# A 22 GHz Water Vapor Radiometer for the VLA


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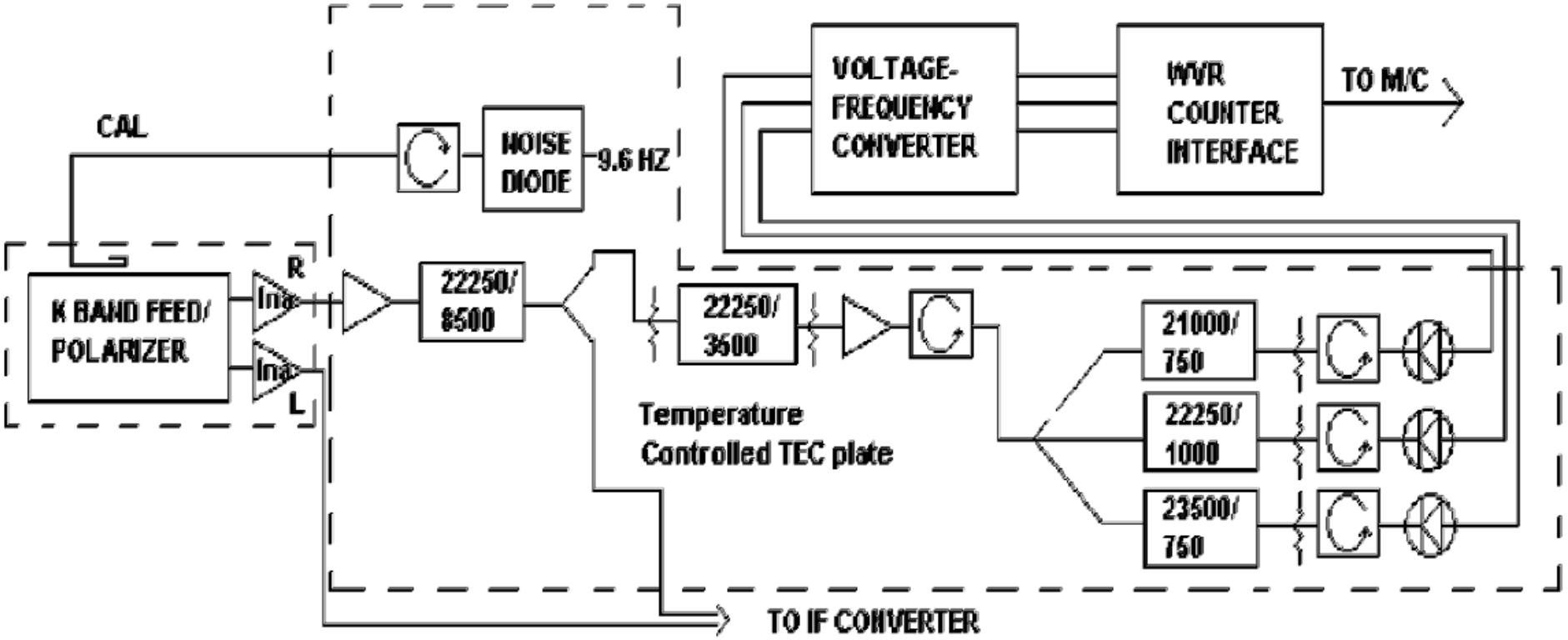
# *Relevant features of the (E)VLA*

- 25m antennas
- Cassegrain feeds span 1.2 to 50 GHz using octave and sub-octave horn feeds
- Feeds arranged in circle at secondary focus
  - asymmetric subreflector directs beam to a feed
- Interferometer baselines between 45m and 30km
- Semi-arid site at 2150m elevation
  - 25 cm annual precipitation
  - Mean p.w.v.: 5mm in winter, up to 15mm in summer
  - p.w.v. rarely less than 1mm
- ~25% of observing above 10 GHz

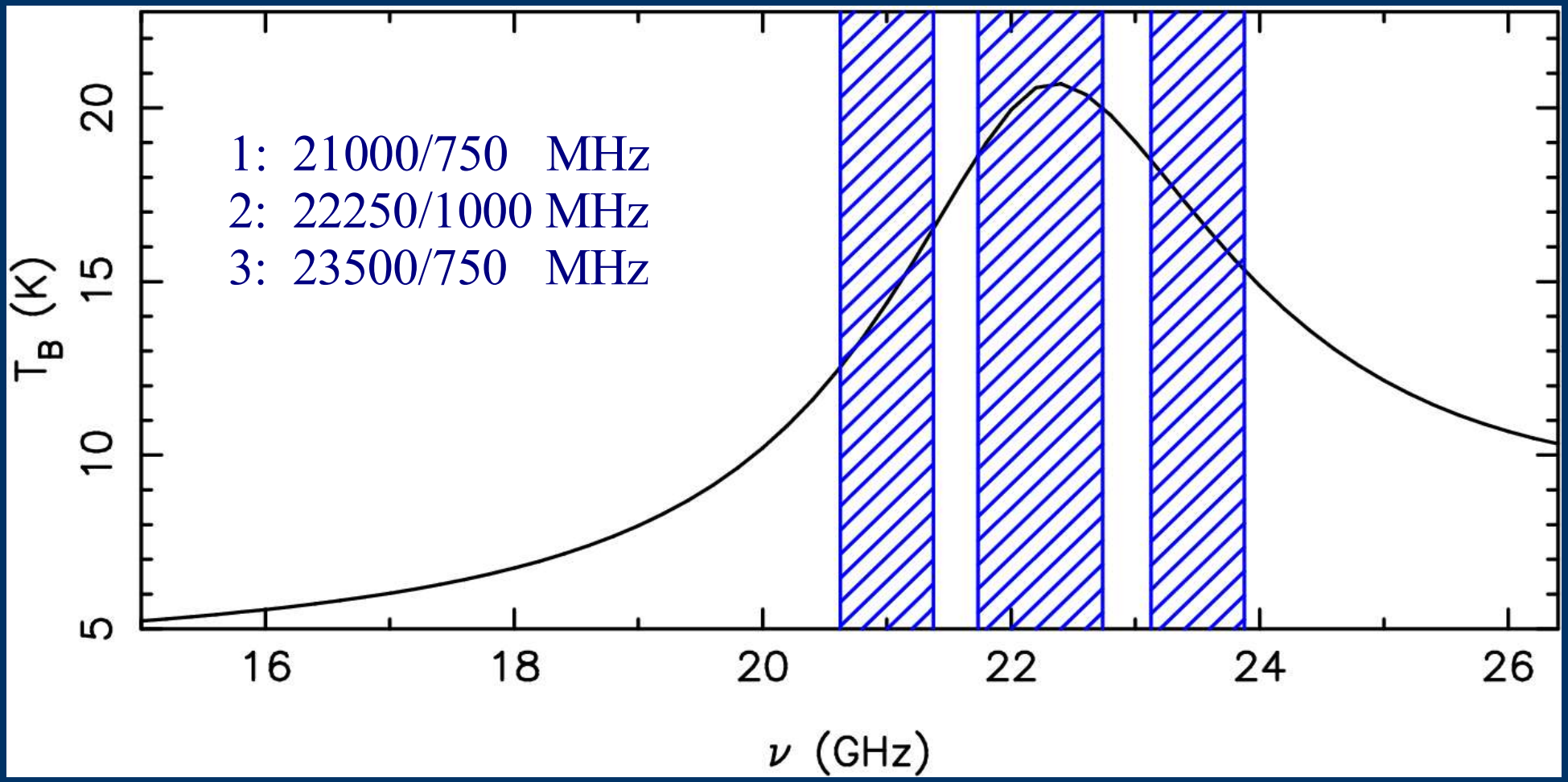
# WVR receiver

- WVR attached directly to astronomy receiver
  - K-band = 18 to 26.5 GHz
  - Cooled LNA: InP 4 stage amplifier
  - $T_{Rec}$ = 34K; $T_{Sky}$ ~ 25K [EVLA estimates]
- Correction will be available at all times
  - KU, KA and Q band receivers are near K-band
  - Beam offsets < 0.5 degrees

# Prototype 22 GHz WVR (2002 to 2004)



# Prototype WVR Filters




Limited to 20.5 to 24 GHz by LO birdies

# Calibration

- Noise diode switched at 9.6 Hz, 50% duty cycle
  - Standard for VLA receivers
  - $T_{cal} \sim 4\% T_{sys}$
  - $T_{cal}$ determined from lab Hot/Cold + field Hot loads
- WVR outputs, V, integrated for 0.83 seconds
  - separate output for noise ON and OFF
- Calibrated channel temperatures computed:

$$T = V \cdot T_{cal} / \langle V_{ON} - V_{OFF} \rangle$$

- $\langle V_{ON} - V_{OFF} \rangle$ is averaged for about 20 minutes

# *WVR Observable*

- Linear combination of channels form “observable”
- Ideal observable is sensitive only to water vapor

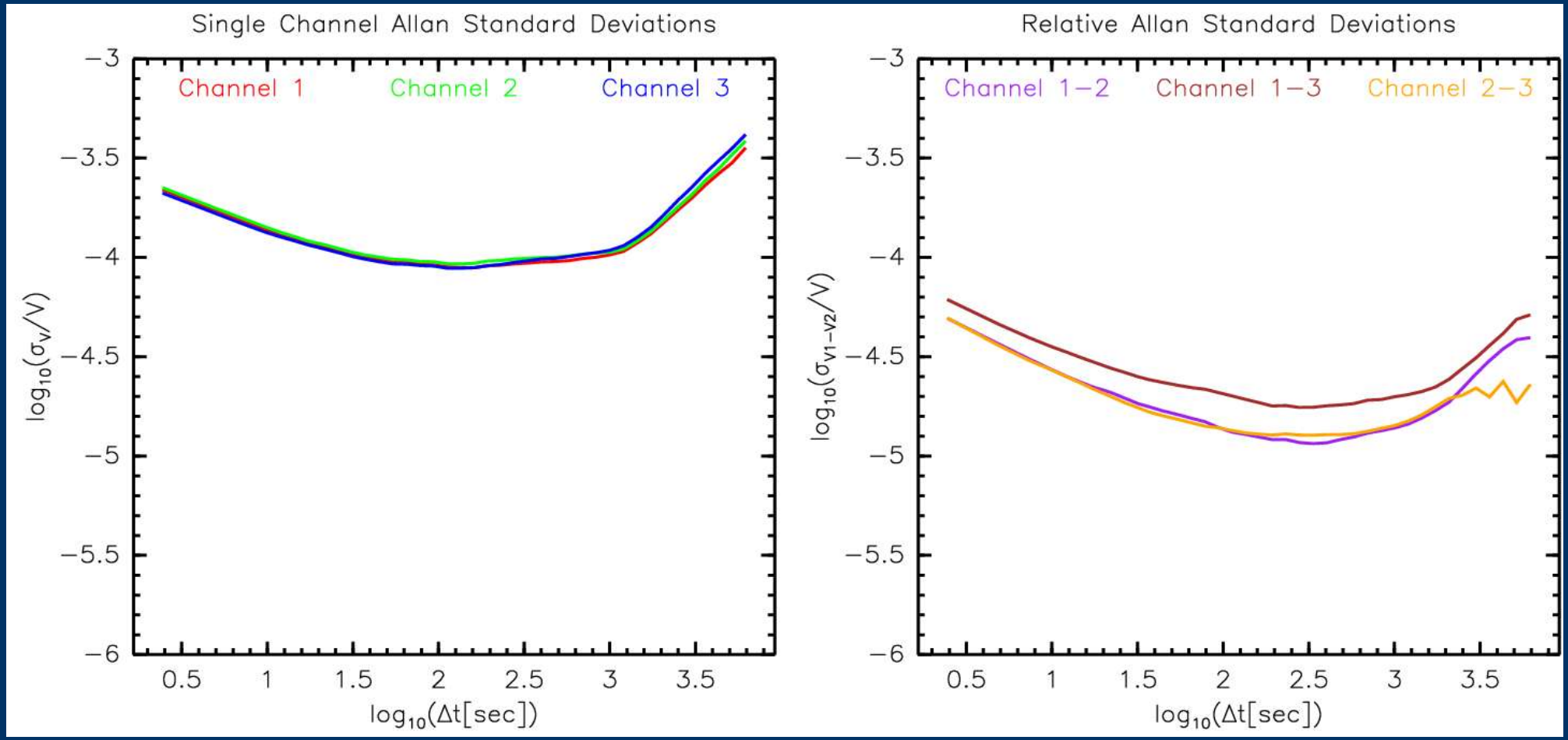
$$T_{Water} = w_1 T_1 + w_2 T_2 + w_3 T_3$$

- Weight vector w=(-0.5, 1.0, -0.5) is used here.
- More channels spanning more bandwidth would improve separation of water vapor from liquid water.

# *Lab testing*

- Early tests: simply “observe” switching noise diode
- Later: use K-band receiver as signal source
- Tests required significant (~12 hour) settling time
- We learned...
  - Temp stability is very important.  We now maintain 15 mK
  - RF cables are annoying
    - Easy to damage
    - Difficult to manipulate
  - Use of many RF isolators improved results

# Lab stability results




Single channel stability: $10^{-4}$ between 30 and 1000 seconds

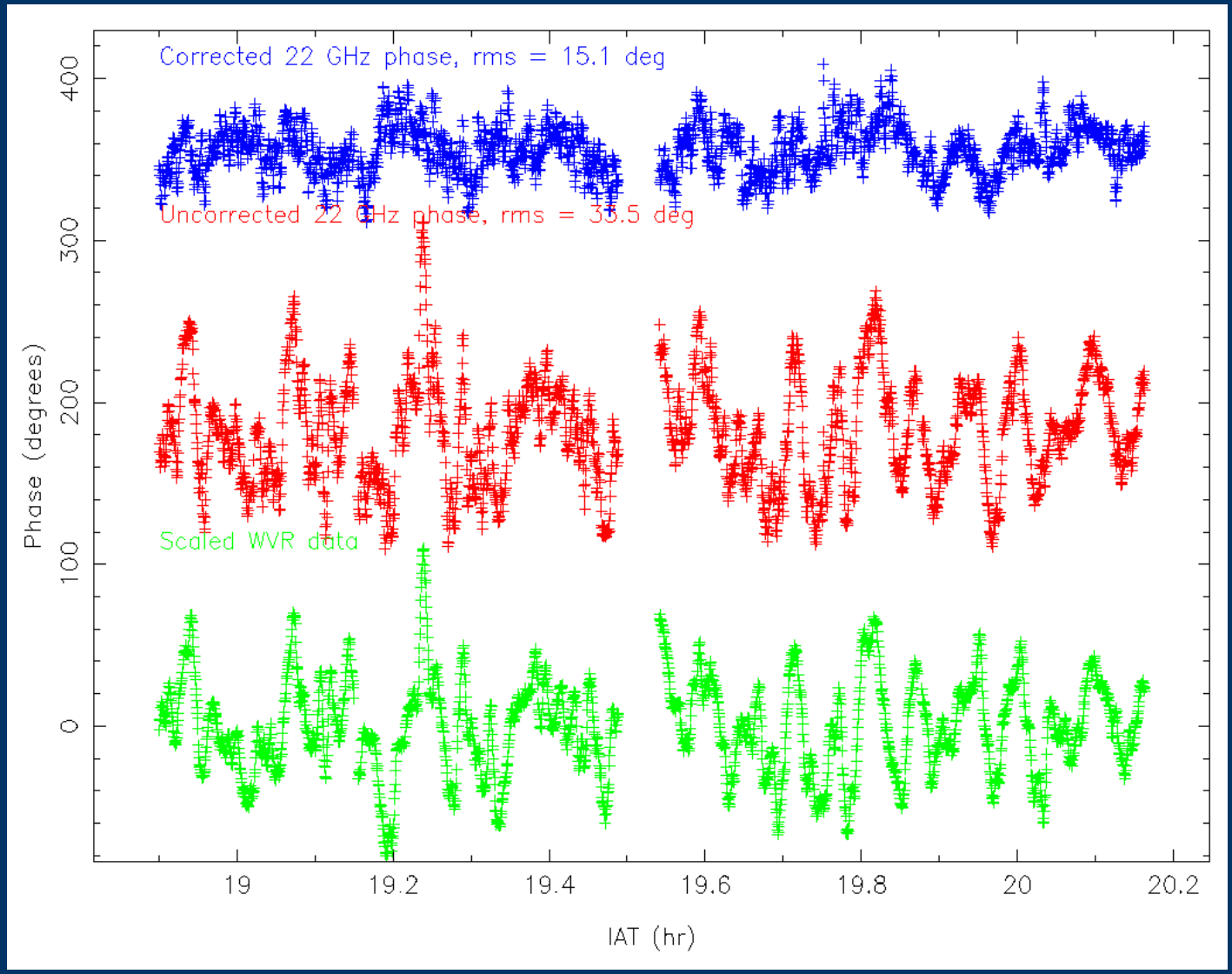
Channel difference stability: $10^{-4.5}$ between 8 and 2000 seconds

# *Sky tests*

- Conditions
  - 11 months on antennas 26 and 28
    - Almost no maintenance required
  - Tested on 800m, 2.5km and 6km baselines
  - Tested at 8, 15, 22, and 43 GHz
  - Various weather encountered
- Results
  - WVR correction improved phase at all frequencies
  - Improvement was minimal when cloudy; best when clear
  - Scale factor $A = \phi_{int}/\Delta T_{Water}$ appears variable and larger than expected by factor 1.5 to 2

*See EVLA memo 73 for more details*

# Sky test results (1)



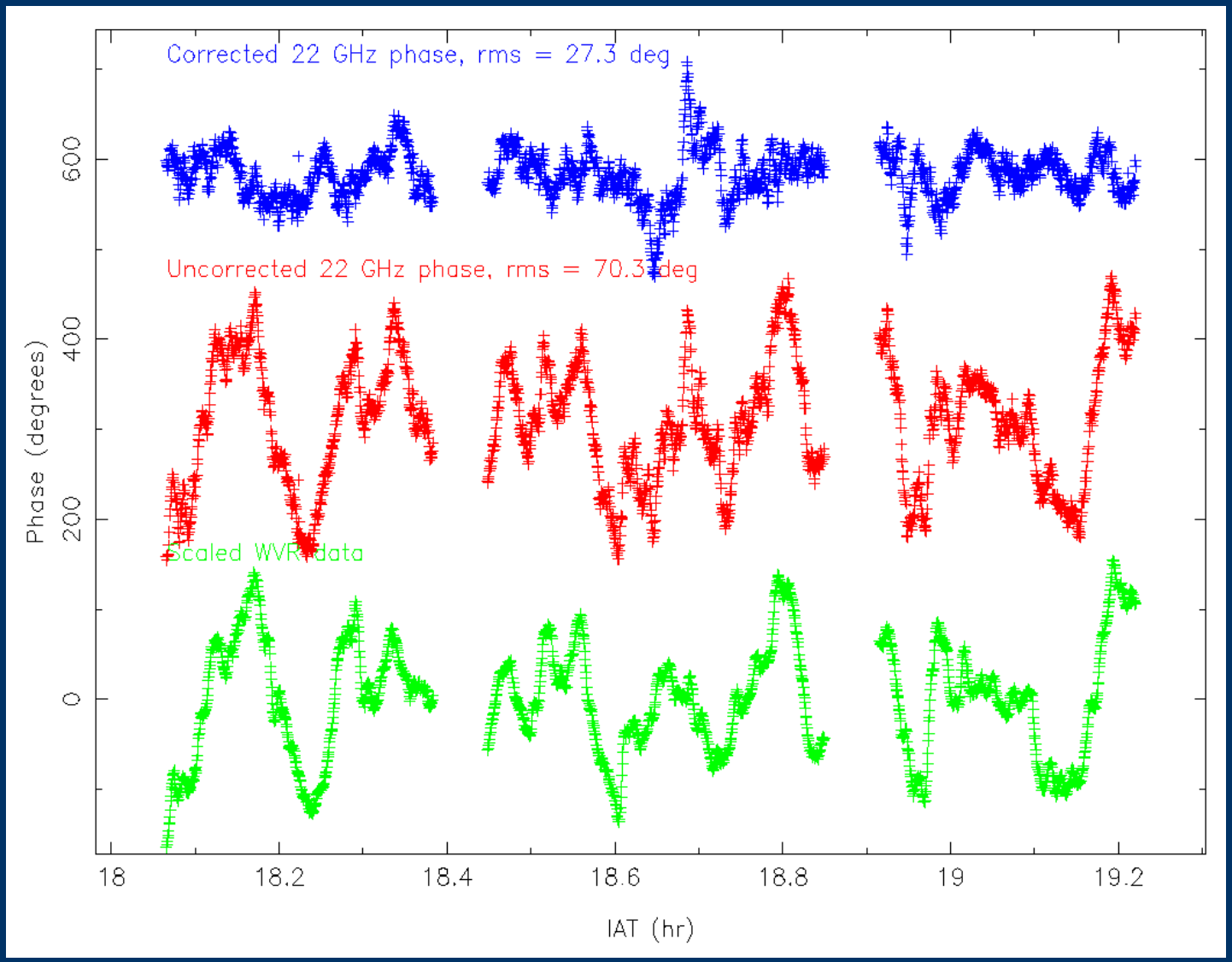

Corrected phase:
15.1 deg RMS

Raw phase:
33.5 deg RMS

Scaled WVR data

Test conditions: 22 GHz, 800m baseline, clear sky, 2003/03/06

# Sky test results (2)



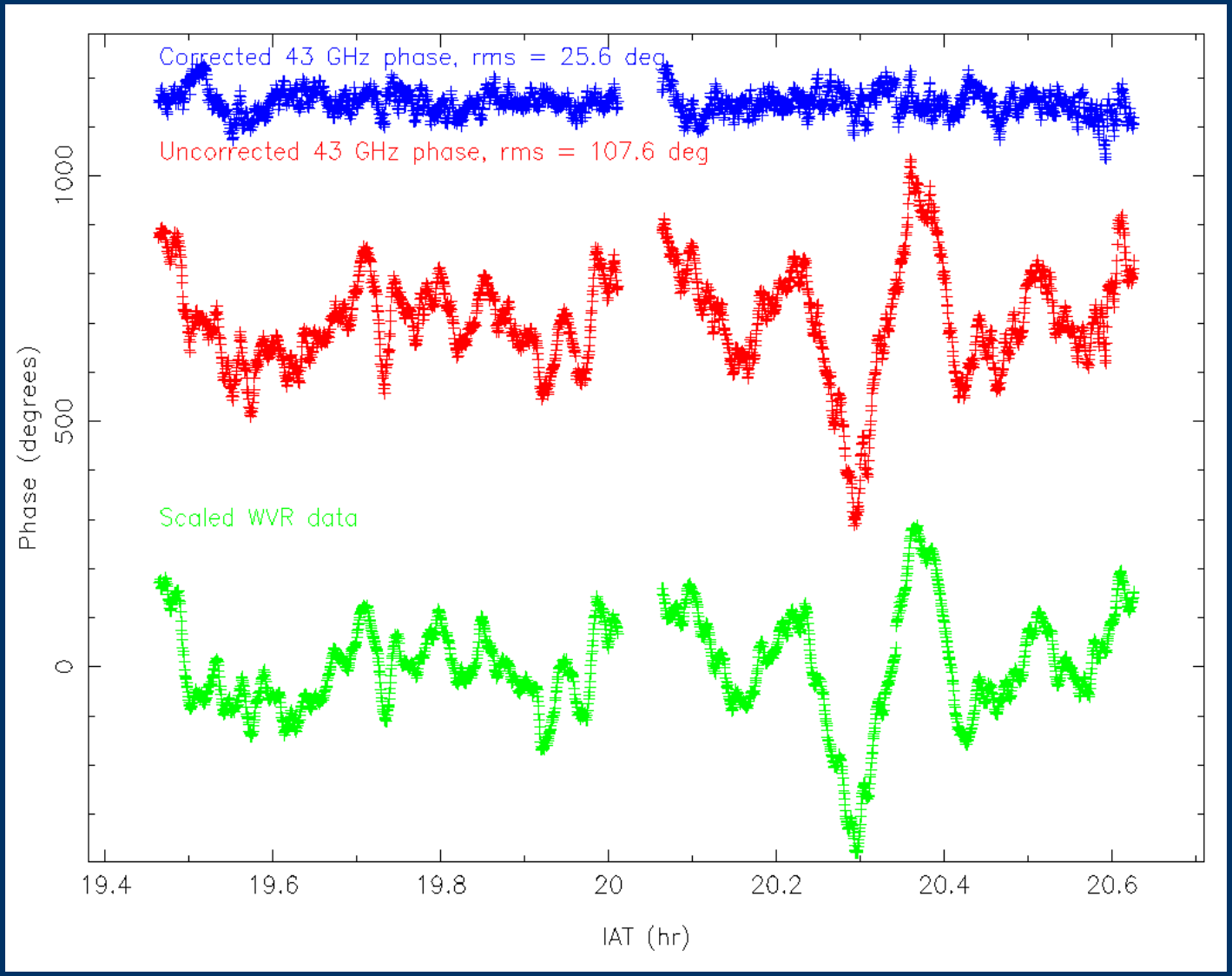

Corrected phase:
27.3 deg RMS

Raw phase:
70.3 deg RMS

Scaled WVR data

Conditions: 22 GHz, 2.5km baseline, partly cloudy, 2003/07/28

# Sky test results (3)



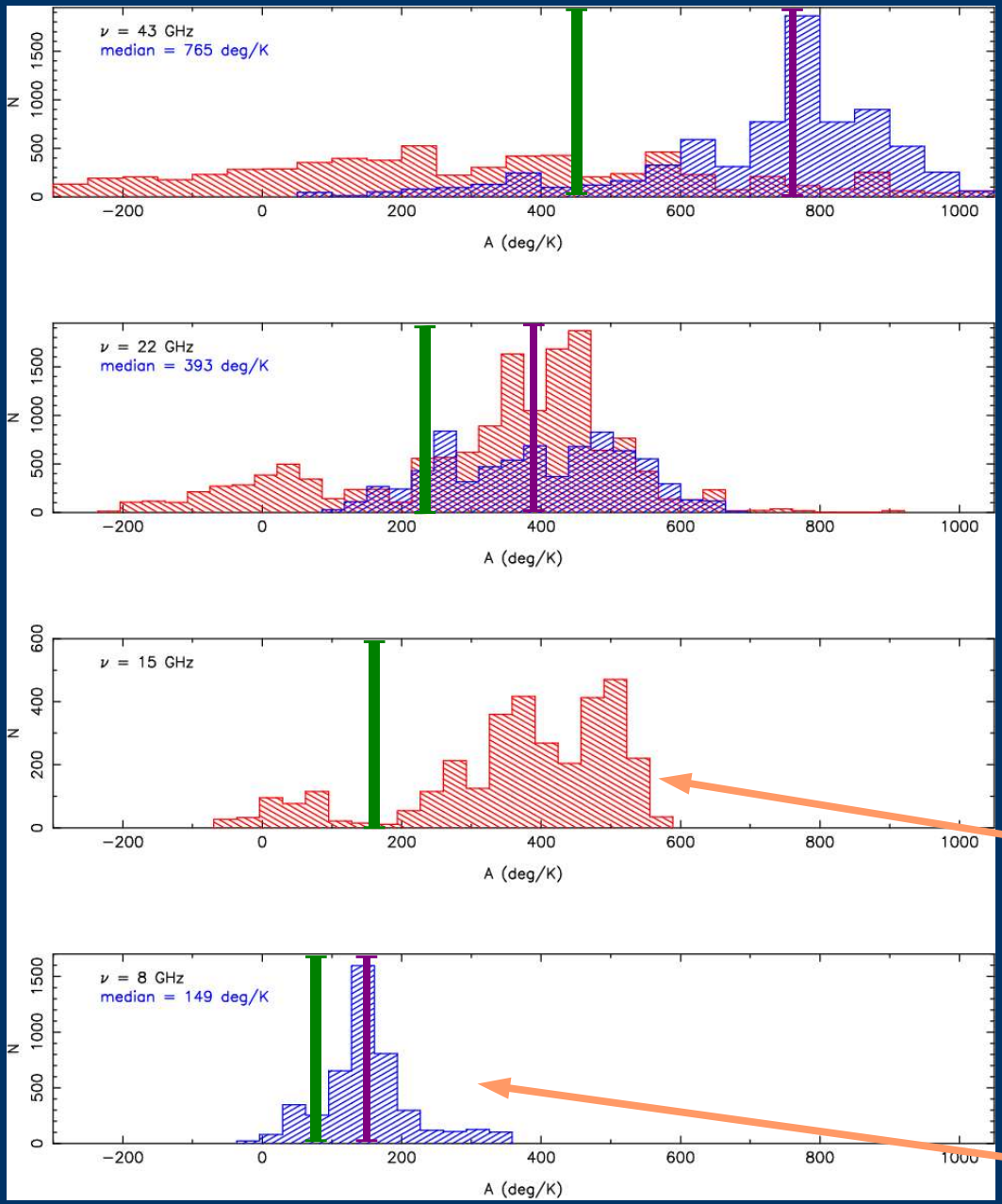

Corrected phase:
25.6 deg RMS

Raw phase:
107.6 deg RMS

Scaled WVR data

Conditions: 43 GHz, 6km baseline, clear sky, 2003/09/28

# Conversion factor




43 GHz: 450 deg/K predicted
765 deg/K median

22 GHz: 230 deg/K predicted
393 deg/K median

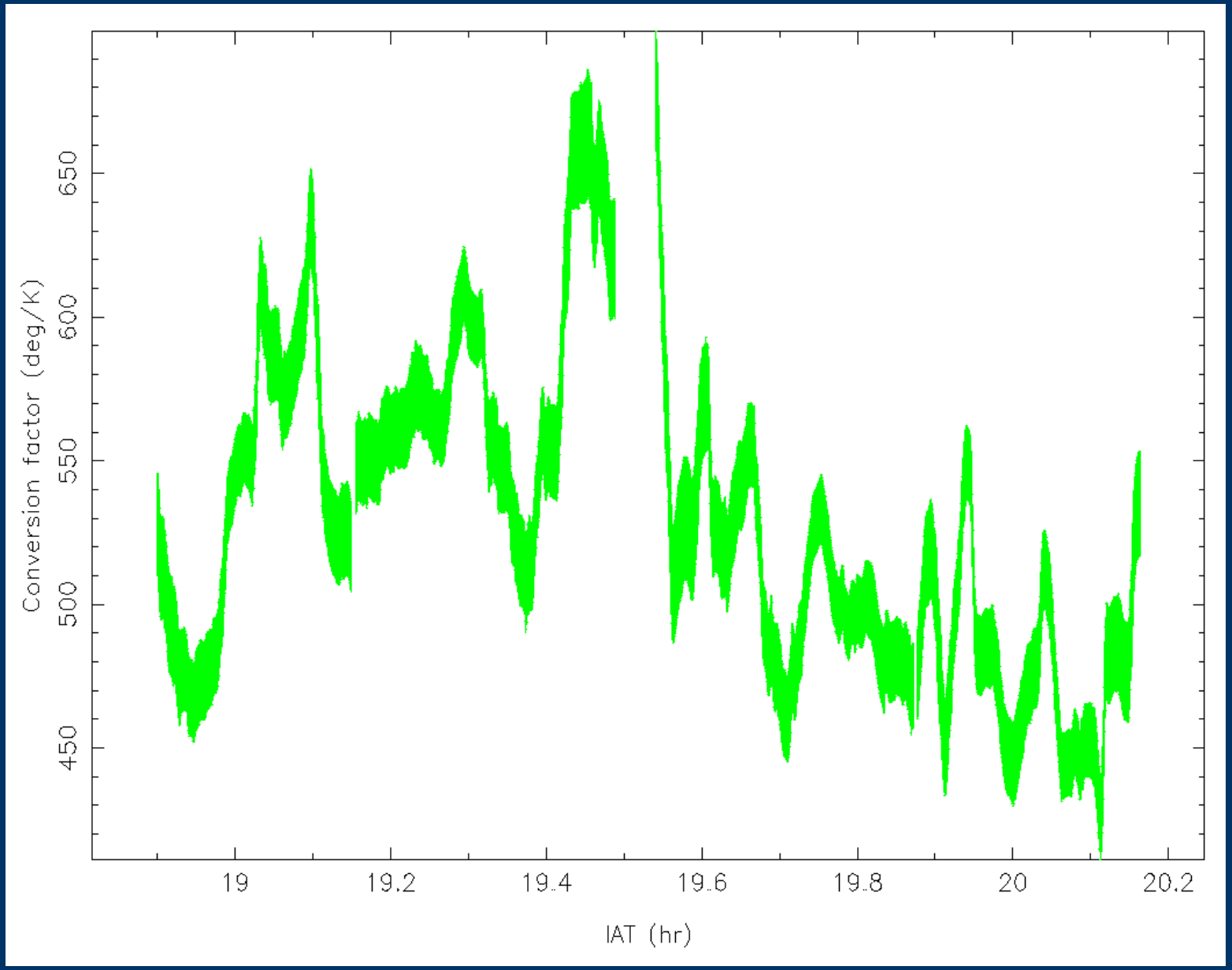
15 GHz: 155 deg/K predicted

*Red = Cloudy weather*

8 GHz: 85 deg/K predicted
149 deg/K median

*Blue = Clear weather*

# Conversion factor variability. Why?

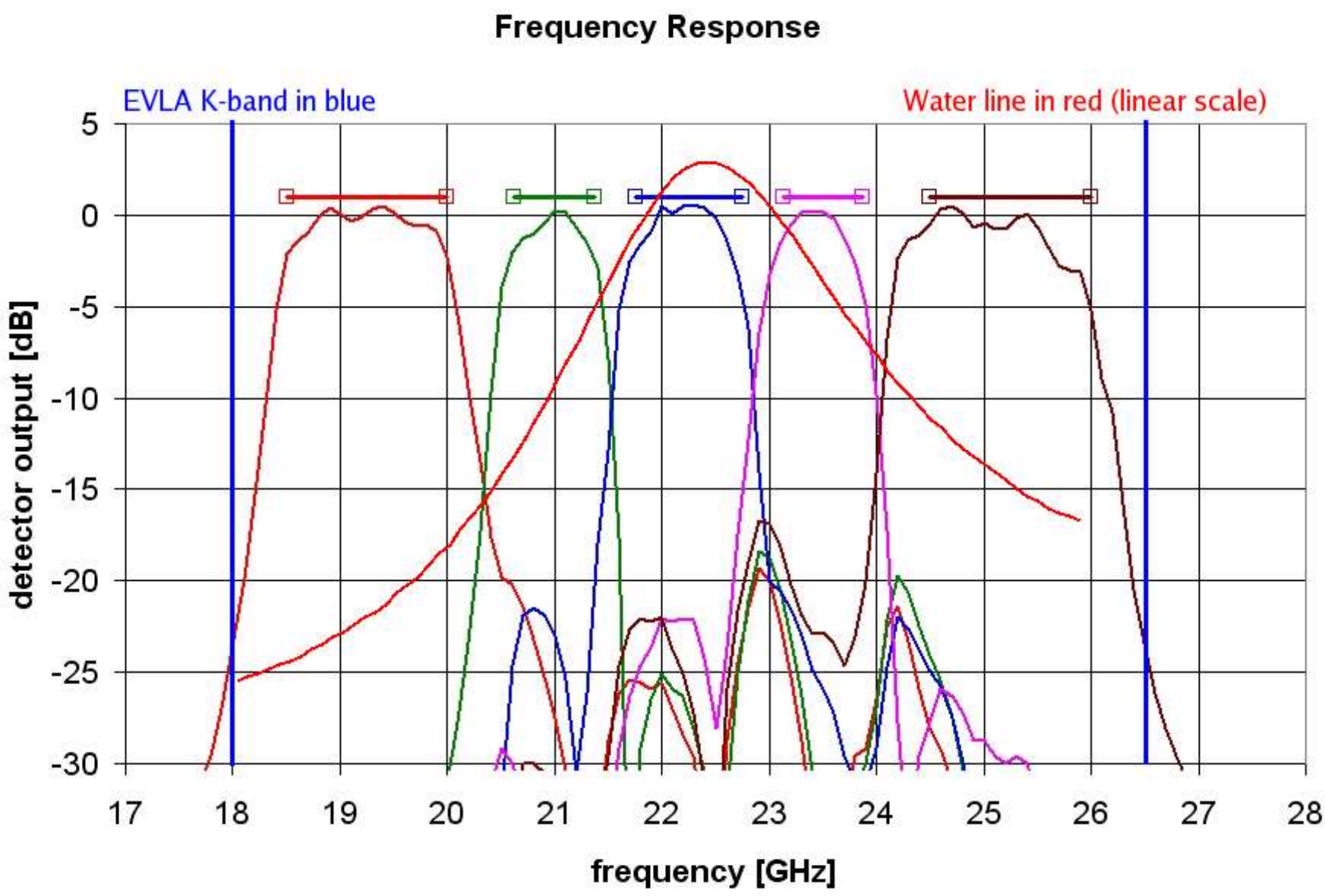



2006/03/06

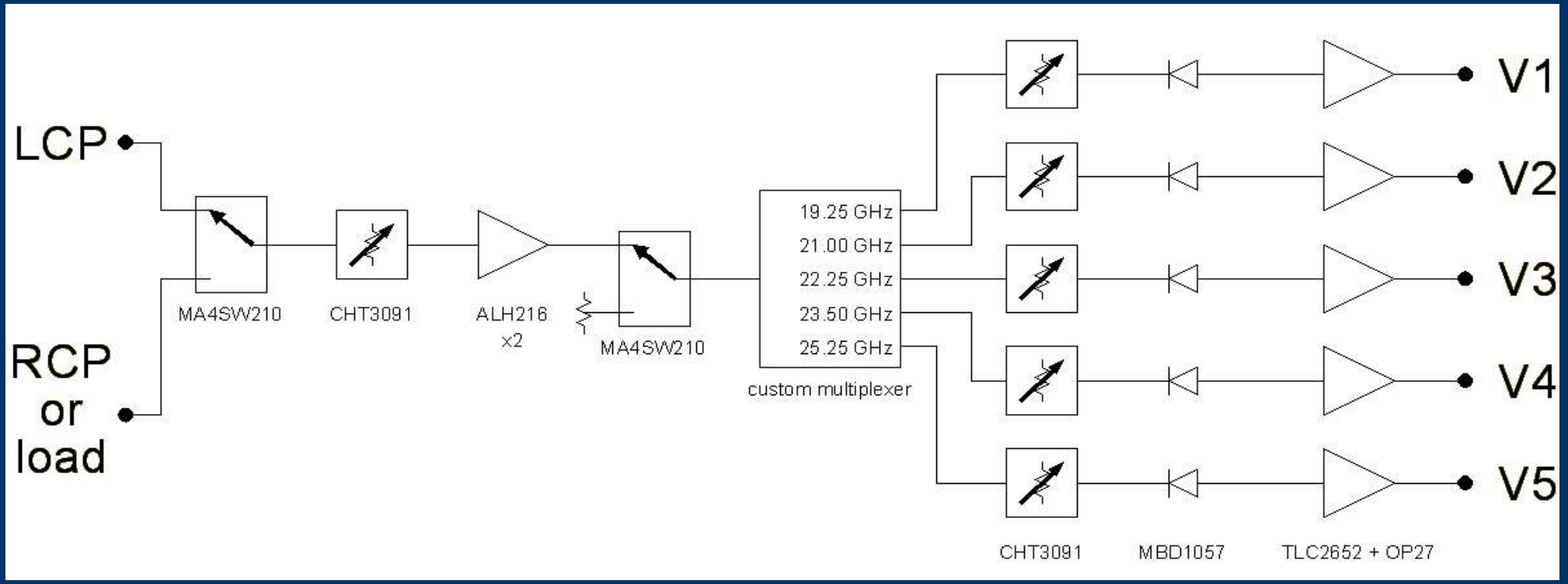
# A Compact WVR (2005 to present)

- New device for EVLA testing
  - Not limited by 20.5 to 24 GHz band
    - Use full 18 to 26.5 GHz band
  - No monitor/control system limitations
- Improved design based on experience
  - 2 additional wide channels
  - Minimal RF connectorization
  - Smaller: easier to temperature stabilize
  - Internal adjustable attenuators and calibration switches
  - Multi-function board at the core
    - 15 MMICs
    - 7 microstrip substrates
    - 110 wirebonds
  - 30% cheaper

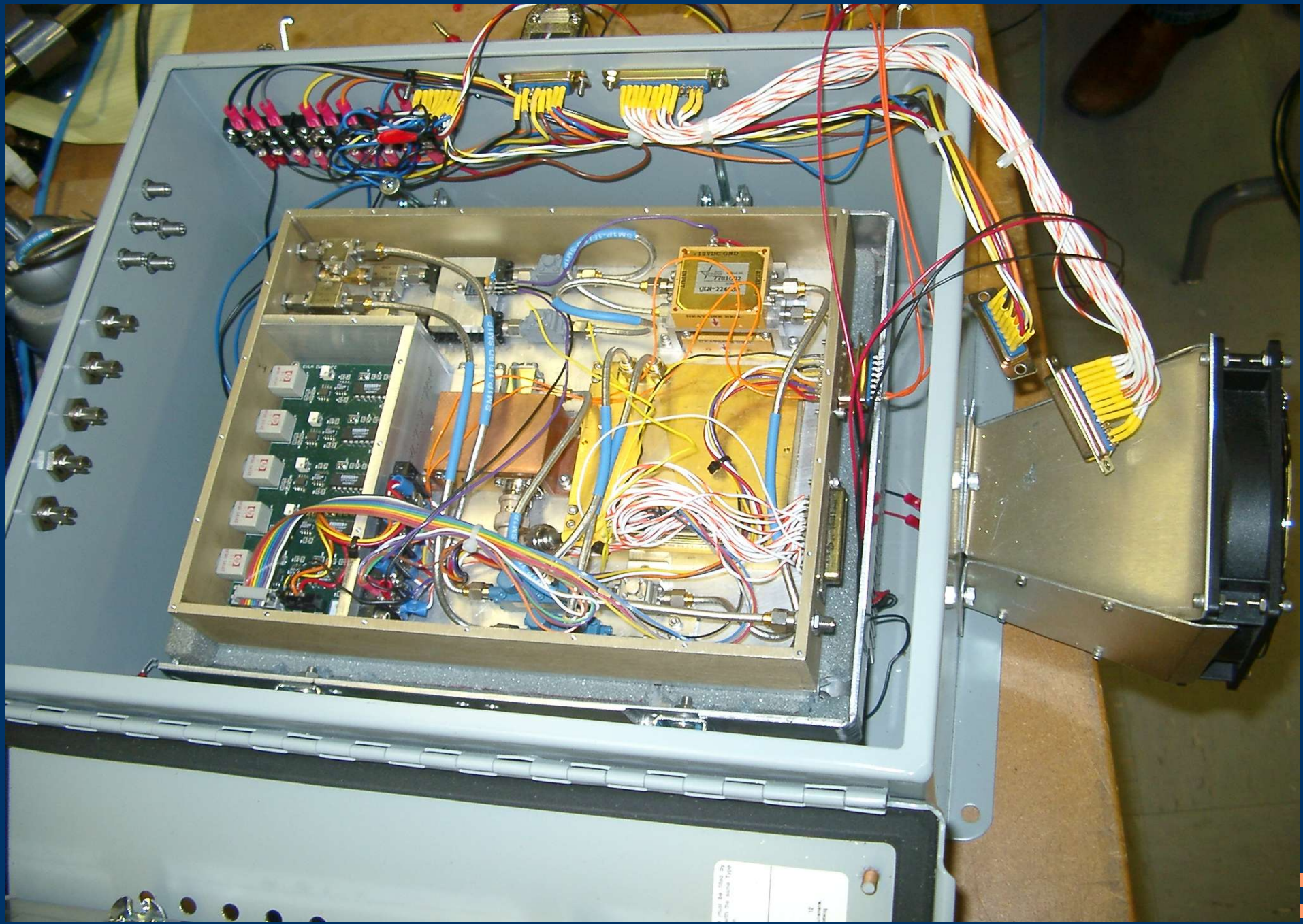
# CWVR Filters



# CWVR schematic



# CWVR prototype



# *Unanswered questions*

- Why is the conversion factor variable?
- Why does the conversion factor differ from models?
- How will the new compact WVR perform on EVLA antennas?

***The end***