# Development of a model for internal calibration of a water vapour radiometer

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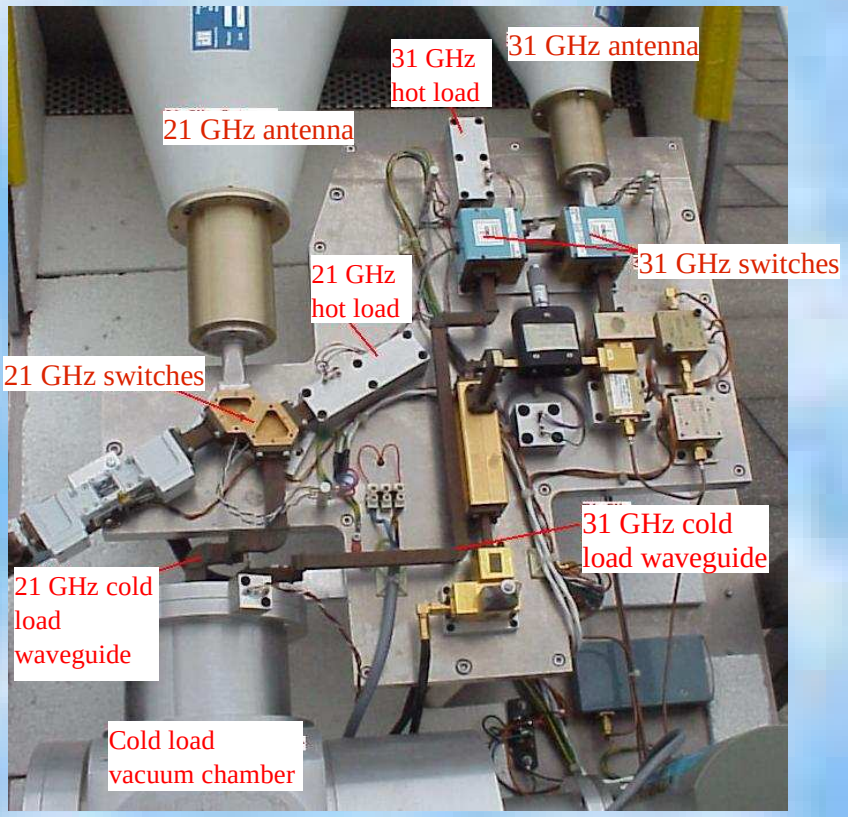
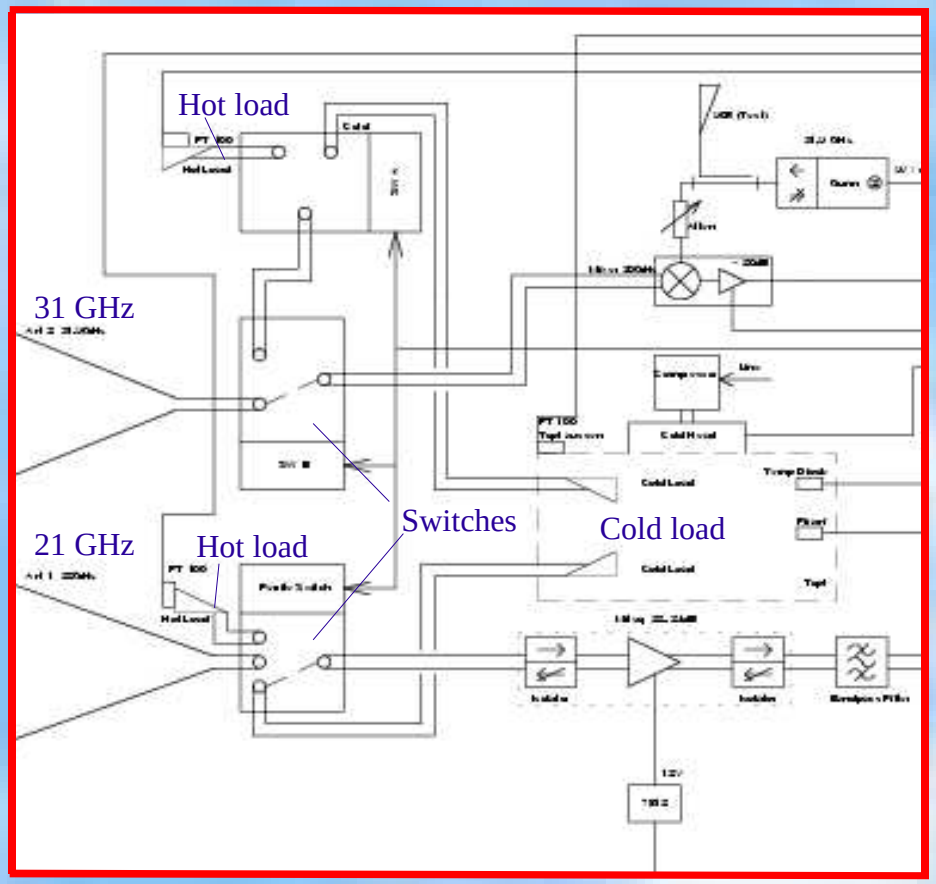
- TROWARA (Tropospheric Water Vapour Radiometer)
  - Channels at 21.3 GHz ( ± 100 MHz) and 31.5 GHz ( ± 50 MHz)
  - Operating on roof of IAP, Bern since end of 1994
  - Measurement angle of 40°, facing North East
- Calibration
  - Internal calibration with hot (312 K) and cold (30 K) loads
  - Hourly external calibration with sky tipping
    - Tipping at 20° to 70° in good weather
    - Tipping at 20° to 40° in rain (LWP > 0.4 mm)

# The TROWARA instrument



## Calibration using internal hot and cold loads

$$BT_{LEVEL0} = \frac{(V_{ant} - V_{hot})}{(V_{hot} - v_{cold})} (BT_{hot} - BT_{cold}) + BT_{hot}$$

## Calibration using sky tipping to determine antenna loss

$$BT_{LEVEL1} = L\ BT_{LEVEL0} - (L - 1)\ T_{LENS}$$

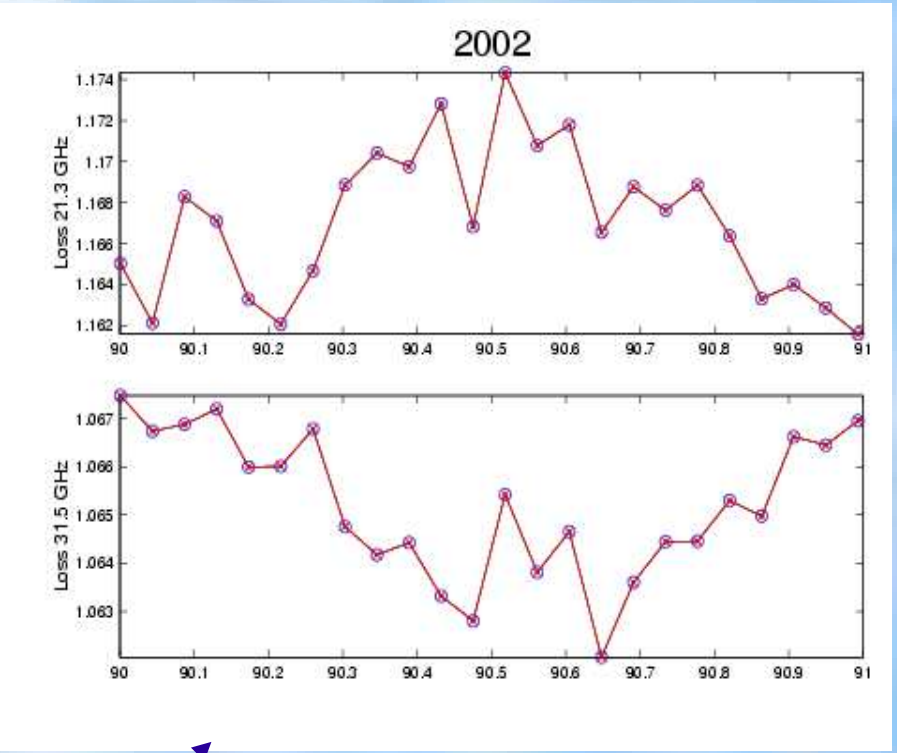
$$BT_{LEVEL0} = \tau\ BT_{LEVEL1} + (1 - \tau)\ T_{LENS}$$

$$BT_{LEVEL1} = (1/\tau)\ BT_{LEVEL0} - (1/\tau - 1)\ T_{LENS}$$

Antenna transmissivity was measured

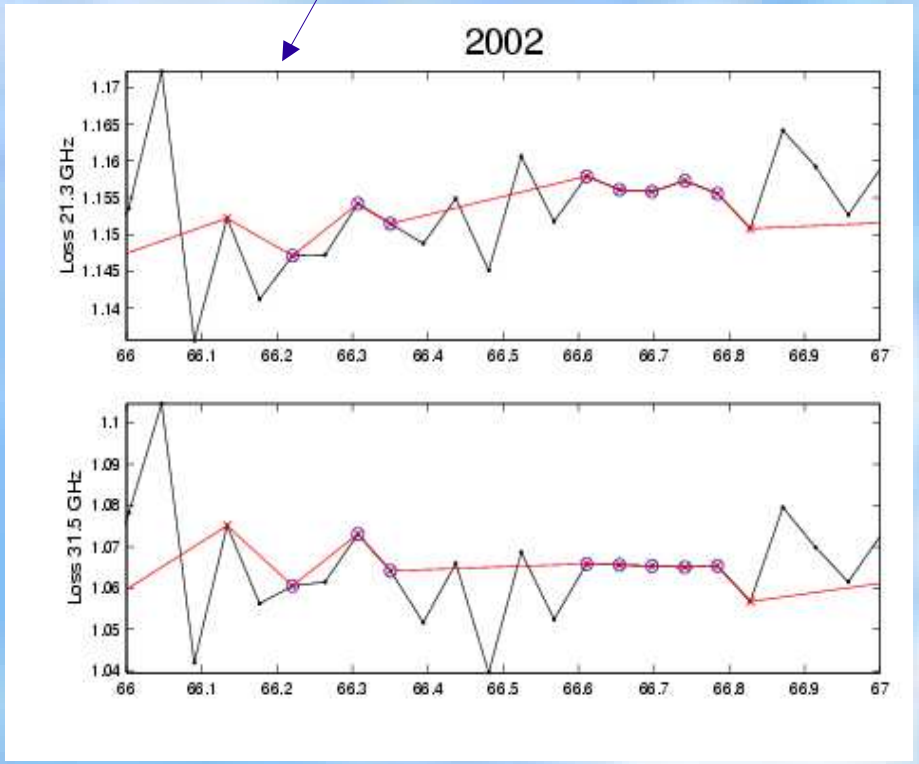
| ***Frequency, GHz*** | τ | ***1/L*** | ***BT_LEVEL0, K*** | ***BT_LEVEL1 using*** τ, K | ***BT_LEVEL1 using L, K*** |
|---|---|---|---|---|---|
| 21.3 | 0.933 | 0.857 | 57.6 | 41.4 | 18.1 |
| 31.5 | 0.905 | 0.939 | 36.6 | 10.7 | 19.7 |

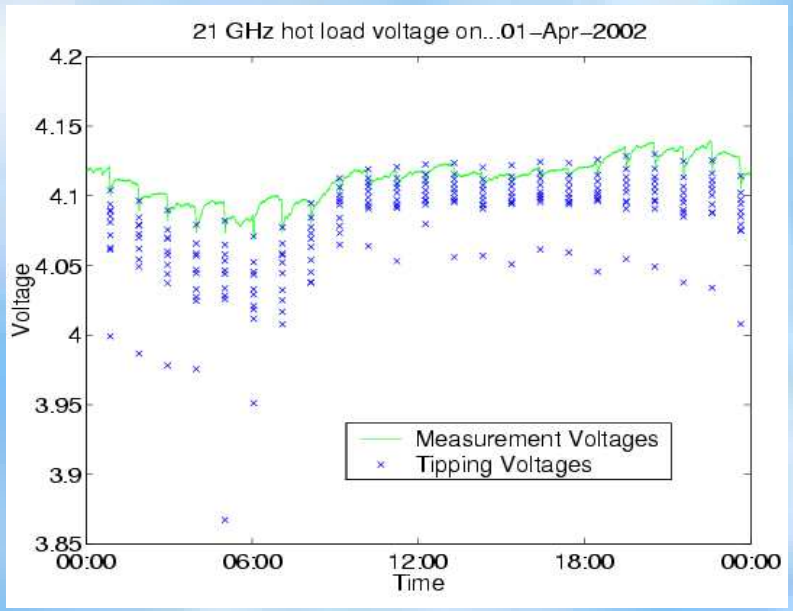
# "Antenna loss" values calculated from tipping calibration

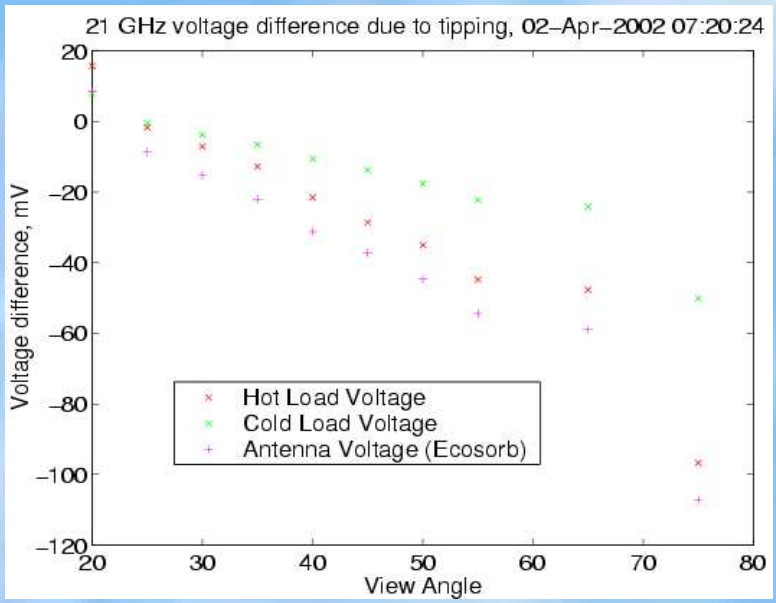


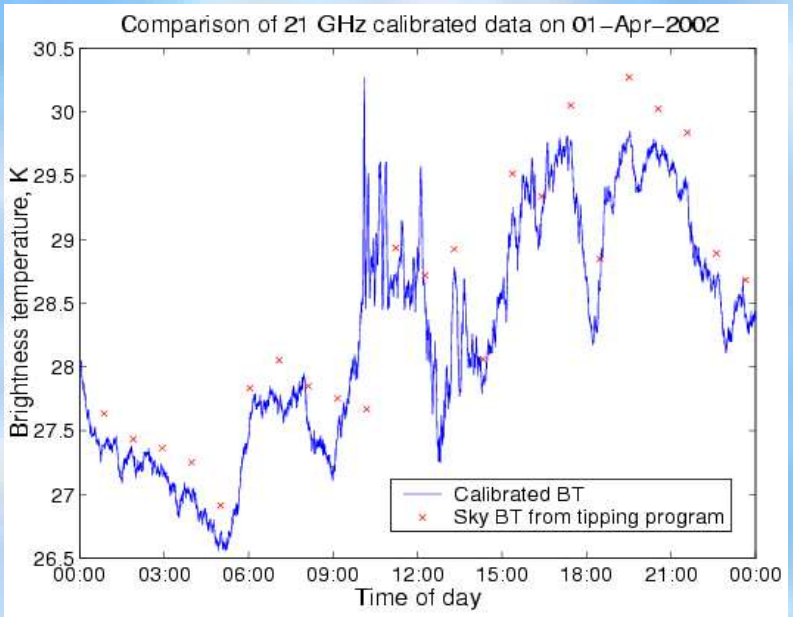

31st March 2002, clear day

7th March 2002, partly overcast



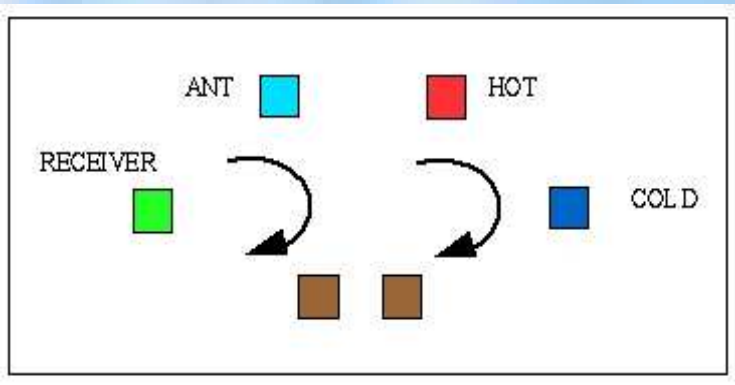



# Effect of the tipping calibration on the Trowara brightness temperatures

- Former situation
  - Instrument not well insulated from solar radiation
  - Rain gathers on lens, particularly if tipping occurs in rain
  - Considerable processing needed to select good tipping curves
  - The change in view angle during tipping affects the voltages
- Proposed solution
  - Place instrument in indoor lab
    - Protection from solar radiation and temperature changes
    - Tipping with mirror outside building, only in good weather
  - Model the transfer of radiation in radiometer, up to and including switch:
    - Antenna transmission
    - Antenna, hot and cold load reflection
    - S parameters for cold load waveguides
    - S parameters for ferrite switches




21 GHz ferrite circulating switch in cold load position

*The following effects must be considered:*

- Transmission from cold load to receiver
- Reflection of hot load at cold load and then transmission to receiver
- Crosstalk − signals from hold load or antenna travelling against switch direction and reaching receiver
- Reflections occurring at the switch output
- Emission in the switch itself

# Hot Load

$$BT_{HOT} = \tau_{HR} \cdot T_{HOT} + ( \tau_{CR}^{H} \cdot BT_{COLD} + \tau_{AR}^{H} \cdot BT_{ANT} ) + R_{R} \cdot T_{ISO} + e \cdot T_{SWITCH}$$

Transmission Cross talk Reflection Emission

| *Contribution to hot load BT* | *21.3 GHz channel, K* | *31.5 GHz channel, K* |
|---|---|---|
| Hot Load temperature | 310.2 | 311.9 |
| Transmission through switch | 295.7 | 262.5 |
| Crosstalk in switch | 0.0 | 0.3 |
| Reflection at switch output | 0.5 | 4.2 |
| Switch emission | 13.9 | 43.5 |
| Total Hot Load Brightness Temperature | 310.0 | 310.6 |

# Cold Load

$$BT_{COLD\_A} = \tau_{WGA} \cdot T_{COLD} + (1 - \tau_{WGA}) \cdot T_{WGA}$$ Transmission and Emission

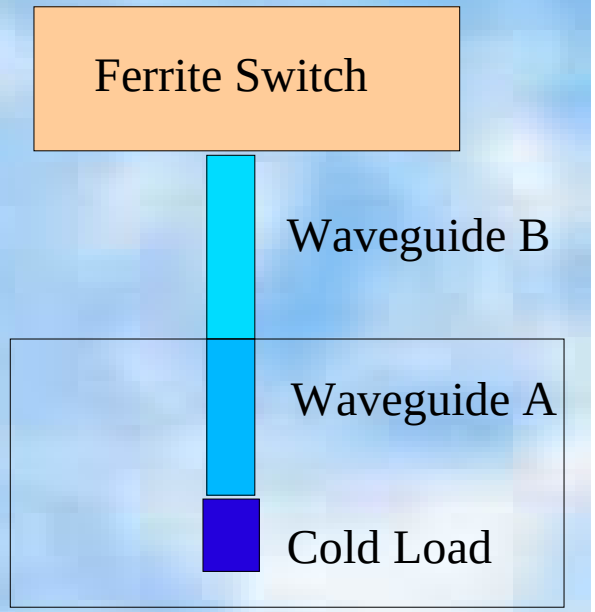
$$BT_{COLD\_B} = \tau_{WGB} \cdot BT_{COLD\_A} + e_{WGB} \cdot T_{WGB} + R_{WGB} \cdot \tau_{HC} \cdot T_{HOT} + R_C \cdot \tau_{HC} \cdot \tau_{WGB}^2 \cdot T_{HOT}$$

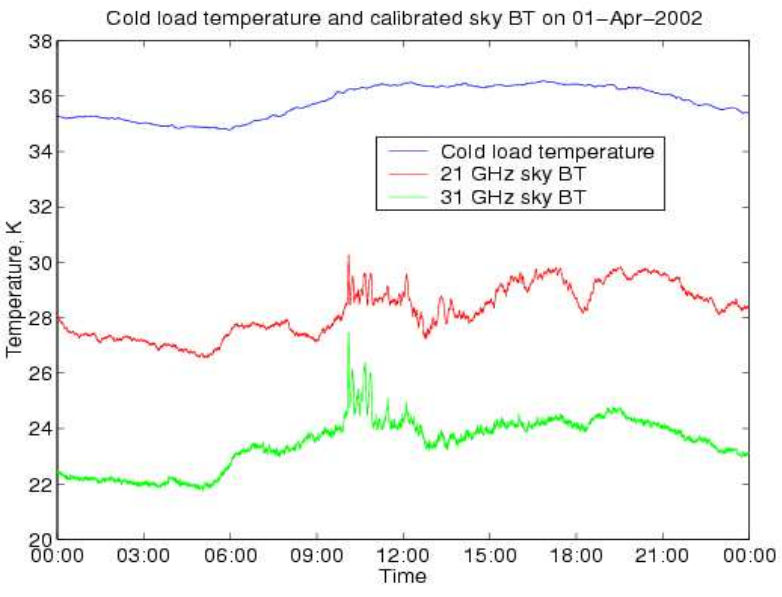
Transmission Emission Reflection in waveguide Reflection at cold load interface

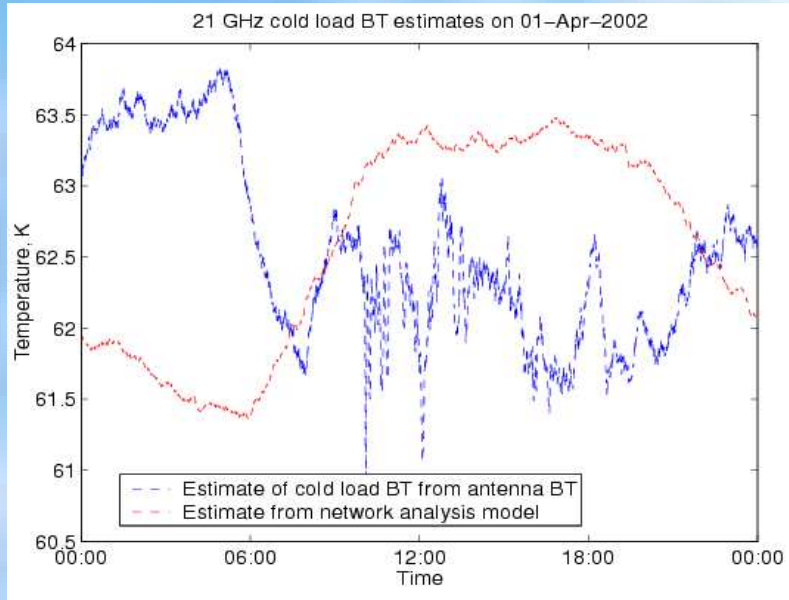
$$BT_{COLD} = \tau_{CR} \cdot BT_{COLD\_B} + (\tau_{HR}^C \cdot T_{HOT} + \tau_{AR}^C \cdot BT_{ANT}) + R_R \cdot T_{ISO} + e_{SW} \cdot T_{SWITCH}$$

Transmission Crosstalk Reflection Emission

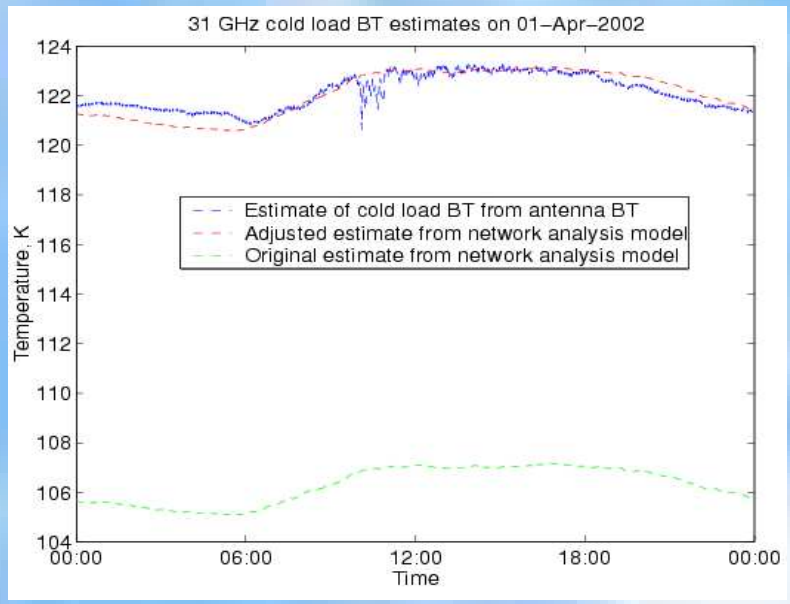
| ***Contribution to cold load BT*** | ***21.3 GHz channel, K*** | ***31.5 GHz channel, K*** |
|---|---|---|
| Cold load temperature | 35.2 | 35.2 |
| BT at the end of waveguide A | 45.2 | 72.6 |
| BT at the end of waveguide B | 54.3 | 89.3 |
| Transmission through switch | 52.6 | 76.2 |
| Crosstalk in switch | 0.2 | 0.4 |
| Reflection at switch output | 1.2 | 1.6 |
| Emission in switch | 7.9 | 43.1 |
| Total cold load BT | 61.9 | 121.3 |






Estimate of the cold load brightness temperature from the sky temperature measured during the tipping calibration.



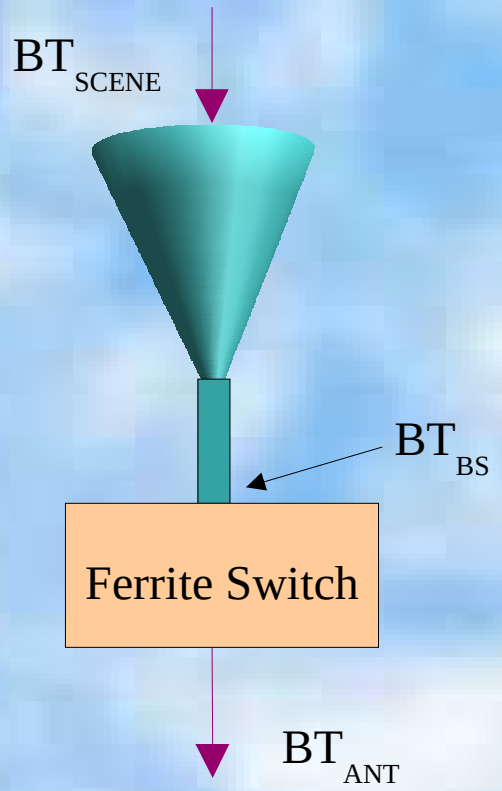
# Antenna

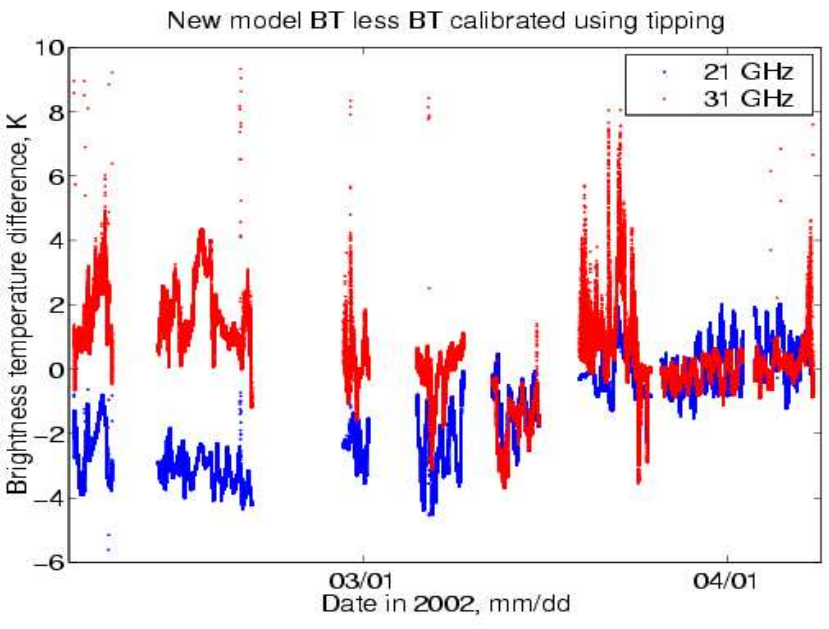
$$BT_{BS} = \tau_{ANT} \cdot BT_{SCENE} + (1 - \tau_{ANT}) \cdot T_{LENS}$$ Transmission and emission in antenna

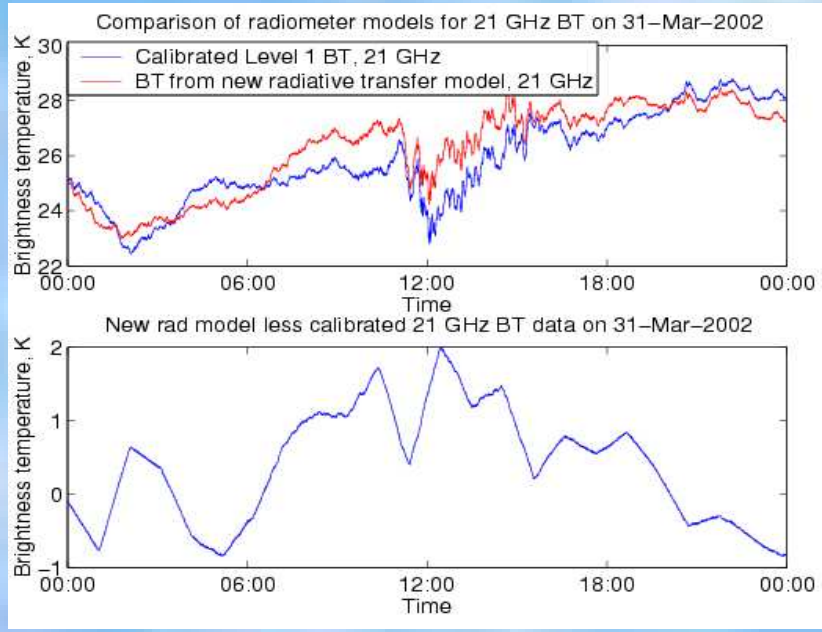
$$BT_{ANT} = \tau_{AR} \cdot BT_{BS} + (\tau_{CR}^{A} \cdot BT_{COLD\_B} + \tau_{HR}^{A} \cdot T_{HOT}) + R_{ANT} \cdot \tau_{HA} \cdot \tau_{AR} \cdot T_{HOT} + R_{REC} \cdot T_{ISO} + e \cdot T_{SWITCH}$$

Transmission Cross talk Hot load reflection Reflection Emission

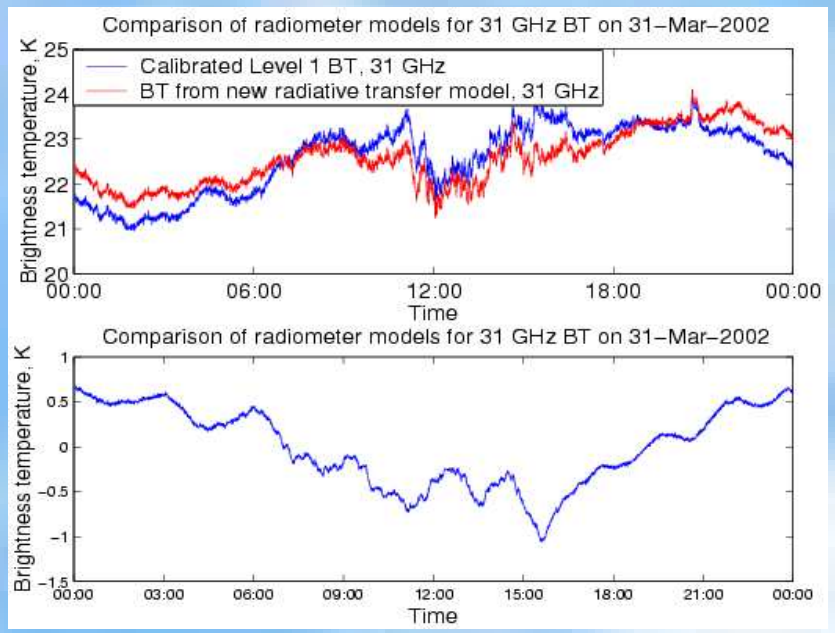
| ***Corrections to antenna BT*** | ***21.3 GHz channel, K*** | ***31.5 GHz channel, K*** |
|---|---|---|
| Antenna BT after passing through switch | 52.5 | 79.8 |
| Reflection of hot load BT at antenna | −3.4 | −3.3 |
| Crosstalk in switch | −0.2 | −3.1 |
| Reflection at switch output | −0.3 | −7.8 |
| Emission from the switch | −5.7 | −25.3 |
| Antenna BT after antenna and before switch | 44.3 | 47.5 |
| Emission from the antenna | −18.9 | −26.7 |
| Correction for the antenna transmission | +1.8 | +2.2 |
| Sky brightness temperature | 27.2 | 23.0 |



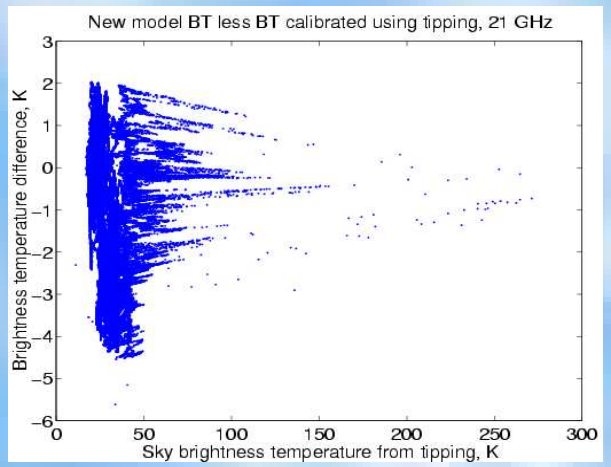


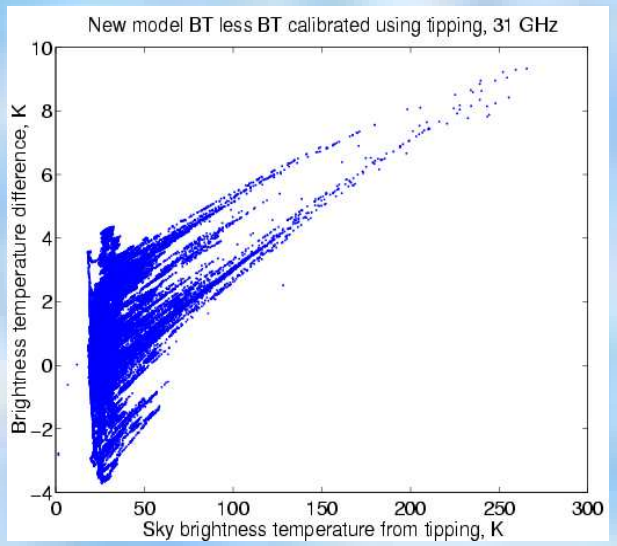



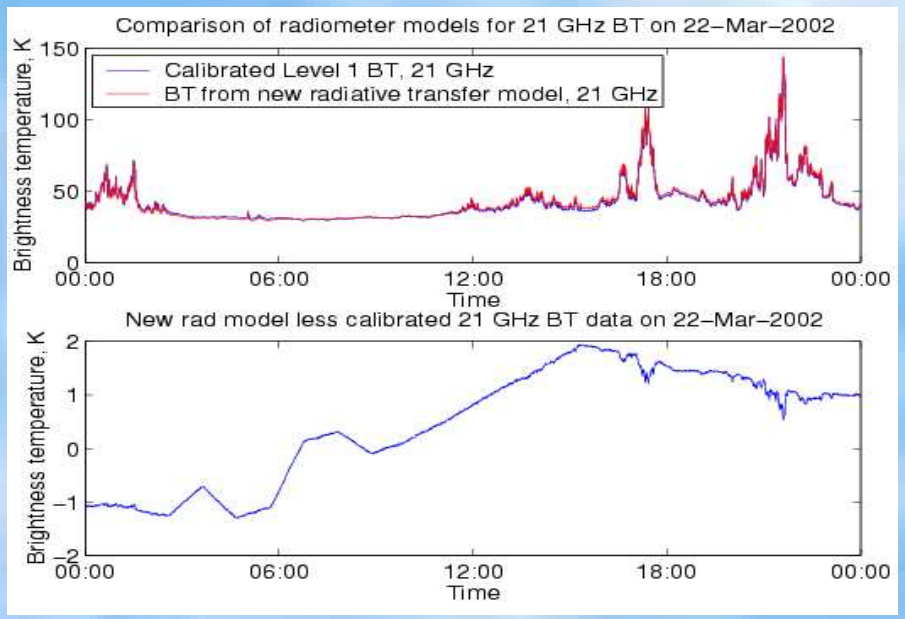

Comparison of new radiometer model with Level 1 data (calibrated using tipping).

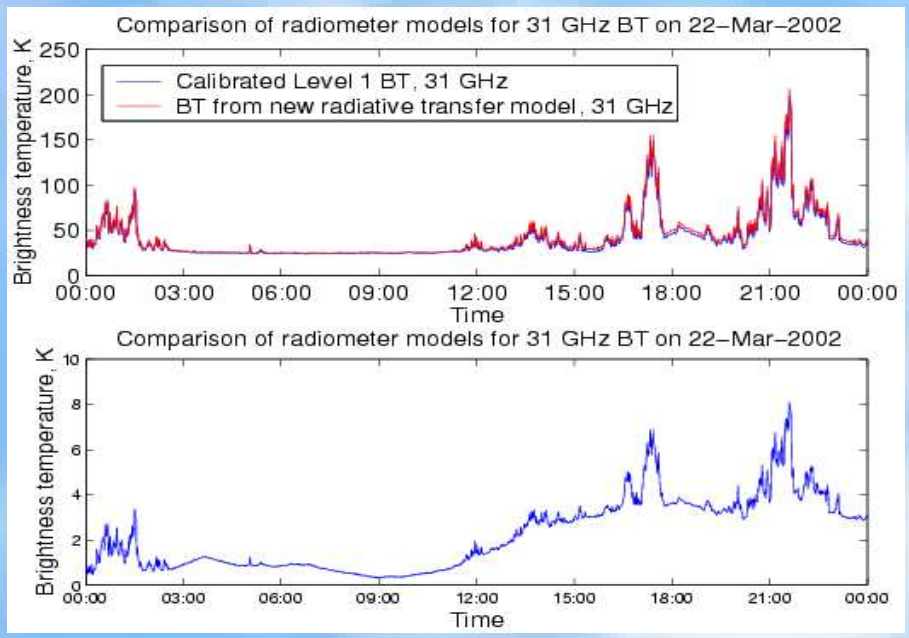


# Dependence of the model differences on the sky brightness temperature.



- Conclusions
  - Movement of radiometer during tipping calibration causes small negative BT bias
  - Demonstrated model for calibration based on internal hot and cold loads
    - Agreement with tipping calibration of −4 to +2 K at 21 GHz
    - Agreement is generally −4 to +4 K at 31 GHz but errors of up to 10 K occur for high sky BTs (rainy conditions)
- Future plans
  - Place Trowara in new position in indoor lab
  - Install new set of temperature sensors
  - Set up system for making occasional tip cals with mirror
  - Evaluate stability of radiometer − how often should tip cals be made?