# Thoughts on the Design of a WVR for the Twin Telescopes at Wettzell


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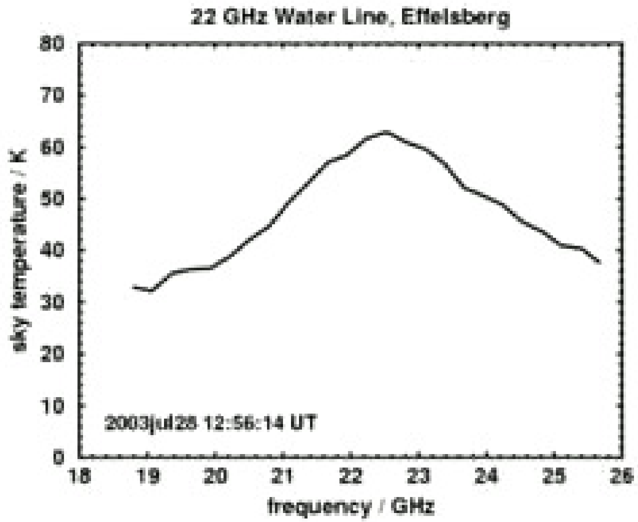
# Scattered Cumulus, 2003 Jul 28, 1300 UT

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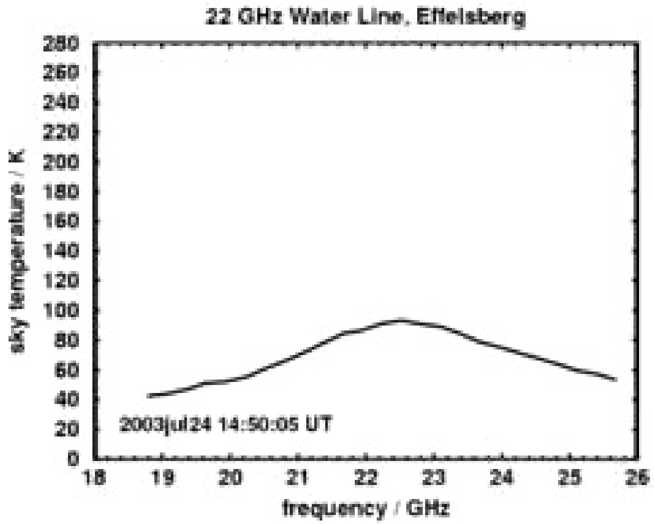
# Storm, 2003 Jul 24, 1500 UT

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# Key Design Decisions

- Location
- Frequencies
- Cryogenic cooling
- Absolute calibration method
- Temperature stability
- Beam match
- WVR illumination pattern
- Spillover calibration
- Dish surface accuracy
- Retrieval algorithm

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# Location

**Standalone?** Not recommended

- Pointing jitter must be < 1 arcmin due to sky brightness gradient

Mount **on main dish**, look through own optics? Better

- Pointing accuracy good, spillover can be calibrated ☺
- But out in weather, and beamshape different from main dish ☹

Mount **in receiver room**, looks through main optics? Best

- Good pointing / good temperature stability / good beam match ☺ ☺ ☺
- But harder to calibrate spillover ☹

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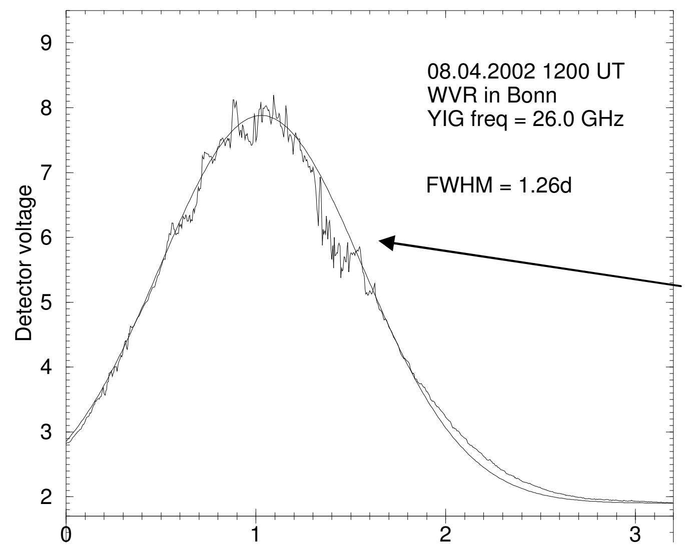
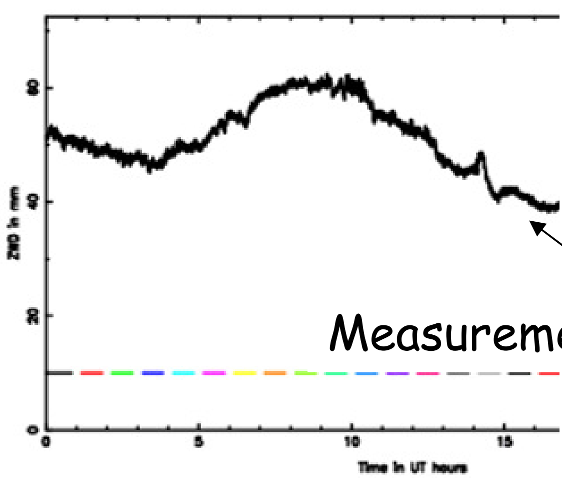
# Location

Drift scan across sun

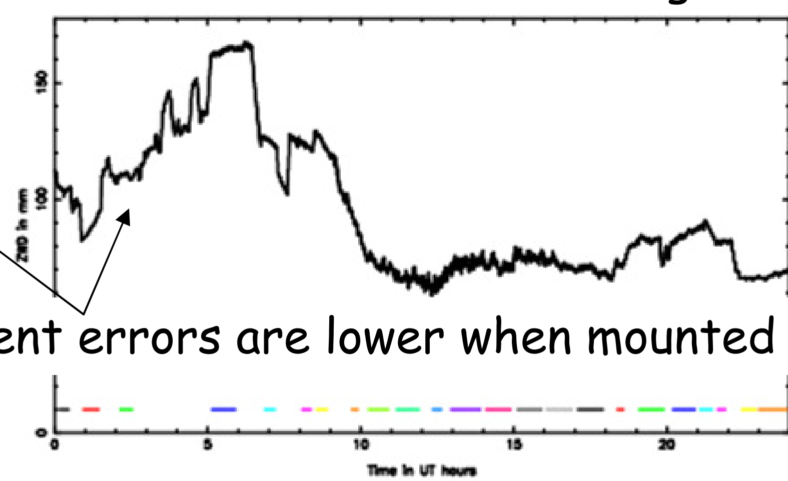



Wind caused small movement of WVR
-> extra noise in measurement
(even light touch on WVR shows up)

WVR Standalone




WVR mounted on Effelsberg




Measurement errors are lower when mounted on main dish

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# Frequencies

**Two channels** (20.7 GHz & 31.4 GHz) as in existing WVRs?

- known, works well, commercial radiometers exist ☺
- wide freq spacing needs two horns, two LNAs, two detectors ☹

**Three channels** (eg 23.0 GHz, 23.74 GHz, and 50.8 GHz)?

- Reduces rms on IWV by 20 % (S. Crewell 2006) ☺
- But extra complexity for relatively small improvement ☹

**Sweep** 18 GHz to 26 GHz?

- Fewer parts (one horn / LNA / LO / detector) ☺
- Can calibrate using waveguide Dicke switch and waveguide load instead of external absorber, giving better stability ☺
- But highest frequency still has significant line contribution 😐

Conclude: choice depends on existing available equipment

# Cryogenic cooling

- Reduces thermal noise ☺
- But harder to maintain / costs more ☹ ☹

- For geodetic VLBI, absolute calibration and stability more important

  Thermal noise already low enough without cooling:

    For path length measurement to 1 mm and 4.5 mm/K one needs rms noise of 200 mK
    RMS noise for uncooled radiometer in 1 s with $T_{sys}$ = 200 K, BW = 1 GHz is 7 mK

**Conclude: Do not cool**

# Absolute calibration method

Use **hot and cold loads** – classic method, irreplaceable.

Hot load:
- External absorber and noise diodes are less stable.
- Internal Dicke switch to waveguide load probably much better.

Cold load:
- Liquid nitrogen is messy, so infrequent calibration.
- Cold sky is easier, though changes based on weather -> use skydip to get sky contribution. Works well.

Conclude: hot load: prefer internal Dicke switch to waveguide load
cold load: use sky with skydip

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# Temperature stability

**Aim: 1 mm path length stability**

WVR box temperature stability:

temperature coefficient of WVR = -0.008 per °C
1 mm in 300 mm wet path = 1:300
-> need box temperature stability = 90 mK

Absorber temperature accuracy:

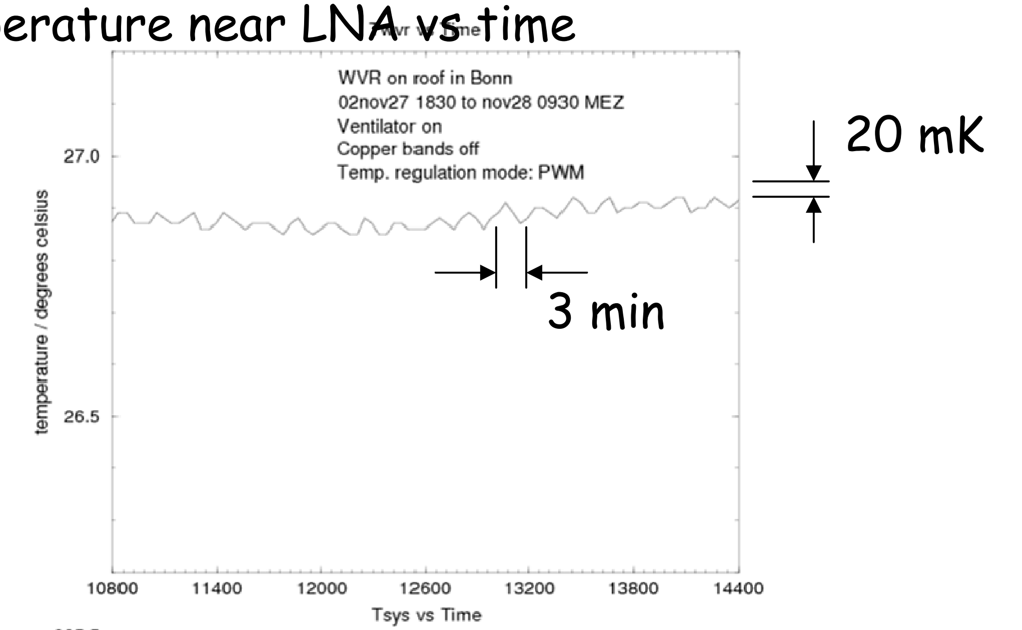
1 mm / 300 mm * Tabsorber => 1 K absorber temp accuracy

Conclude: Need 90 mK WVR box temperature stability
1 K absorber temperature measurement accuracy

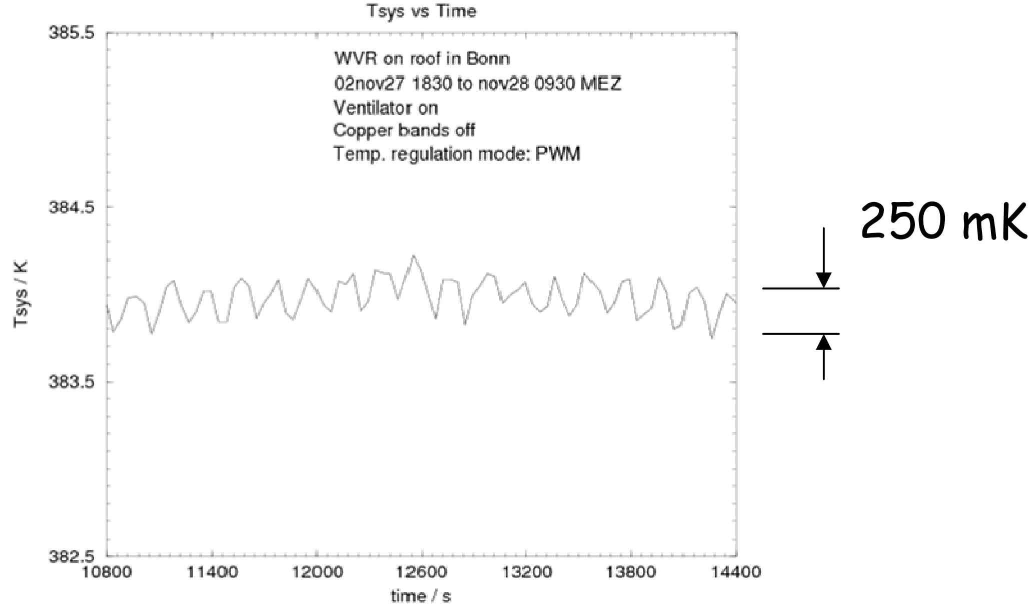
Two-stage temperature regulation (box within a box construction) can give 0.5 mK temperature stability (Tanner 1998; Bremer 2006)

# Temperature stability

Physical temperature near LNA vs time




$T_{sys}$ vs time



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# Beam Match

Want WVR and VLBI receivers to sample the same volume of troposphere.

| | |
|---|---|
| Conclude: | WVR looks through main optics<br>Then both receivers sample same cylindrical volume in near field |

(10 m offset -> 0.1 mm error, error grows with sqrt(offset))

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# WVR dish illumination

Problem: spillover past dish edge terminates on 300 K ground
-> additional radiation not from sky -> measurement error

For 1 mm accuracy, want max spillover of 1 mm / 4.5 mm/K = 0.2 K

Conclude: edge taper = -30 dB

(equivalent to illuminating central 5 m of a 12 m dish for a universal feed horn illumination profile)

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# Spillover Calibration

Problem: spillover might be a few kelvin to 15 K
but need 0.2 K for 1 mm path accuracy
-> measure and correct for spillover

Conclude: Plan for a calibration method for spillover

Methods:

1. Cover dish with absorber and make skydip -> any change is spillover

2. If dish is too big for absorber, use Perley (2005 EVLA memo 90) method:

- skydip with dish
- fit and subtract 1/sin(el) for sky signal and fit and subtract constant for Trec + Tcmb
- Remainder assumed to be spillover (EVLA C-band: Tspill = 15 K at 10°, 3 K at zenith)
- (Could use existing WVR to measure sky signal instead of fitting?)

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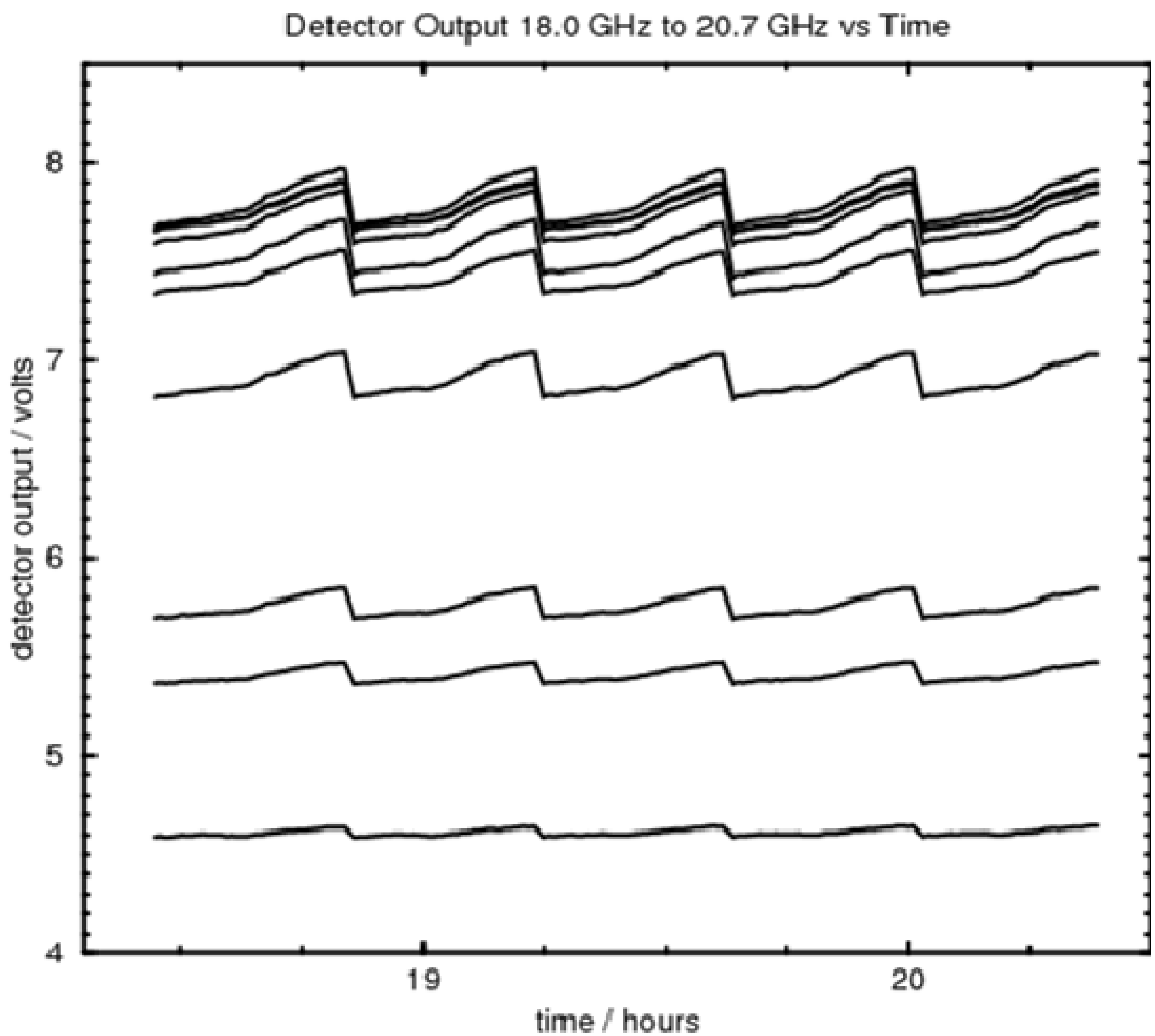
# Spillover Cal: Skydip with Absorber on Dish



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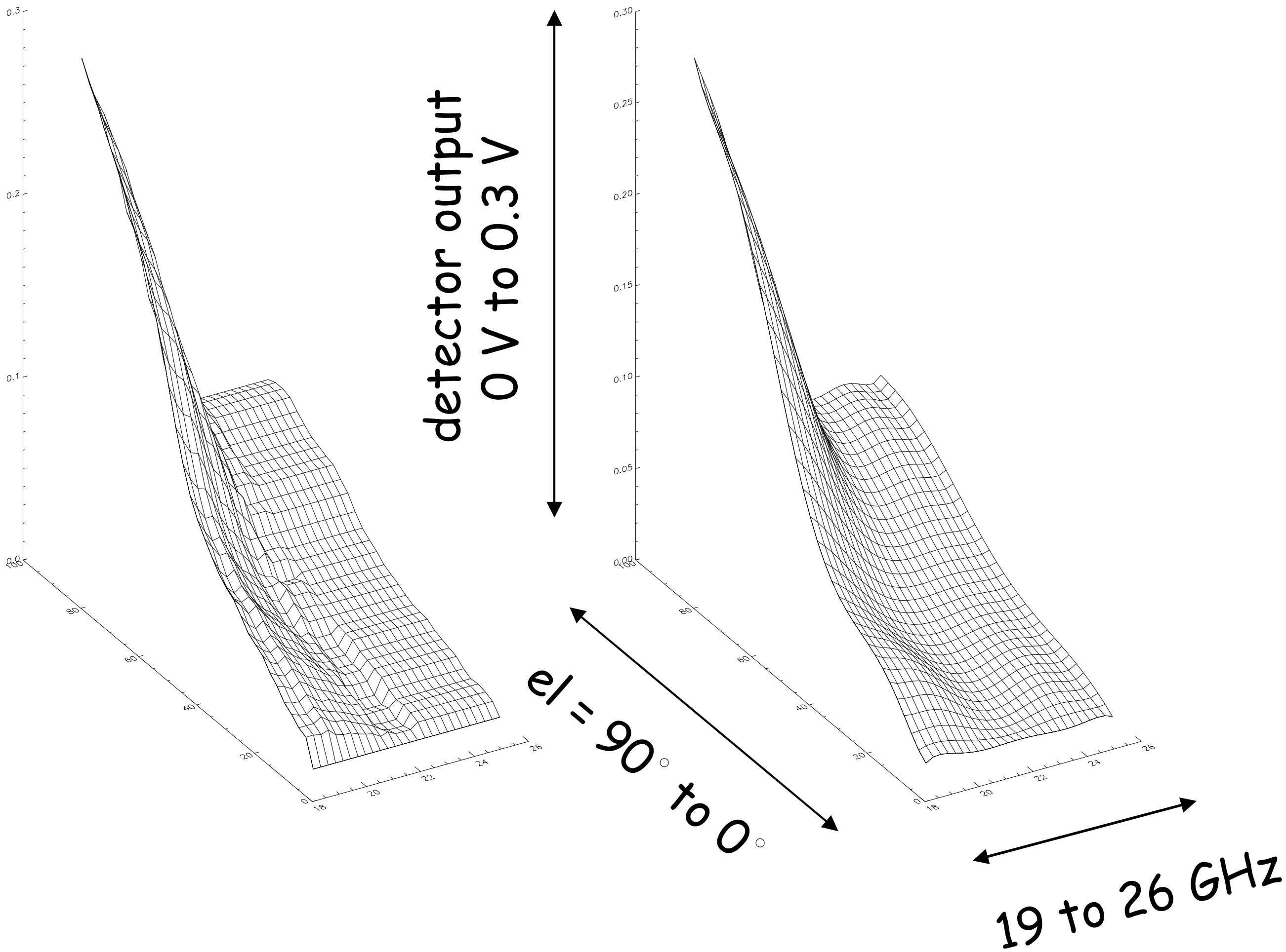

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# Dish Surface Accuracy

Water vapour is in near field and therefore out of focus

Conclude: WVR frequency can be far above the range specified for the dish

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# Retrieval Algorithm

For 1 mm path length accuracy, need 0.3 % accuracy.

But gas absorption models have 5 % uncertainty.

-> Gas absorption models do not meet geodetic requirements ☹☹☹

Conclusion: use WVRs for removing short-term changes only (A. Niell)
do not use them for absolute tropospheric path

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# Conclusion

For details, see memo at
http://www.mpifr-bonn.mpg.de/staff/aroy/wvr.html