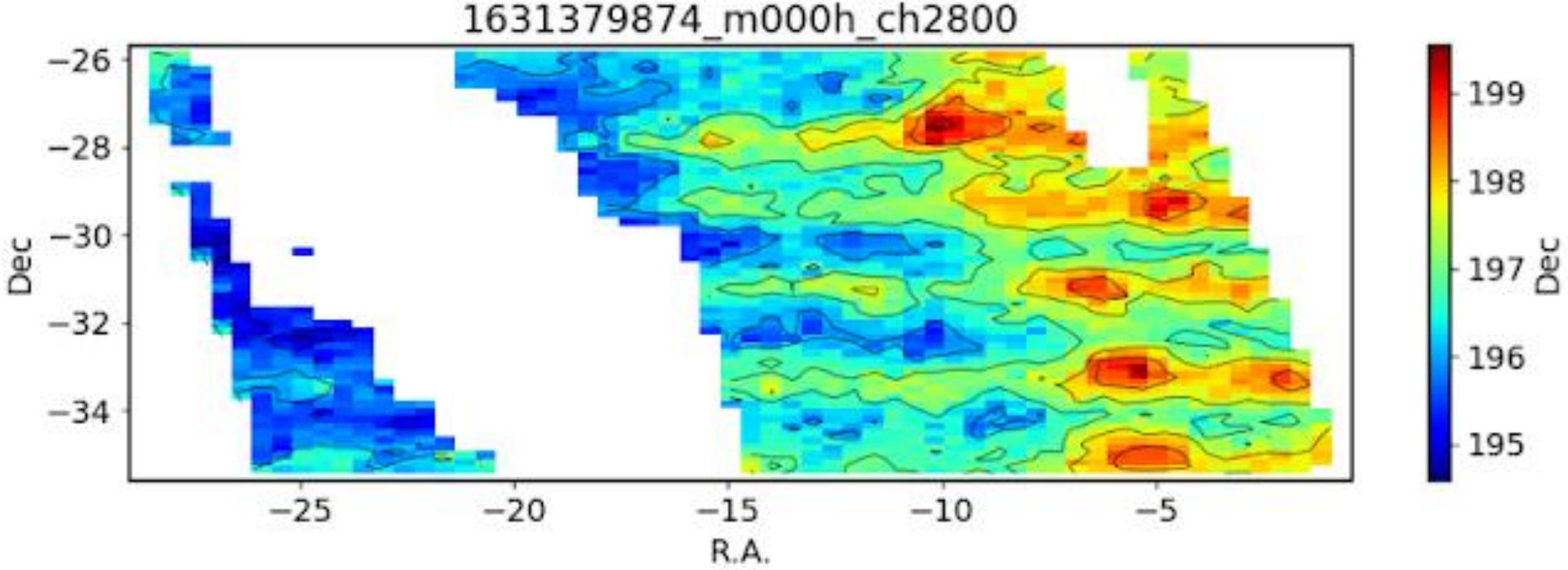
- Observe at constant elevation
  - Constant ground spill
  - Constant atmosphere emission
- Drive at 5’ per second
  - Map large amount of sky
  - Suppress 1/f noise
- Scan for ~12 deg in azimuth
- Reverse direction
- Map ~300 sq deg in 90 minutes
- Remap hours later for cross-hatching

Sky maps

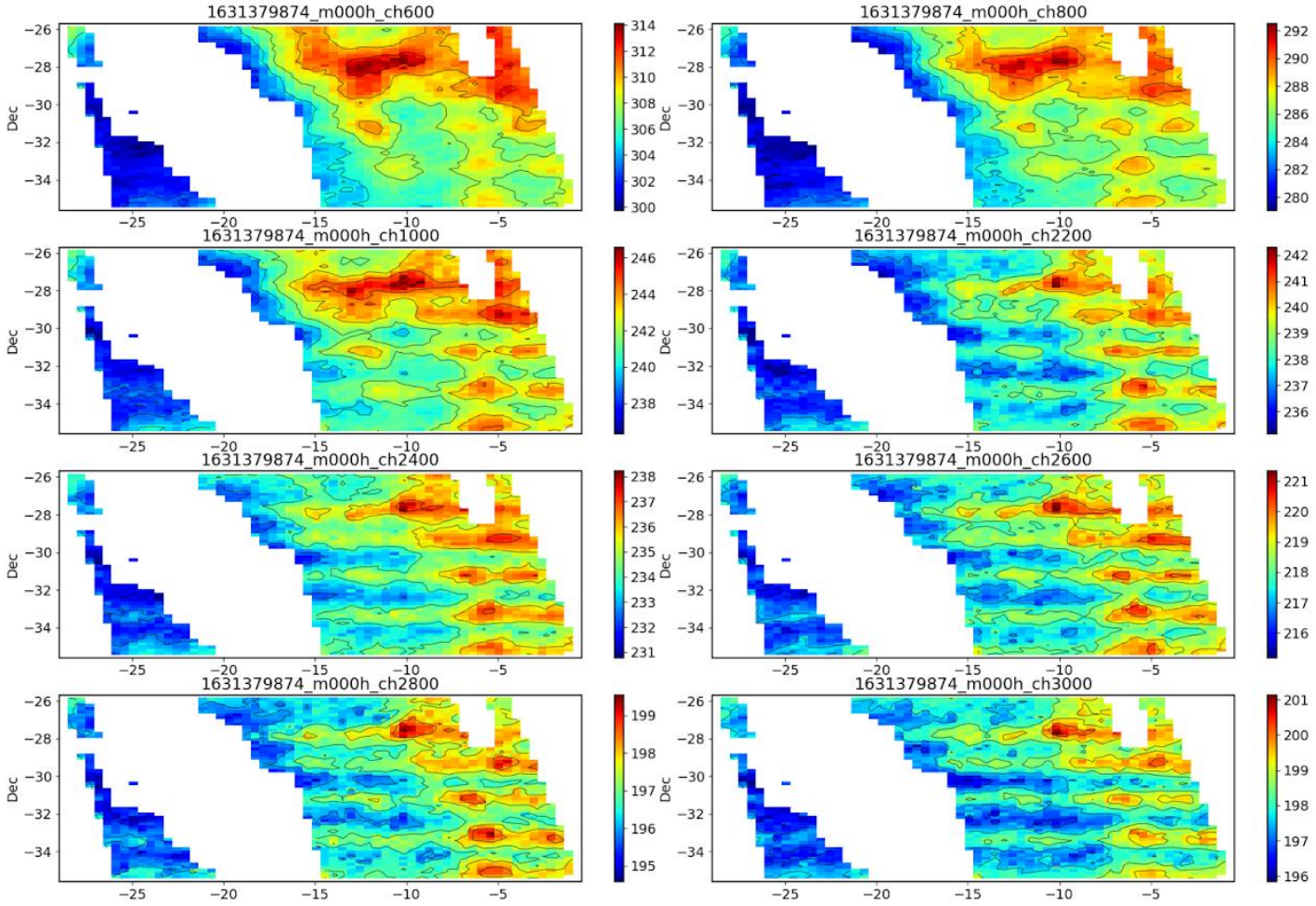


- Single antenna map
  - 90 minutes of data
  - ~300 sq degrees
- Large DC offset
- Largely synchrotron dominated
  - Common features at all frequencies
  - Fainter at high frequency
  - Make use of spectral smoothness
- RFI a major problem
  - Satellite track visible

The “zebra” phenomenon

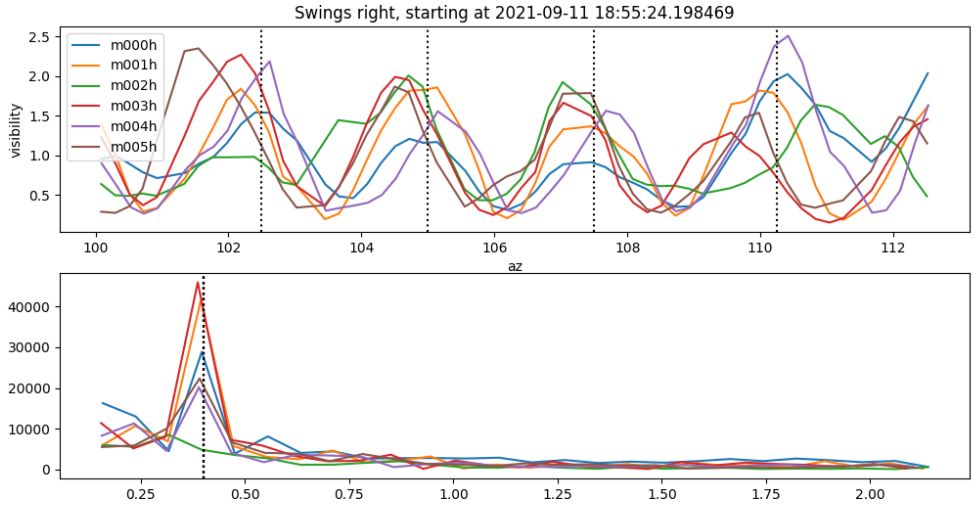


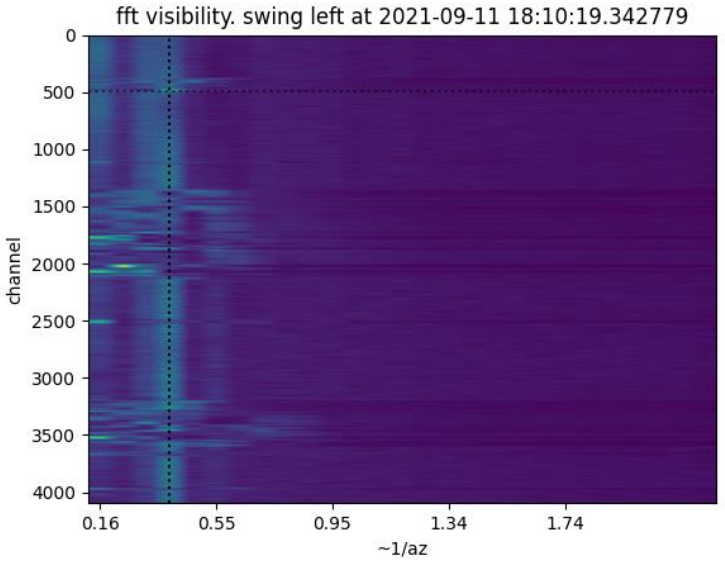
The “zebra” phenomenon



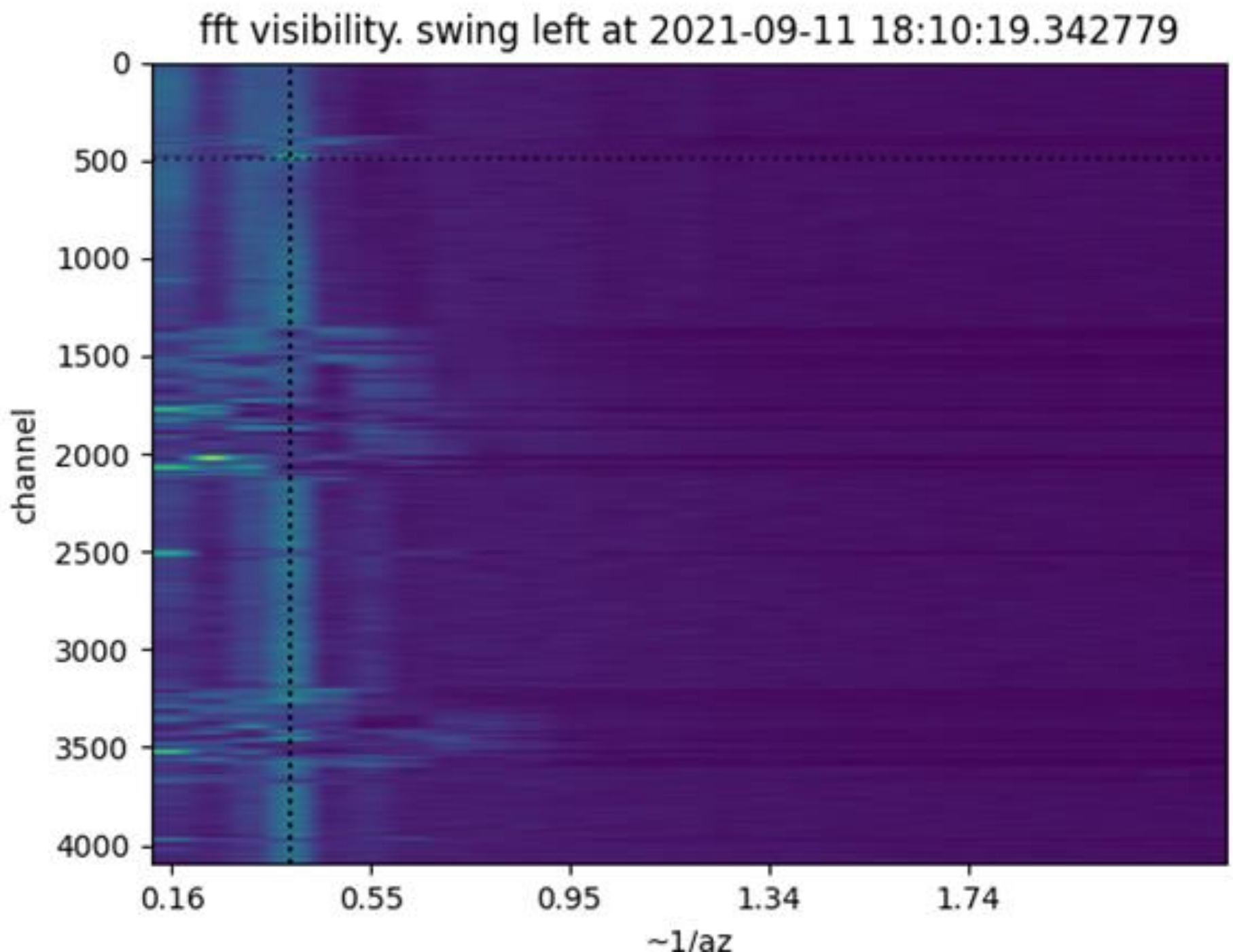
- Stripes running across map
  - At all frequencies
    - Harder to see at low frequency
  - At approximately constant Dec
  - Corresponds to Az dependence

Periodicity in azimuth

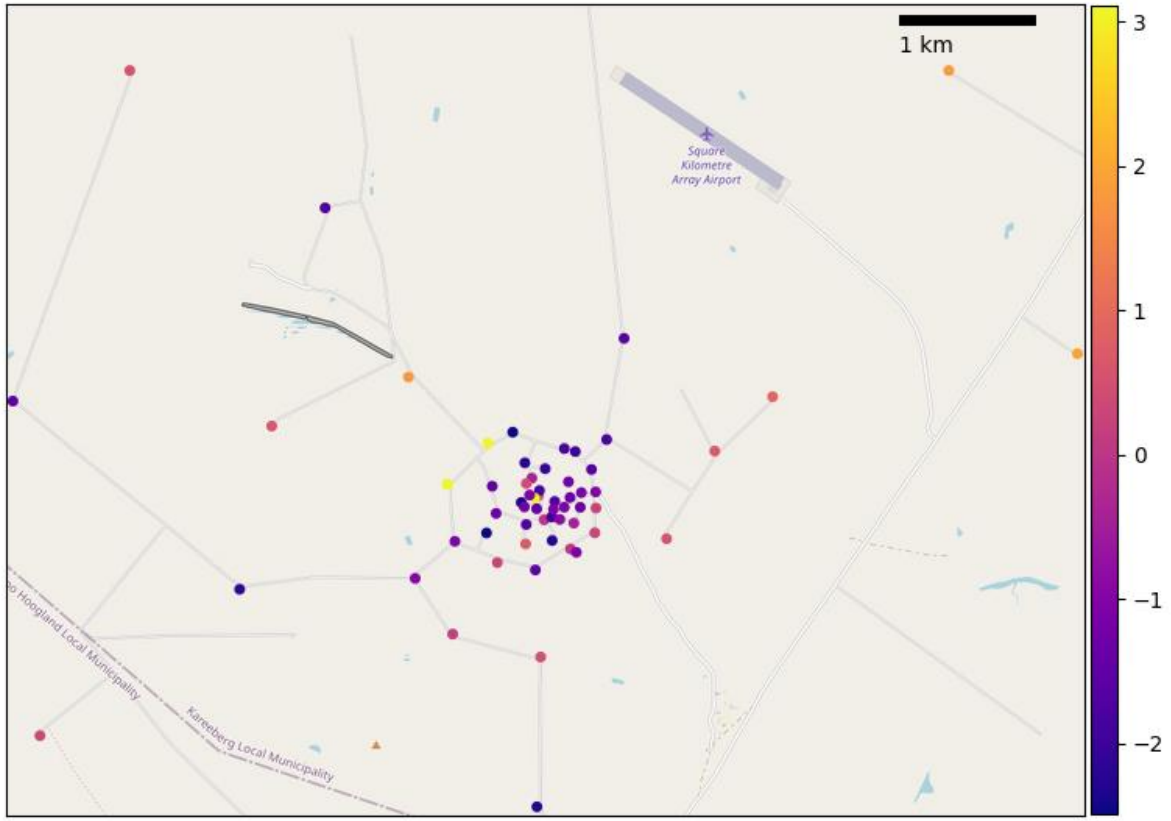




- Stack data as a fn of azimuth
- Not consistent between antennas
  - Though spacing between stripes is
  - i.e. common azimuthal frequency
- FT of azimuthal data
  - In RFI free channels see signal
  - RFI generally not similar
  - Except around channel 500
    - 958 MHz
    - Terrestrial GSM towers

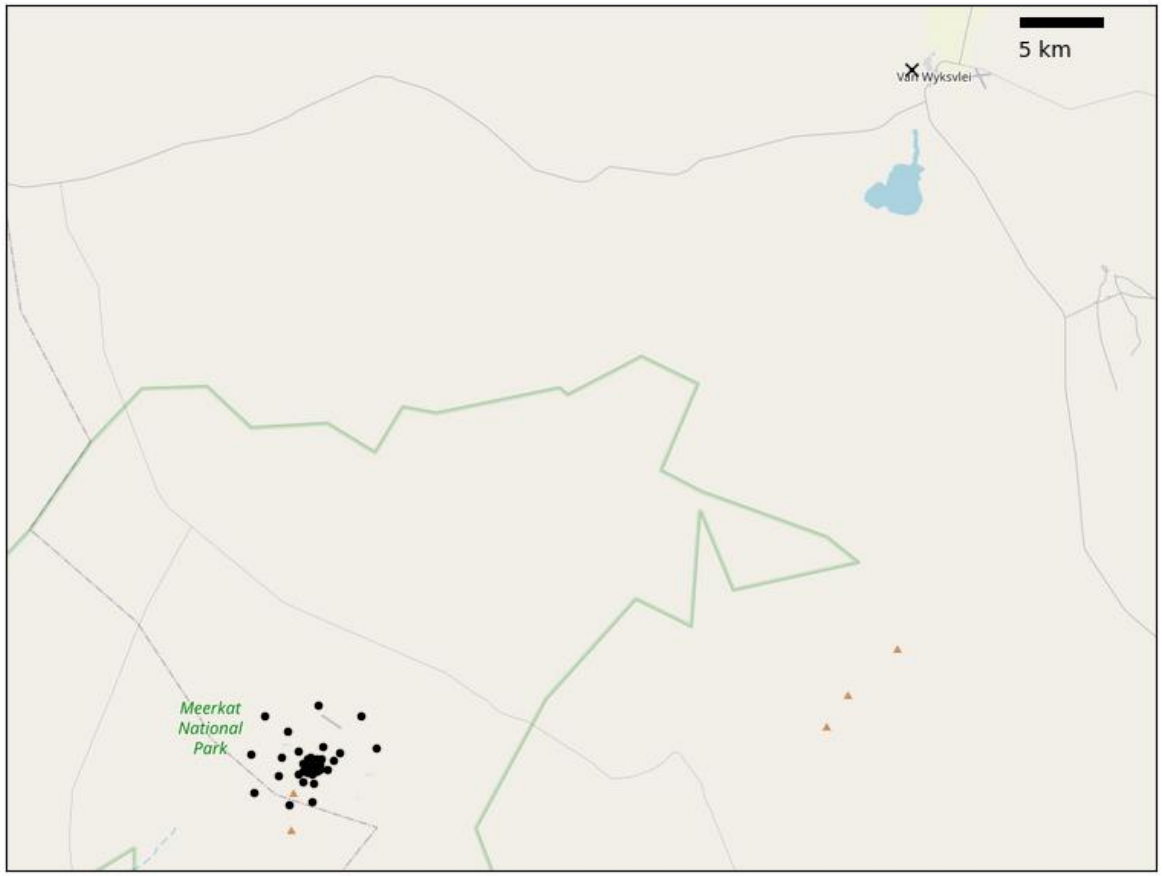

fft visibility. swing left at 2021-09-11 18:10:19.342779
channel
0
500
1000
1500
2000
2500
3000
3500
4000
0.16
0.55
0.95
1.34
1.74
~1/az

Phase of azimuthal FT



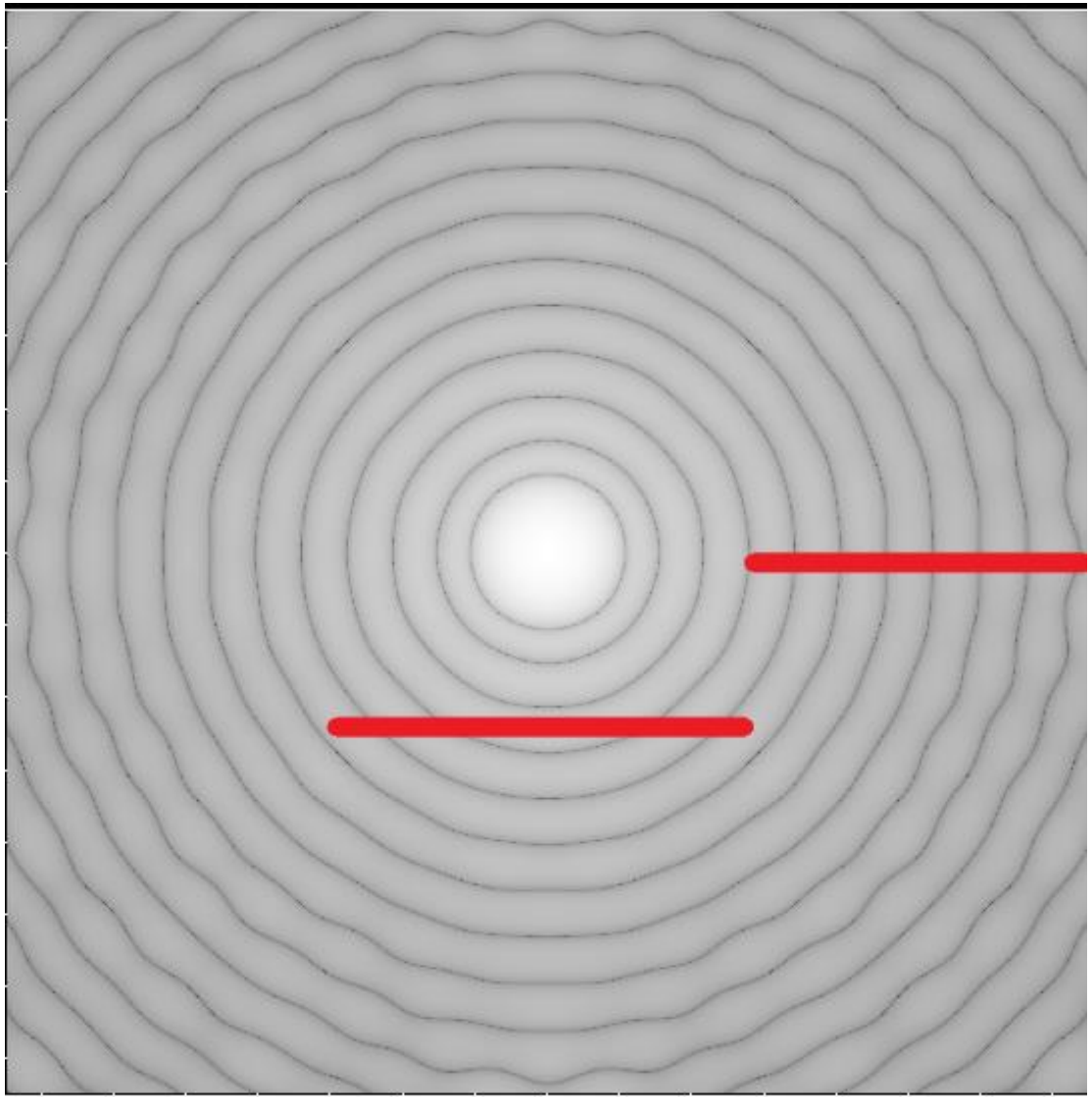
- The phase of the azimuthal dependence is not random
  - Good agreement between closely spaced antennas
  - Approx constant phase along lines at bearing ~45 deg

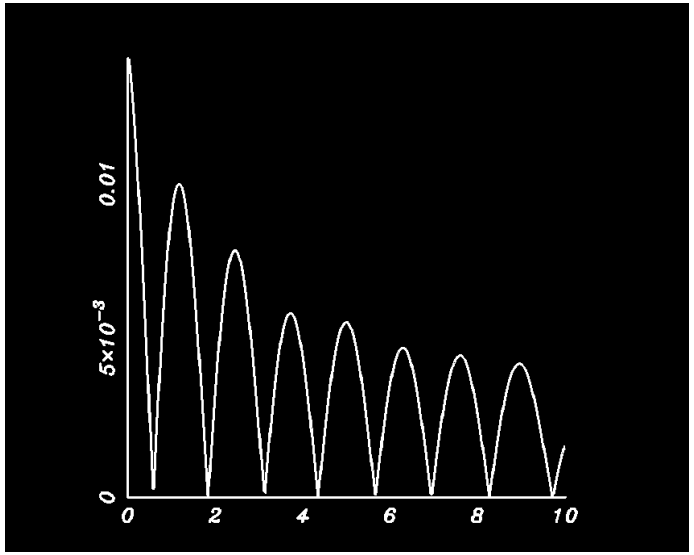
Vanwyksvlei GSM tower

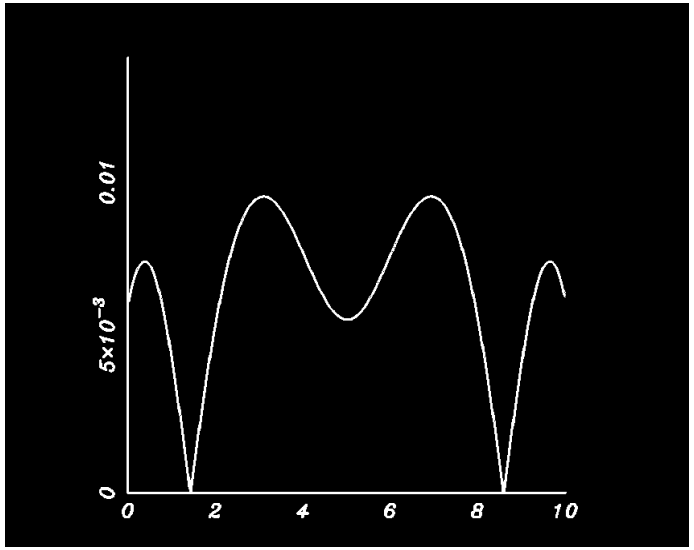


- Closest GSM tower at Vanwyksvlei
  - Distance of 54 km
  - Azimuth bearing of 41 deg
- Even in far sidelobes is bright
  - Approx 1K addition to system temperature

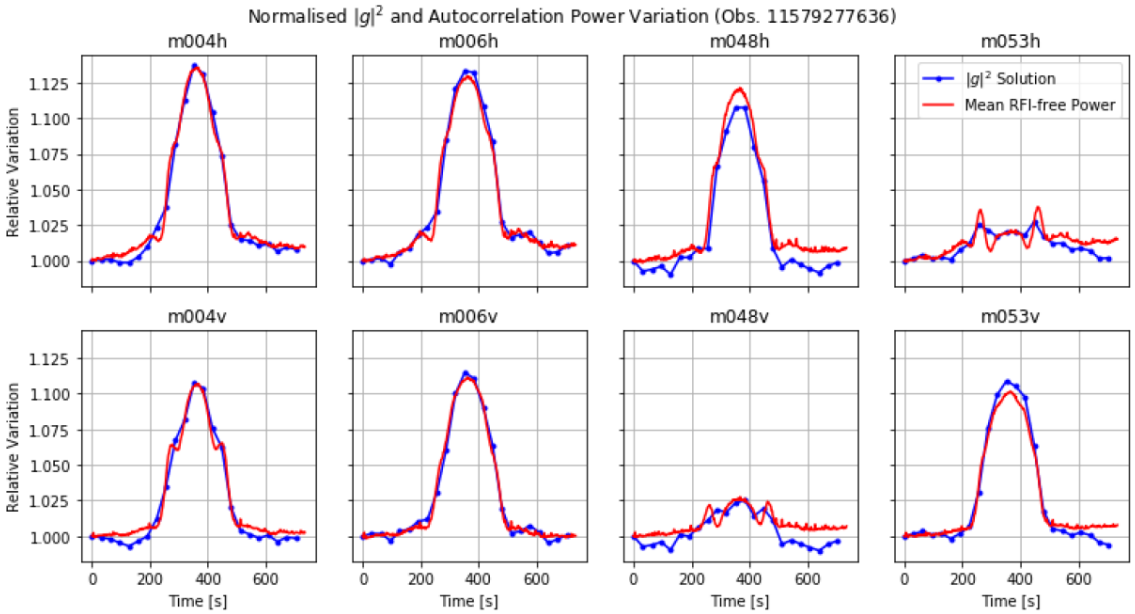
Cartoon of strong source in sidelobe







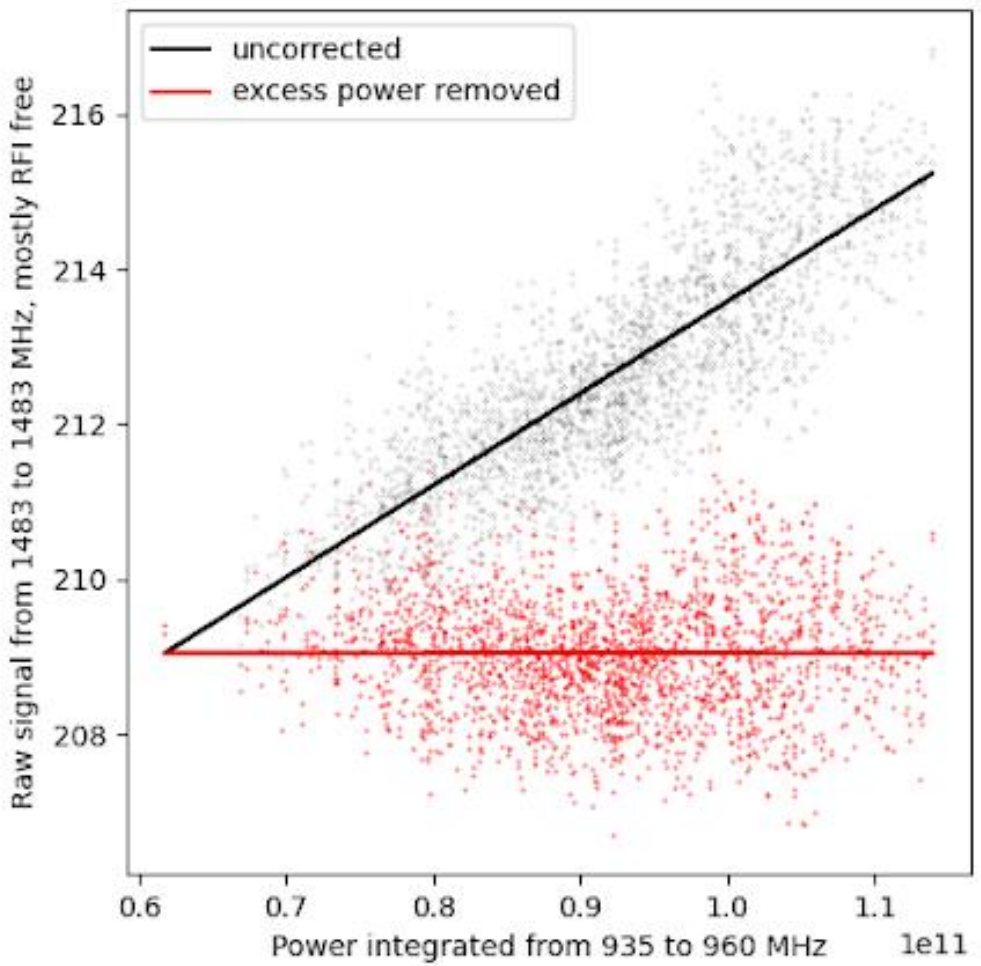
Non-linearity of MeerKAT receivers



Gain of MeerKAT receivers when observing a bright source (M Gouws 2020)

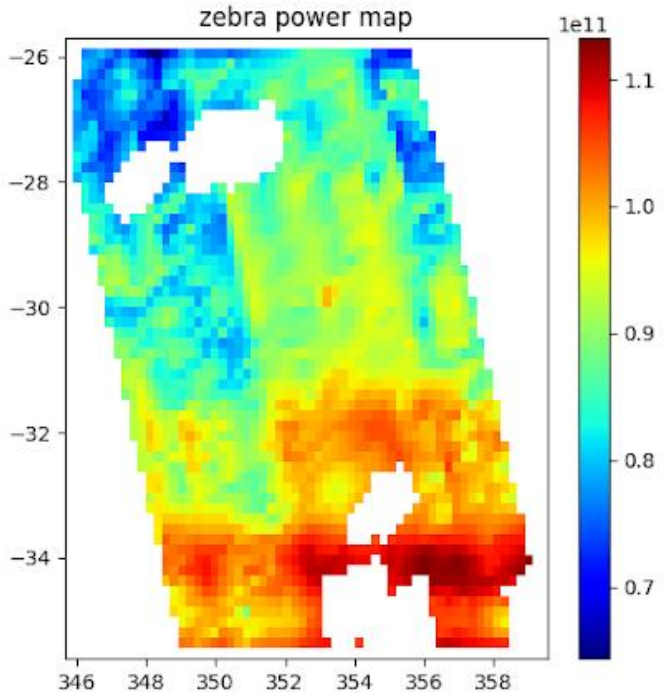
- MeerKAT receivers are non-linear
  - Gain increases with input power
  - Different response between antennas
  - Approx constant gain change across channels
- A strong RFI source can change the broadband gain
  - Even for RFI free frequencies
- Total power measurements mean a large DC offset
  - Small gain changes affect map
- GSM tower seen in sidelobes
  - Azimuth dependant gain
  - → Zebras!

Correcting the non-linearity

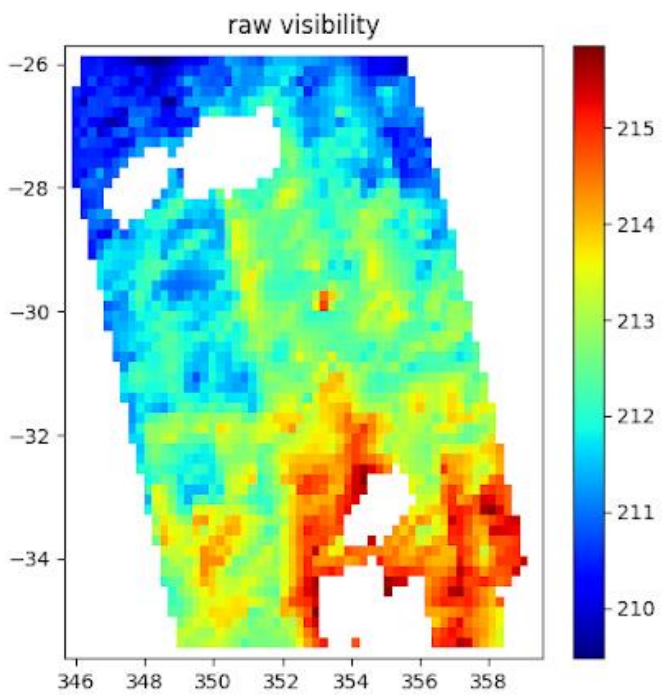


- Plot of power in RFI against power in RFI free channels
- Decent correlation
  - Remove with linear correction

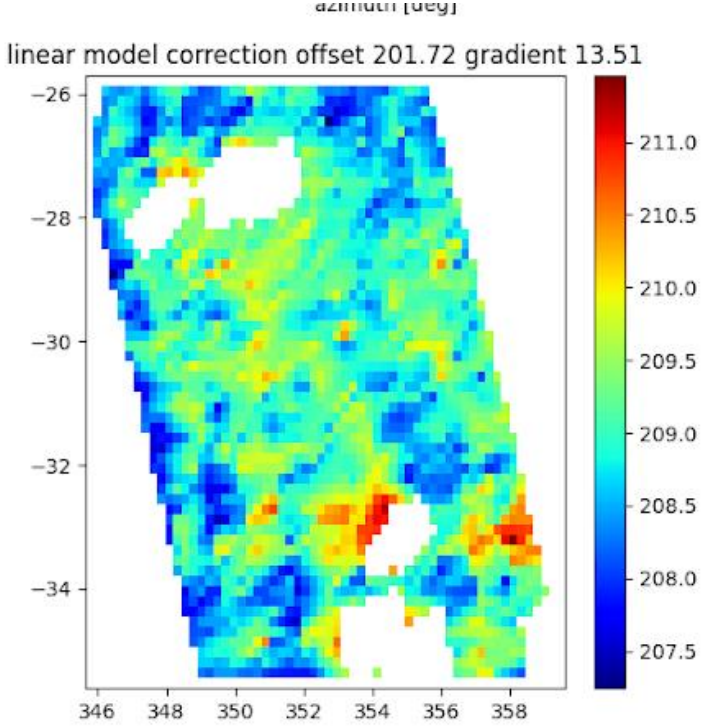
Corrected maps



RFI power map



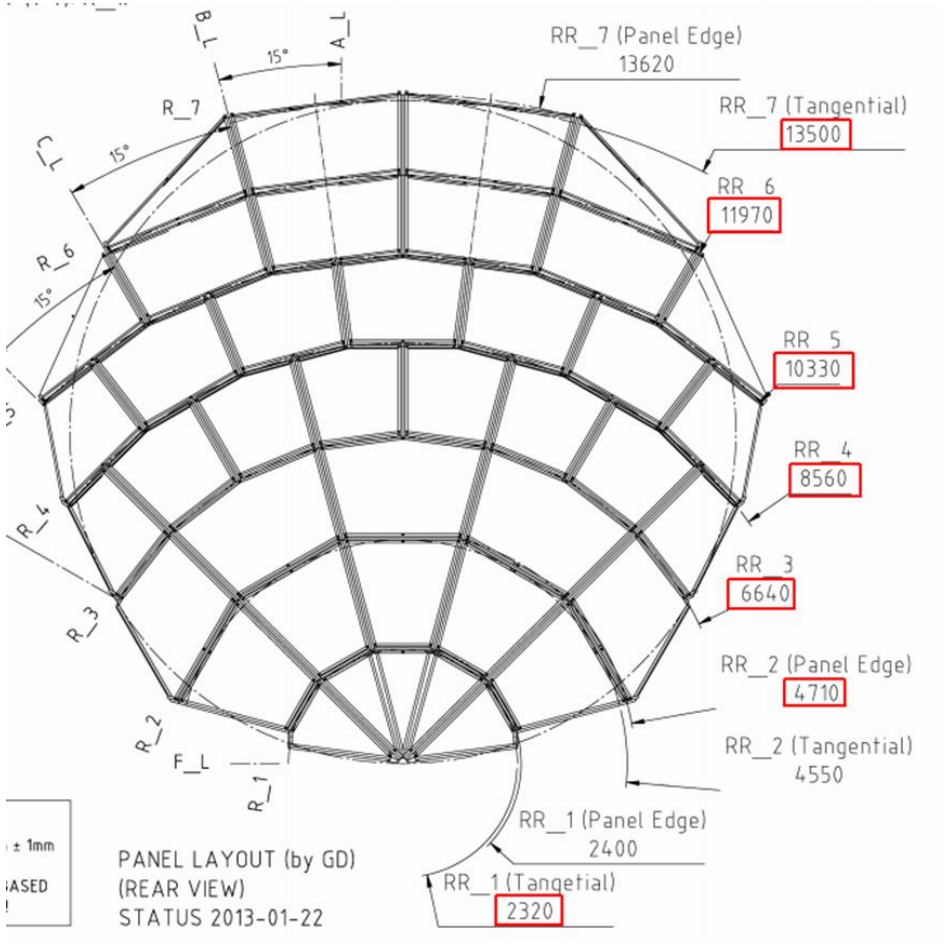
Uncorrected sky map



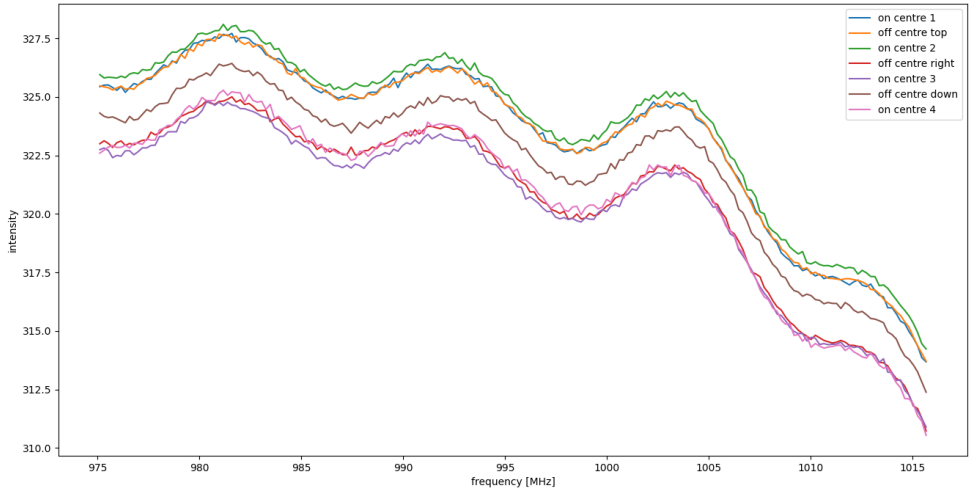
Corrected sky map

- Correction important even when “zebras” not visible

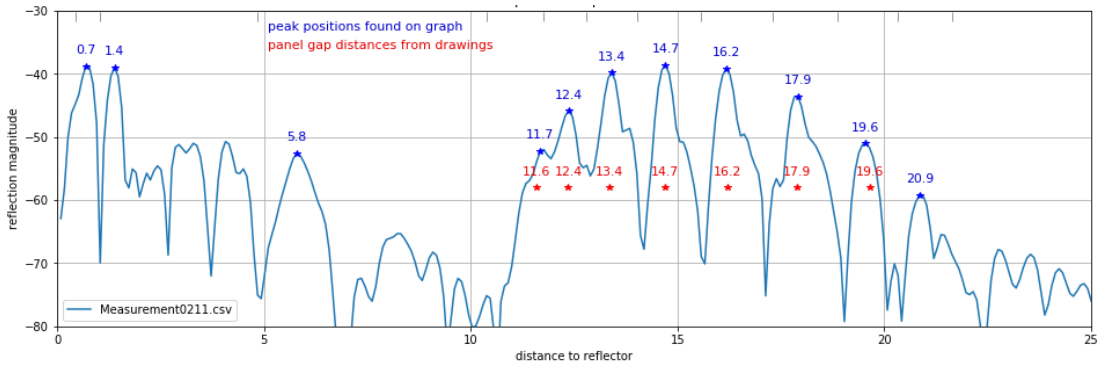
MeerKAT Bandpass and standing waves



- Panel layout on MeerKAT antenna
- Gaps lead to standing waves
- Bandpass critical for HI IM

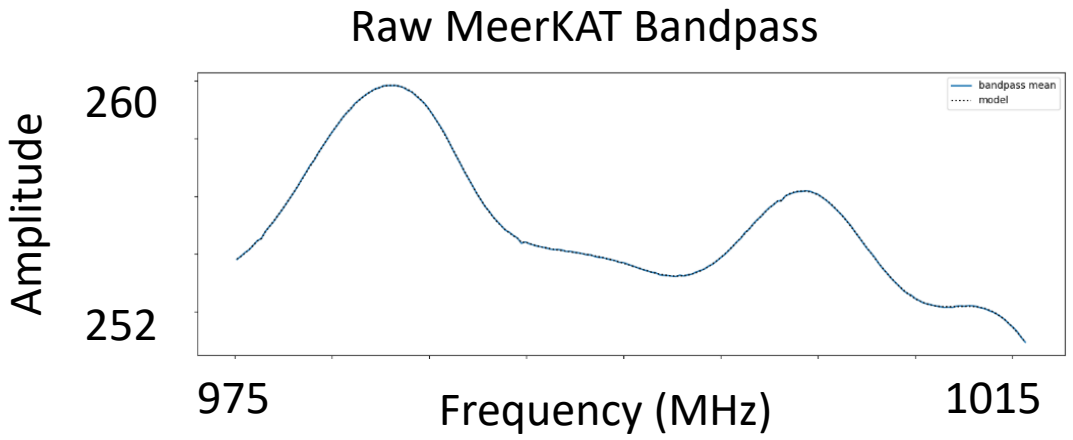


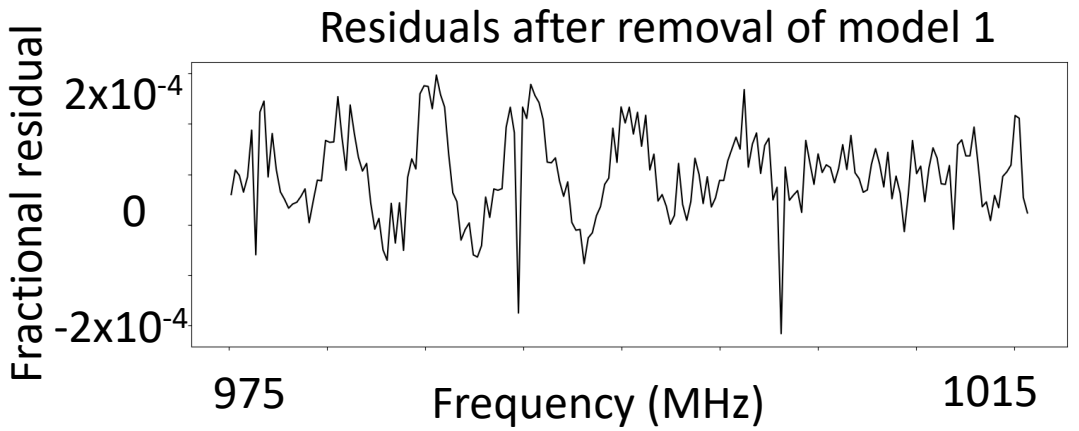
- MeerKAT bandpass; 10 MHz ripple



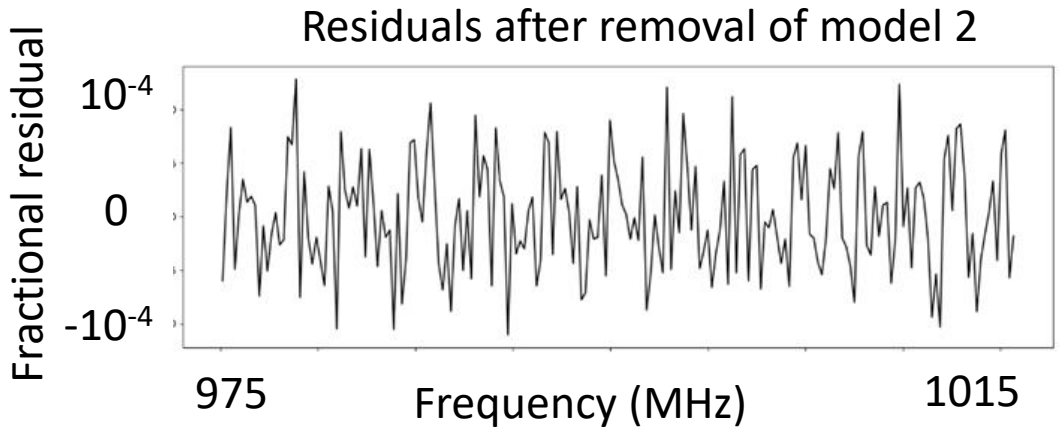
- FT of VNA measurements on MeerKAT antenna
- Peaks correspond to path differences
- Physically motivated model for standing waves

Bandpass calibration

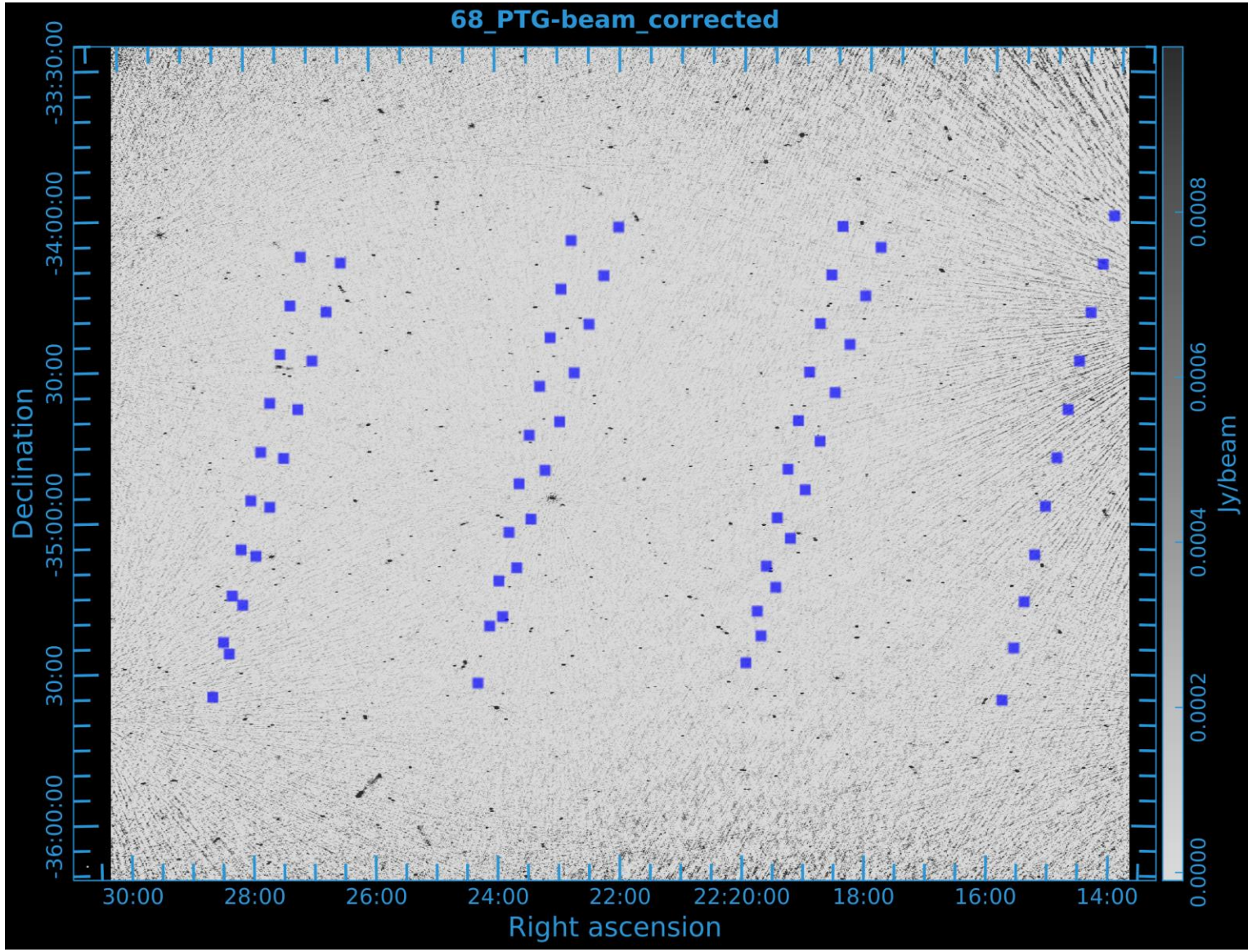




- Bandpass appears constant with azimuth
  - But appears to vary with elevation…
- Bandpass in RFI free window smoothed over 90 mins
- Model 1: reflections based on optics
- Model 2: double reflections and PPF correction
- Residuals at approx. the thermal noise level
- Work in progress
  - Fitted parameters don’t appear physical
  - Does this matter?



On-the-fly mapping



- Use the visibilities for high resolution maps
  - Commensality
- 68 samples of 2s
  - Pointing centres in blue
- DDFacet reduction
- 140 µJy noise
- 410 sources at 7σ
- Work in progress...

Summary

- Control of systematics vital for HI IM in total power mode
- MeerKAT receivers have non-linearities
- Strong RFI signals cause gain changes in RFI-free channels
- Signal from Vanwyksvlei tower moves through sidelobes
  - Azimuth dependant gain
  - Can correct for this effect as a function of power in RFI channels
- Bandpass complicated by standing waves
  - Promising models for these allow fitting
- OTF mapping of visibilities gives commensal science