All you should know about riometers

Martin Friedrich

Graz University of Technology

Graz, Austria*)

*)*true*

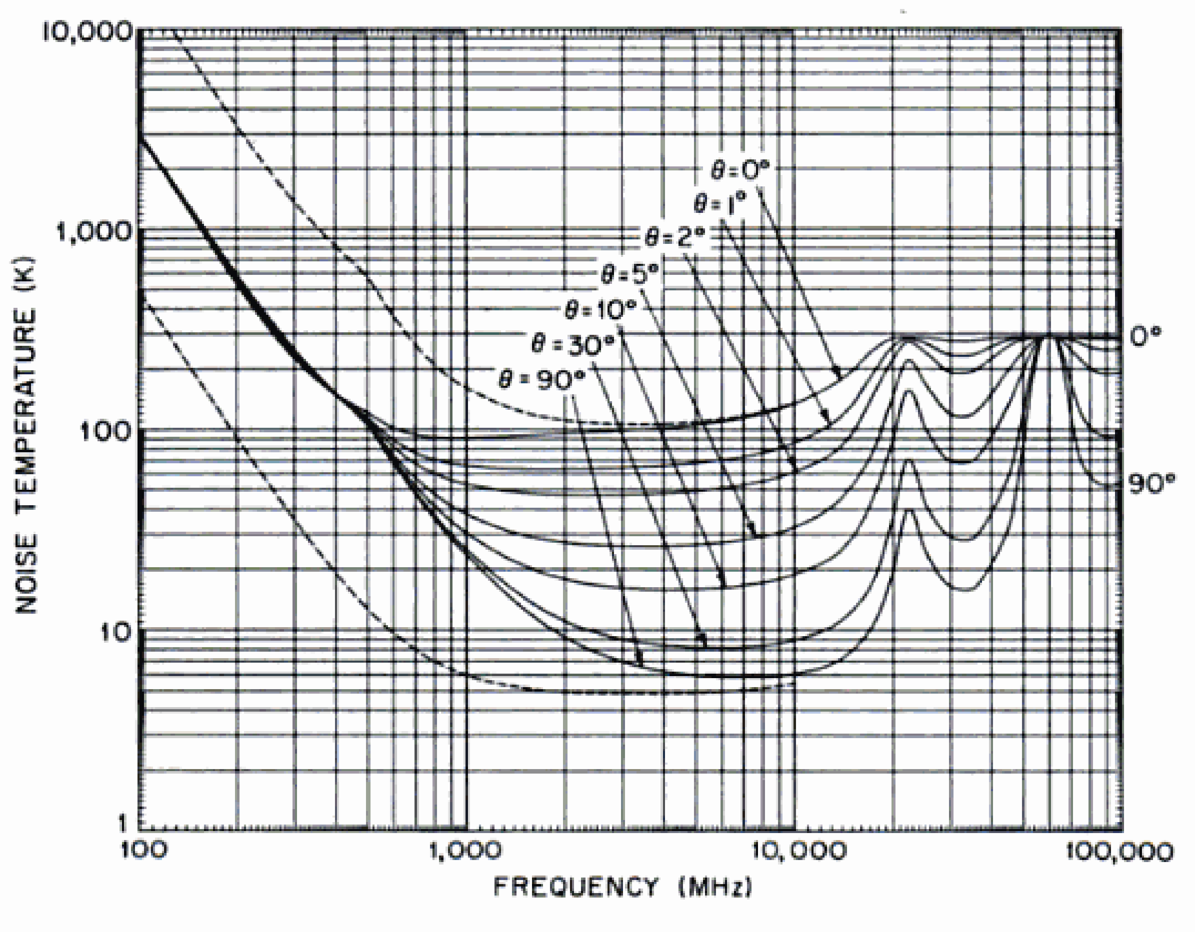
*)*false*

RIO-meter

= *R*elative *I*onospheric *O*pacity meter

(aka: absorption method A2)

All you should know about riometers



external

instrumental

noise sources

atmospheric

$$P_N = kT_s B_n$$

P_N…noise power, W

k … Boltzmann constant

T_s… noise temperature, K

B_N…bandwith, Hz

fundamental for radio engineering

<u>(wo)man-made</u>: - discrete frequencies
- harmonics of 50/60 Hz (fall off with frequency)

<u>natural</u>: various extraterrestrial sources in the sky

<u>preferred frequencies</u>: - too low: can not penetrate *F*-region peak
- too high: not sensitive
- *e.g.* 38.2 MHz internationally reserved

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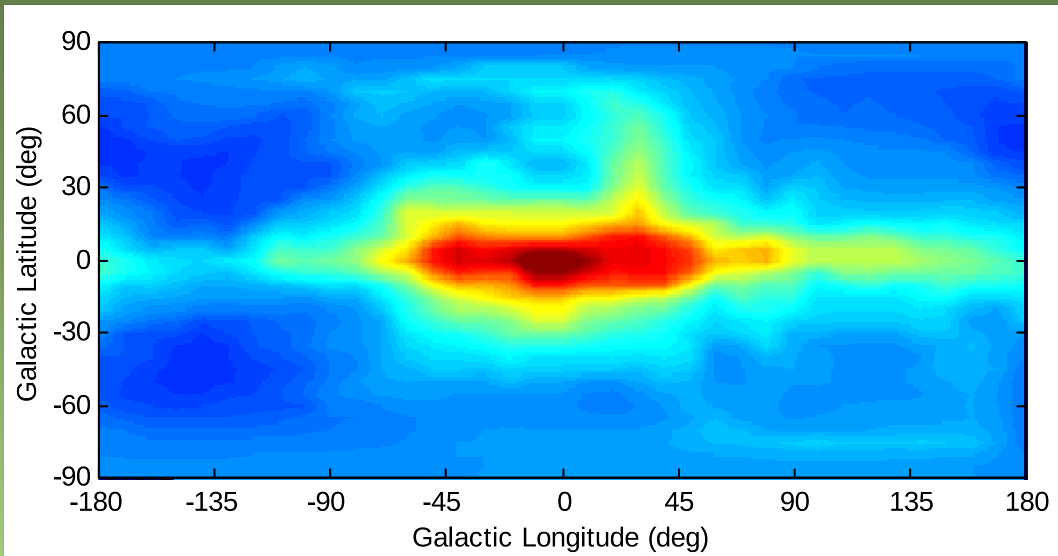
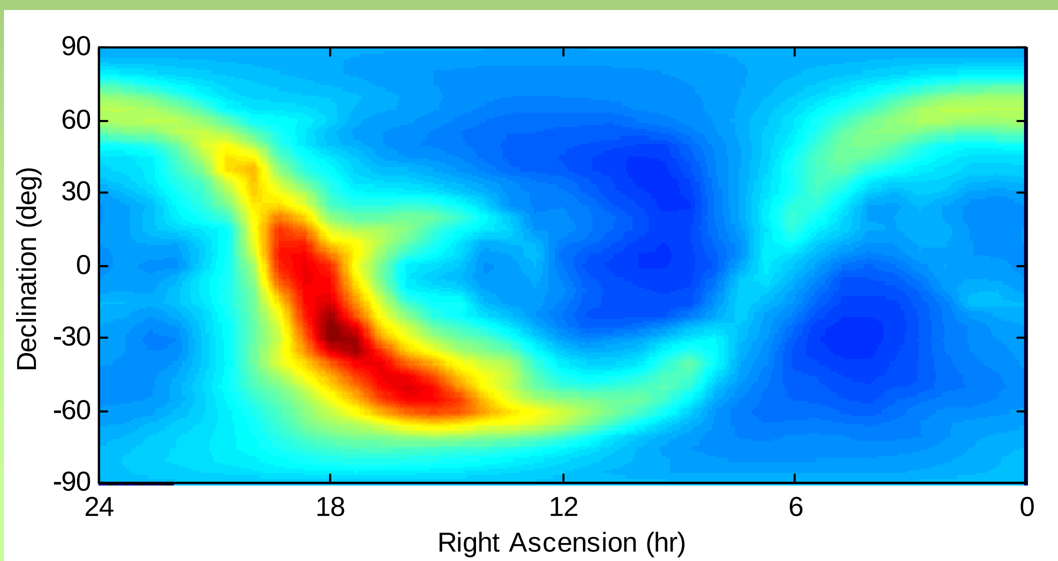
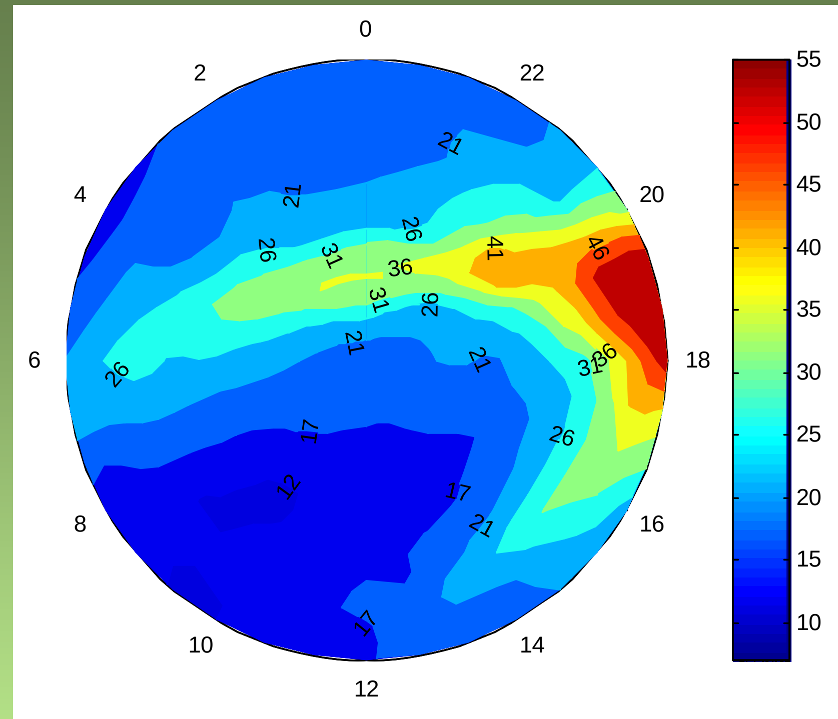


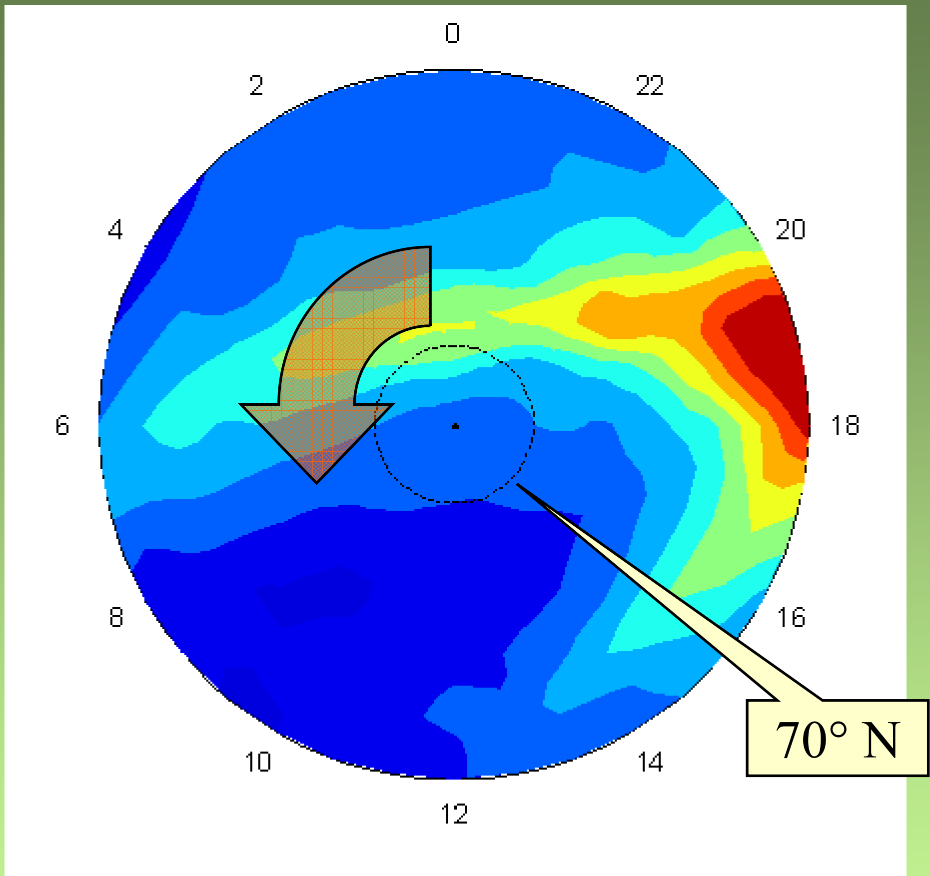


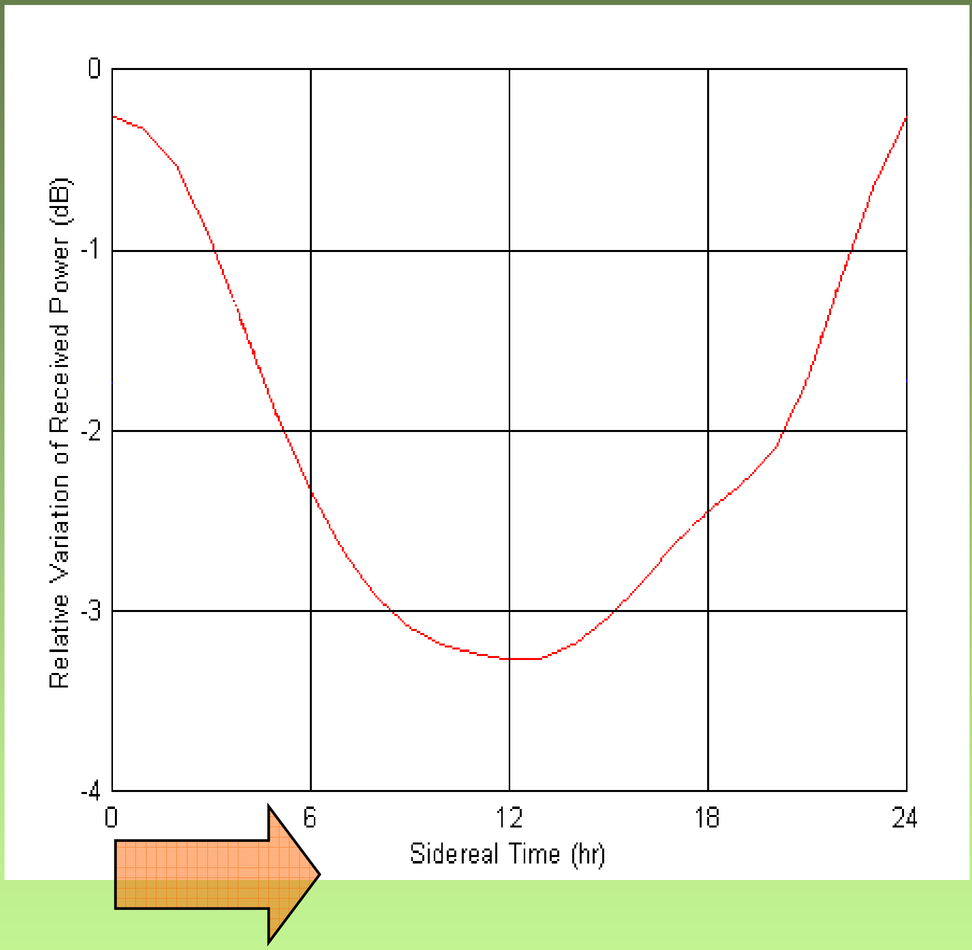


looking to the celestial north pole

sky noise temperature (in 1000 K)
measured at 30 MHz in
different co-ordinate systems (Cane, 1978)

All you should know about riometers





Sky noise between the equator and the north pole. Sidereal midnight at the top.

Received power at 70°N over a sidereal day

(power - theoretically - constant when pointed to pole star)

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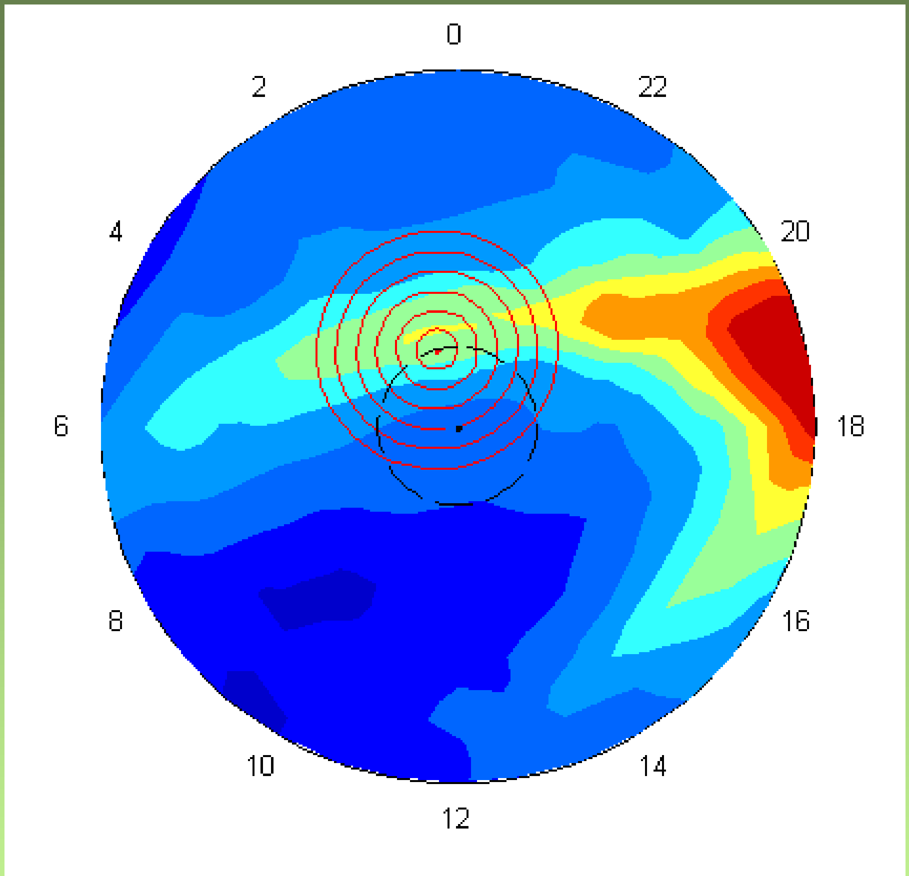
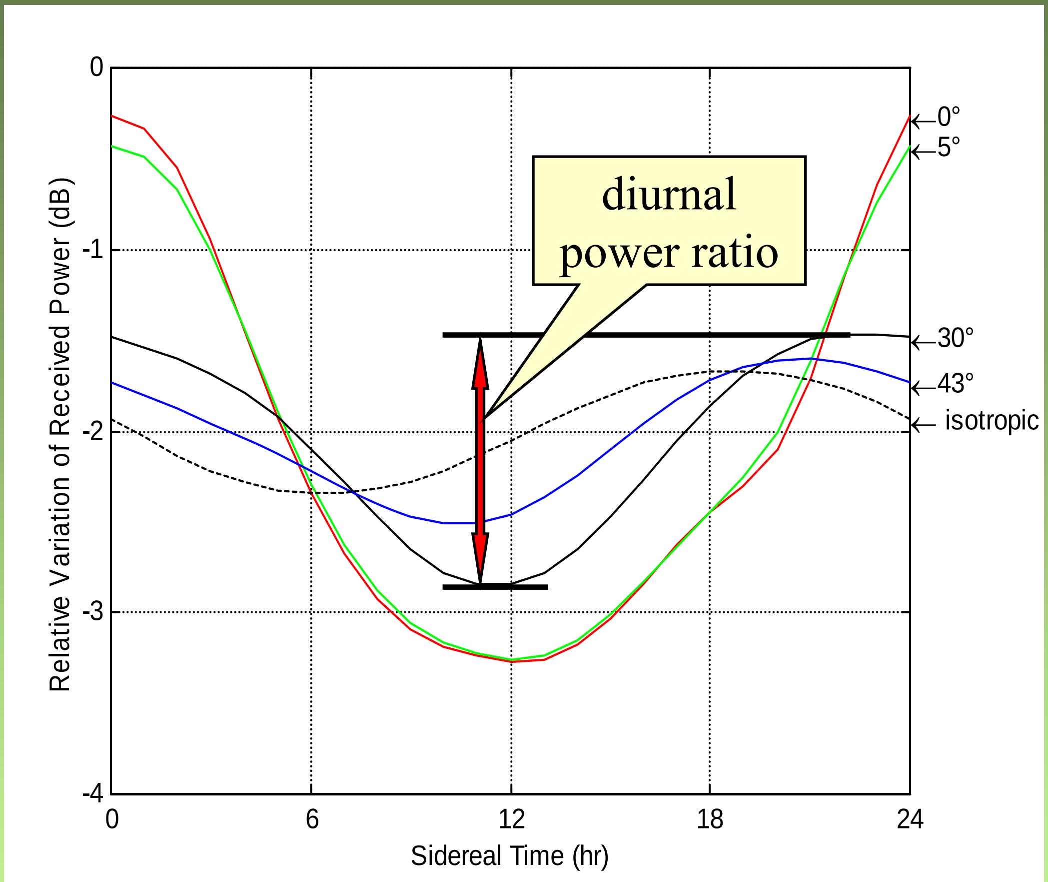
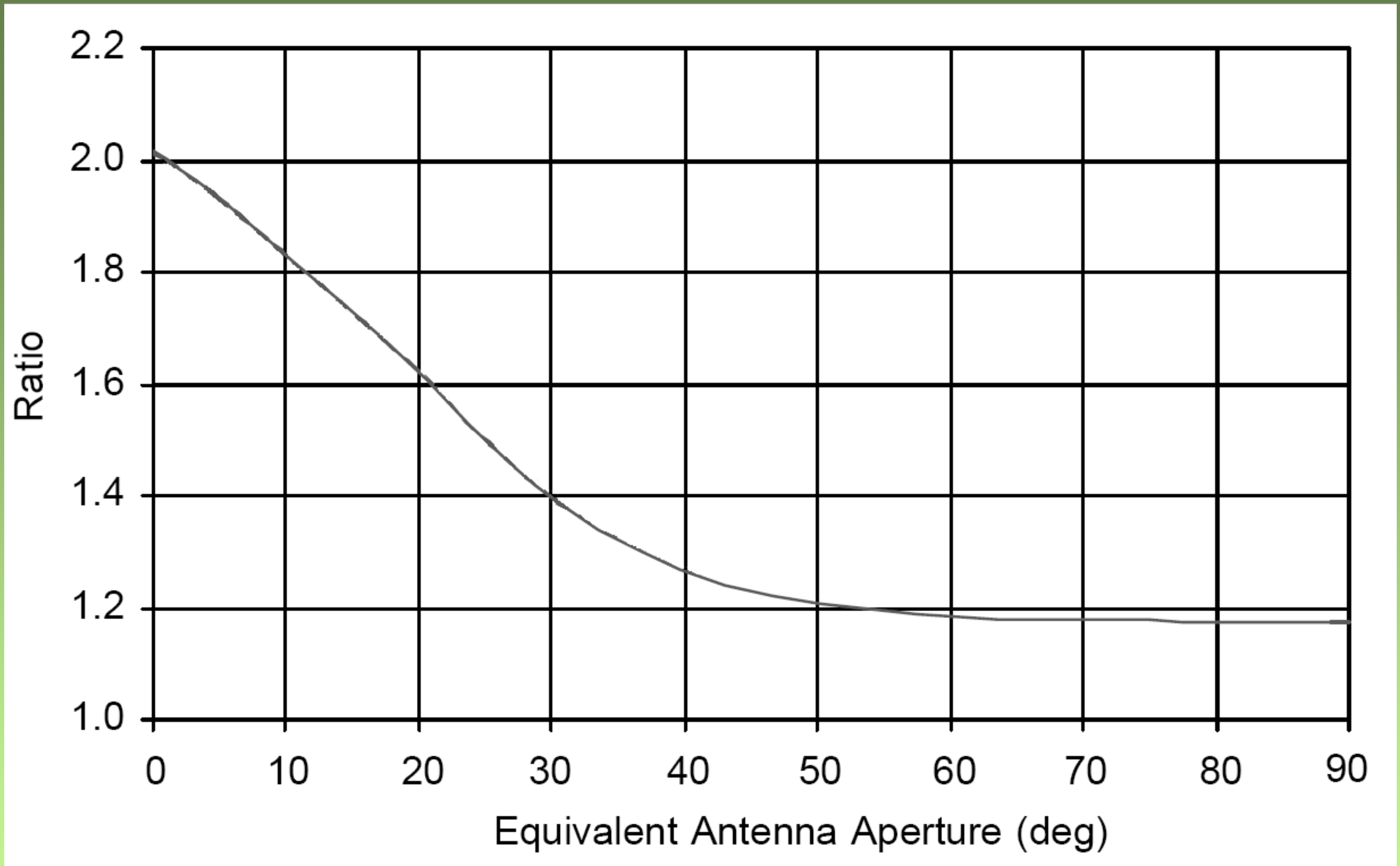




Red circles represent antenna opening angles between ±5 to ±30°

Received power at 70°N over a sidereal day for different antenna opening angles



Antenna opening angle from diurnal power ratio
(for 70°N)

Received power is a function of:

- geographic latitude
- sidereal time
- antenna opening angle
- look direction

All you should know about riometers

$$k_L = \frac{1}{\mu} \frac{e^2}{2\varepsilon_o mc} \frac{N_e \nu}{(\omega \pm \omega_c)^2 + \nu^2}$$

(absorption per unit path element; quasi-longitudinal propagation, “classical“ theory)

in other words:

- there are two modes (x-mode a little more absorbed)
- absorption is ~ $N_e \times \nu$
- absorption is ~ f^2 (for $\omega >> \omega_c$ and $\omega >> \nu$)

since $\nu \sim p \Rightarrow$

- <u>absorption is ~ $N_e \times p$</u>

$$L_i = const. \int_{x=0}^{\infty} N_e \, p \, dx$$

const. = function of:

- frequency,
- magnetic field,
- propagation direction.

integral absorption L_i

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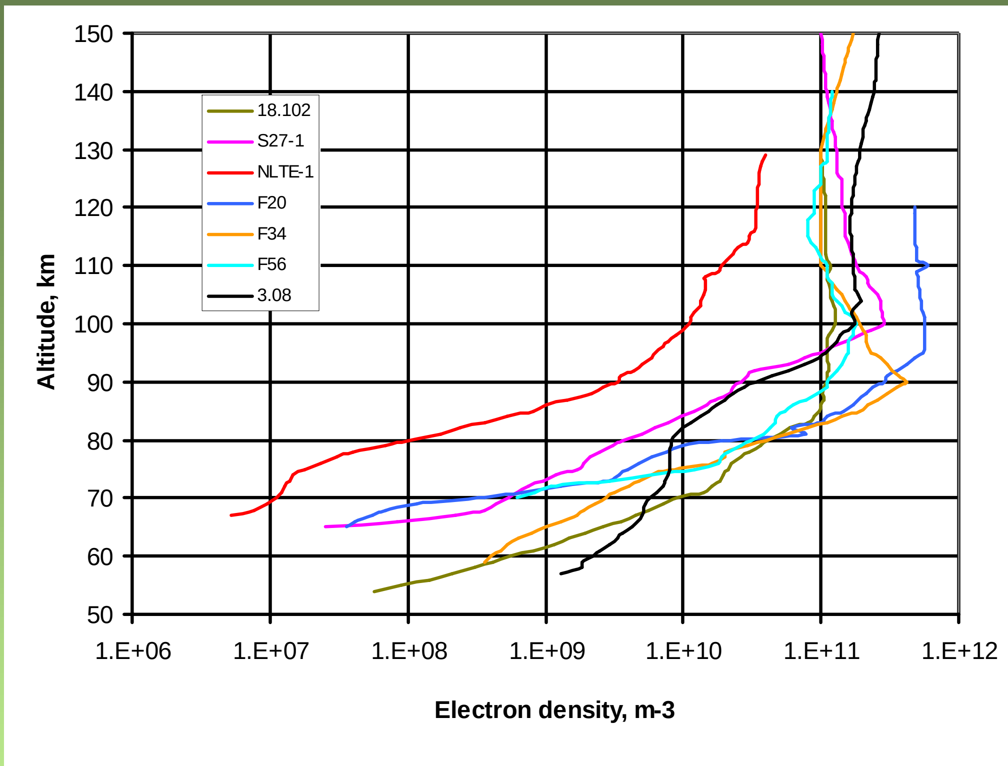
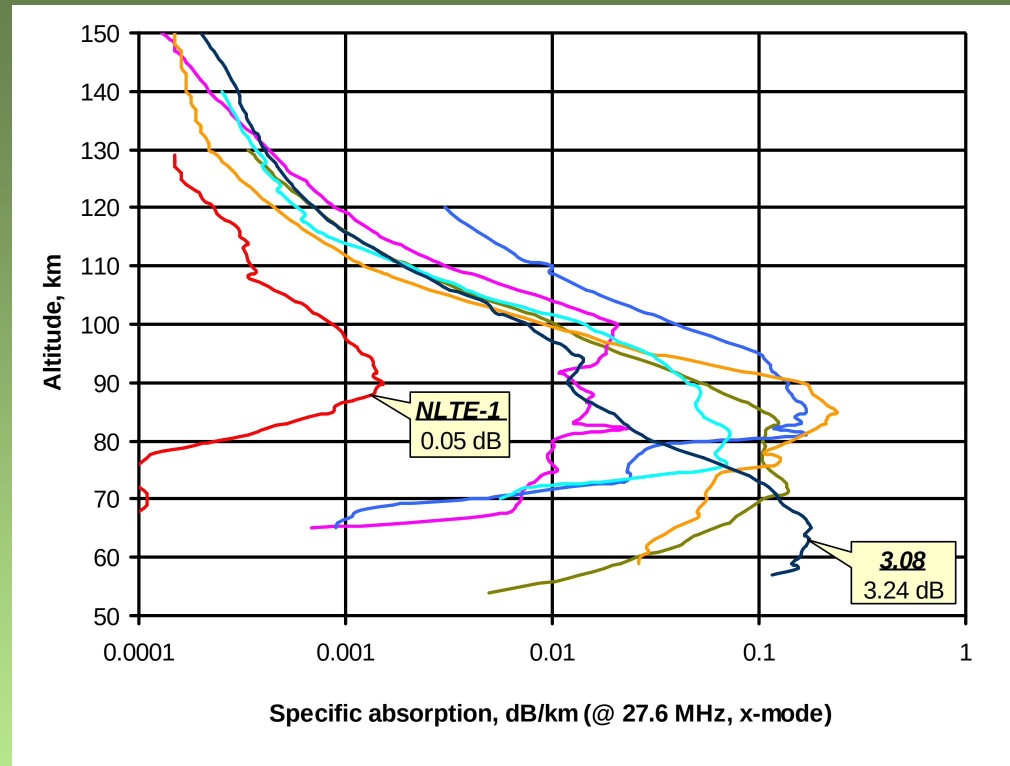
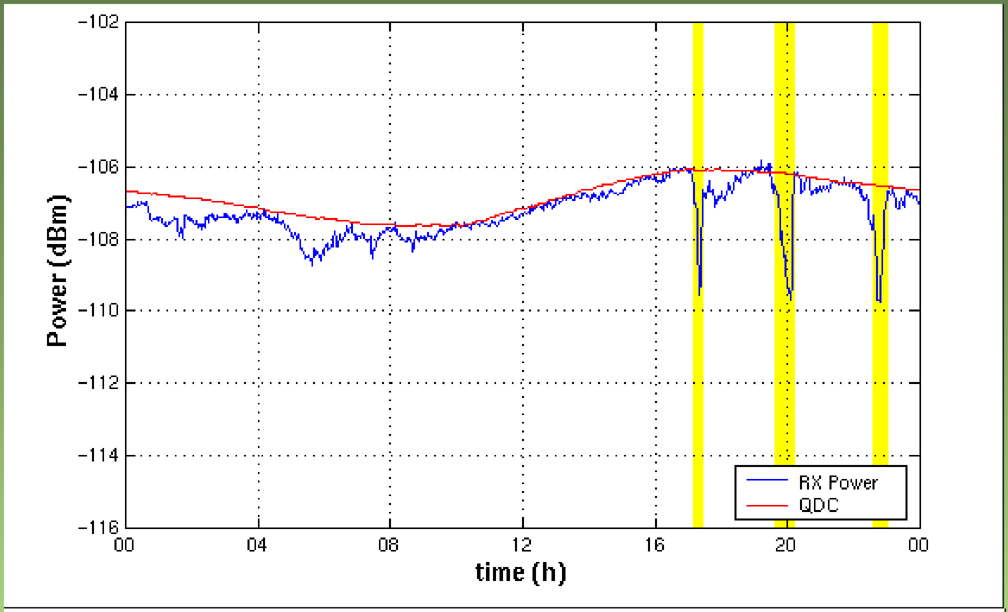




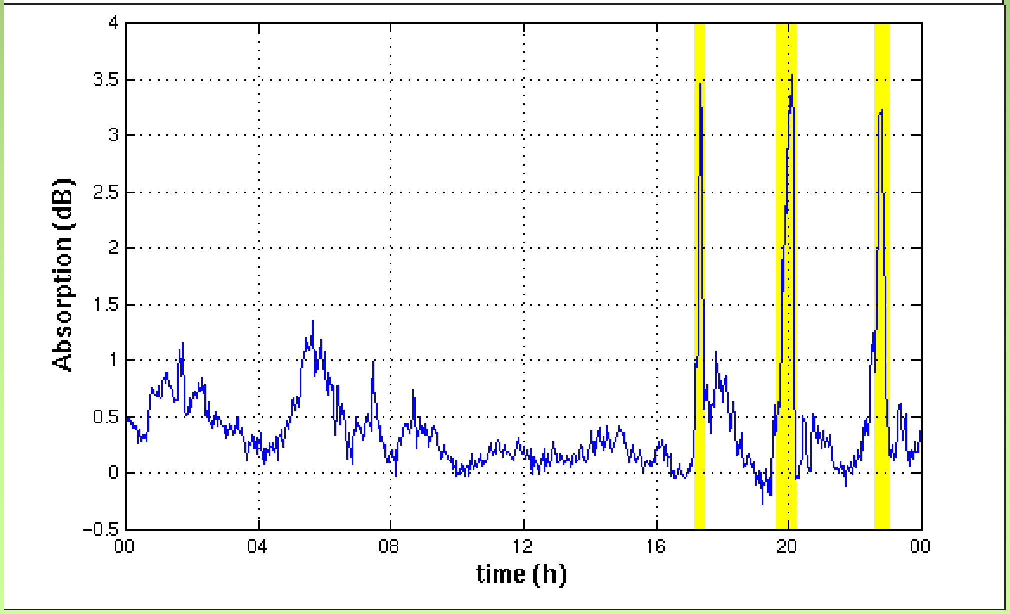
Large absorption events tend to originate in the lower ionosphere (notably PCA‘s due to protons)

typical absorption profiles

All you should know about riometers



received power



absorption = QDC - received power

►exact QDC is crucial!

real raw data

note:

- even the “normal“ (quiet) ionosphere absorbs (L_Q)
- a riometer measures *additional* absorption (L_R)
- absorption calculated from measured N_e is integral absorption (L_i)

$$L_R = L_i - L_Q$$

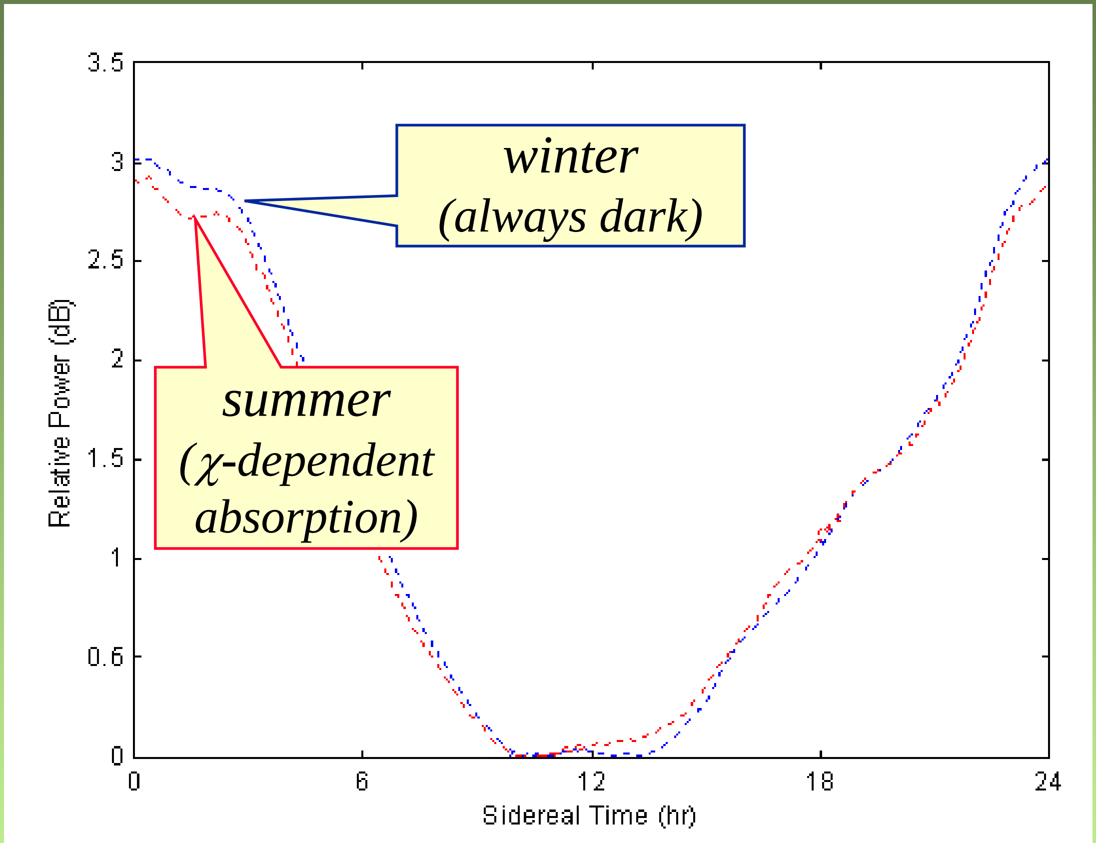
what is L_Q?

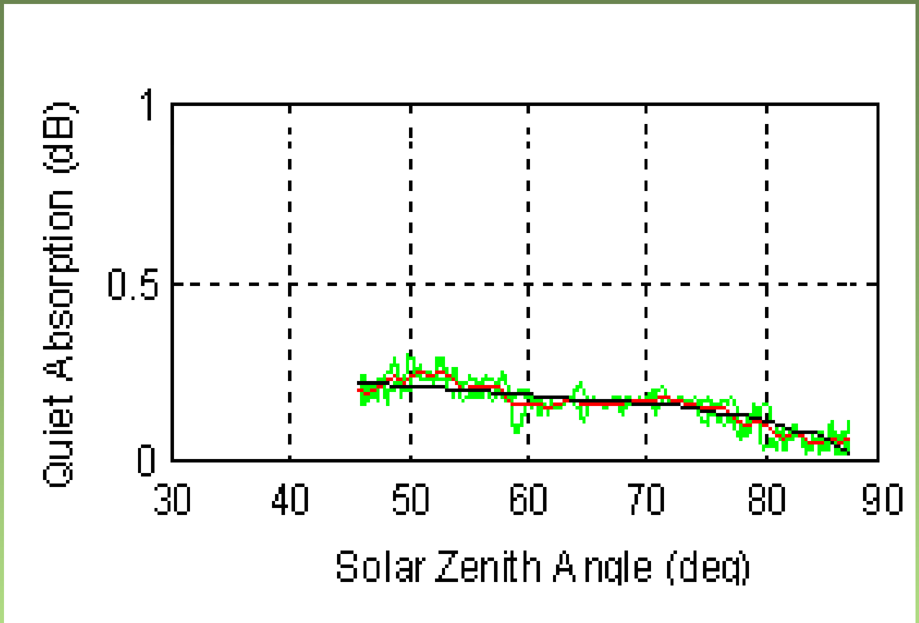
three ways to obtain L_Q:

- (1) QDC_{winter} - QDC_{summer} = $L_Q(\chi)$
- (2) L_i(calculated) - L_R(measured) = L_Q
- (3) determine True Quiet N_e from envelop of all N_e and calculate L_Q

how to arrive at L_Q?

All you should know about riometers

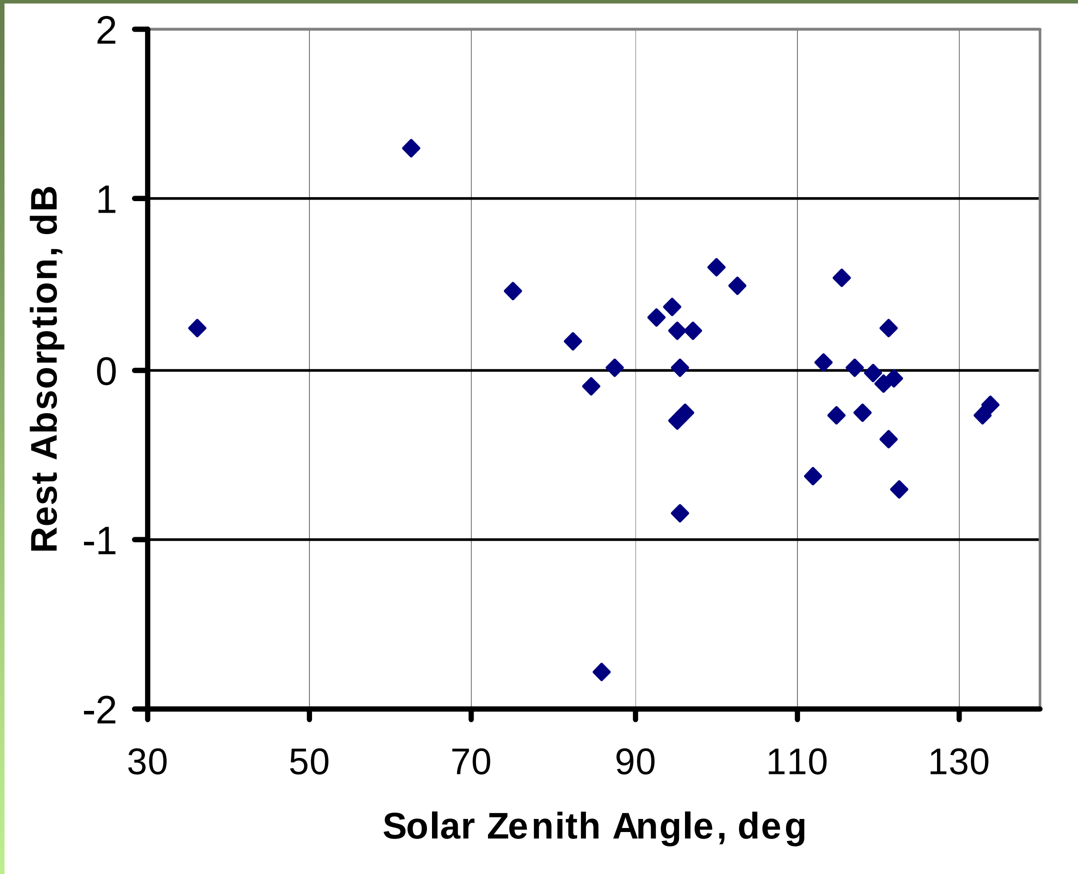




Winter-Summer difference *vs.* solar zenith angle χ

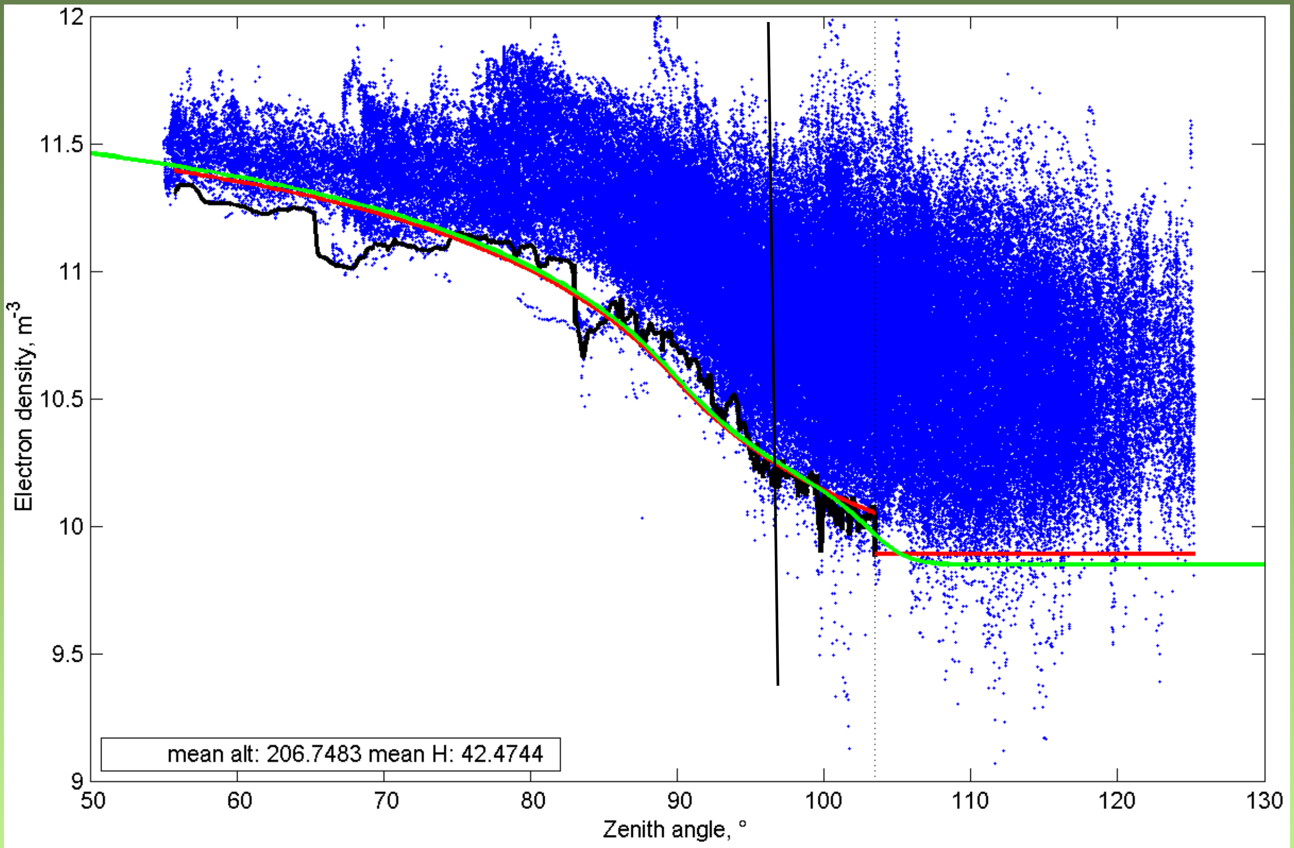
- ► requires extremely stable riometer
- ► can still not determine L_Q at night

All you should know about riometers



- subtract measured L_R from calculated L_i
- only few cases with sufficient height coverage!
- huge scatter!

All you should know about riometers



day *night*

Using True Quiet N_e

Assimilate envelope by Chapman-layer $\Rightarrow$ TQ-N_e

$$N_e = N_o(\cos\chi)^n$$

Calculate L_i

Assimilate absorption by

$$L_Q = L_o(\cos\chi)^n$$

Critical Design Review

NittanySat

The Pennsylvania State University

April 10, 2008

Rest in Peace

All you should know about riometers

for $\omega >> \omega_c$

$\Rightarrow L \sim \omega^{-2}$

frequencies f_1, f_2

absorption L_1 and L_2

$\Rightarrow L_2 = L_1 (f_1/f_2)^2$

measured quantity: $\Delta L = L_1 - L_2$

$\Rightarrow L_1 = \Delta L[1-(f_2/f_1)^2]$

for $f_2 >> f_1$

$\Rightarrow L_1 \cong \Delta L$

Measure L_T

$\Rightarrow$ ABEX on NittanySat

and subtract L_R

Rest in Peace

All you should know about riometers

TU Graz

- check the QDC (at night when L_Q is negligible)
- check the QDC (during the day using established L_Q)

  for vertical *and* oblique beams (⇒ imaging riometers)
- establish L_Q during the day (when L_Q can be appreciable)
- provide electron density estimates based on empirical model

Rest in Peace

All you should know about riometers

Rest in Peace

- *the receiving antenna generally does not point to the ground station*
  - stabilise the satellite by magnet (always along the Earth's ***B***-field)
  - gravity gradient stabilisation ("bottom" always points earthward)
- *residual antenna misalignement emulates absorption*
  - feed all receivers from the same antenna (same "pseudo" absorption)
- *the polarisation can have any orientation at the satellite (Faraday rotation)*
  - transmit circularly polarised waves
- *the satellite has a velocity component in propagaton direction (Doppler)*
  - transmit to the satellite with the expected frequency offset
  - sweep frequency enough to safely cover any Doppler shift
  - identify Doppler shift and adjust ground transmitters in real-time

All you should know about riometers

- *transmitters for each frequency and location (with or without riometer)*
  - ≥100 W, but switch off regularly to check background power
  - switch to low power for linearity check of receivers
  - track the expected Doppler shift
  - crossed dipoles for each frequency, phased for x-mode
- *choose frequency high enough to always penetrate the ionosphere*
  - max. 70° off zenith (most oblique beam of an imaging riometer)
  - for $f_o F_2$ =10 MHz at 300 km ⇒ 22.6 MHz
- *choose frequencies low enough to be more sensitive than the riometer*
  - *e.g.* 10 MHz is $(38.2/10)^2$ = 16.6 more sensitive than IRIS
- *telemetry and telecommand*
  - for each location for real-time download, or
  - at Penn State only.

Rest in Peace

- *receivers for each frequency*
  - narrow band (to cover Doppler shift would unduly increase the noise)
  - sensitivity 1 to 10 μV full scale
  - one (electrically short) antenna for all receivers
- *some mechanism to activate receivers when within reach of ground station*
  - coded signal on the higher frequency
  - activated from internal memory, or
  - leave them on all the time.

Rest in Peace

Realistically L_Q can only be determined by simulation using TQ-N_e

absorption L_Q is a function of: - solar zenith angle χ
- solar activity

Approximation of L_Q by $L_o(\cos\chi)^n$; at night $L_Q = L_n$

	Low solar activity (67 Jy)	High solar activity (200 Jy)
L_o, dB	0.140	0.191
n	0.570	0.546
L_n, dB	0.012	0.012

Table of annual means
(27.6 MHz, x-mode)

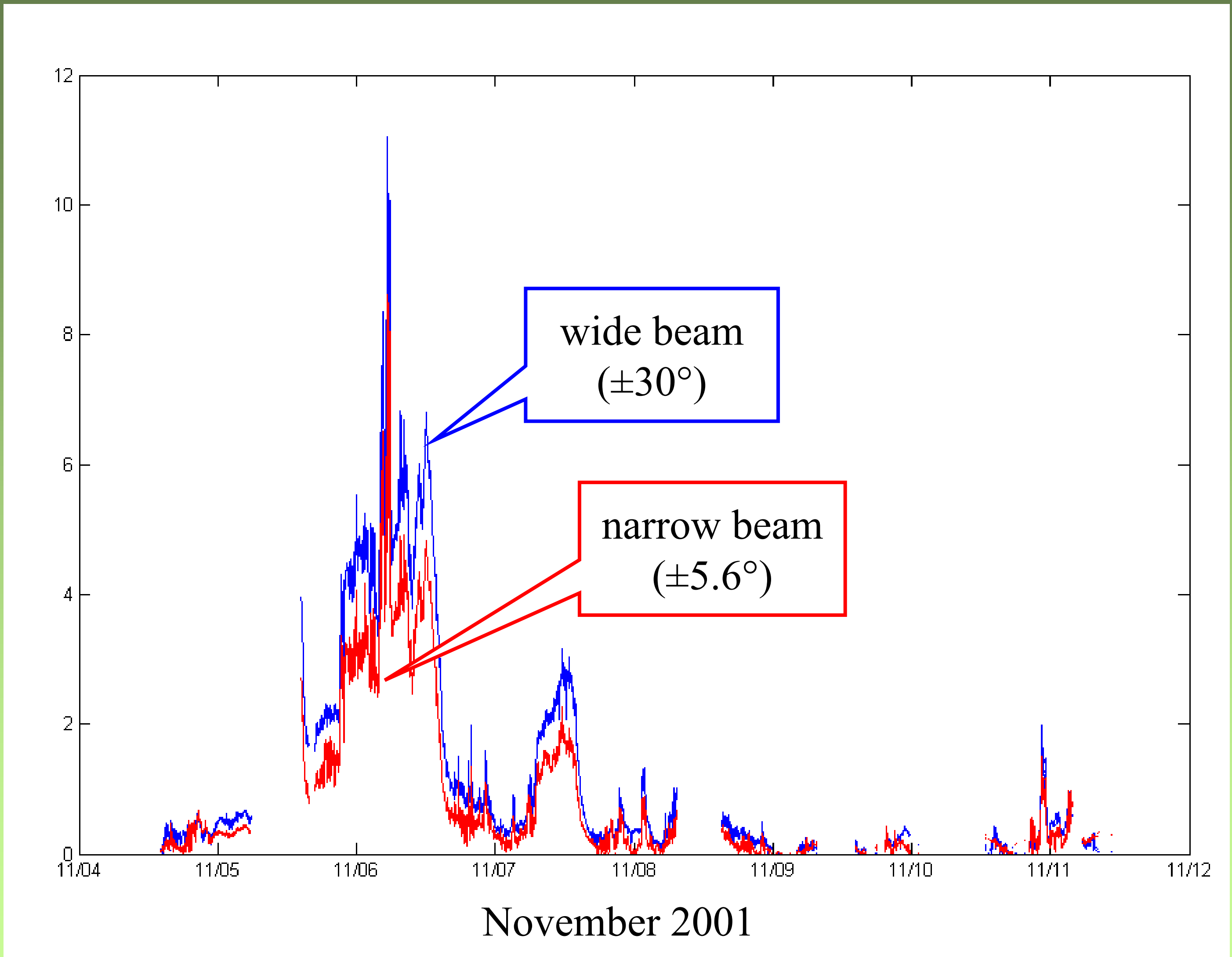
All you should know about riometers

IRIS imaging riometer
at Kilpisjärvi, Finland
(69.1°N, 20.8°E)

- 64 antennas
- circulary polarised (x-mode)
- forming 49 beams
- central (vertical) beam ± 5.6°
- most oblique beam (69° off) ± 6.2°
- beam # 50: single antenna (wide beam)

more is better

All you should know about riometers



Why does the wide beam consistently “see“ more absorption?

wide vs. narrow beam (1)

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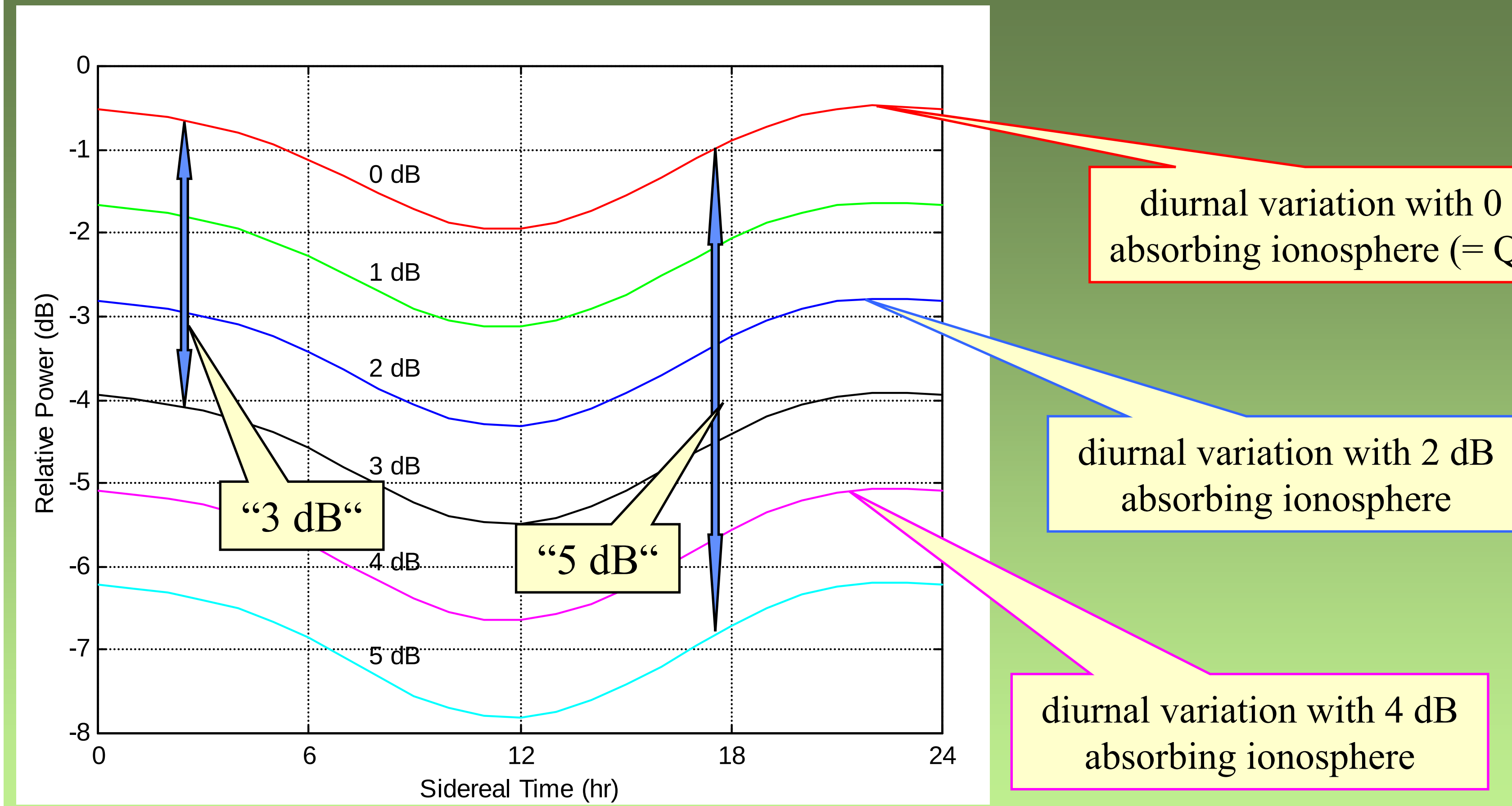

calculation for a ±30° antenna, absorption at 90 km

… because contributions from the side have a longer path through the absorbing ionosphere.

wide *vs.* narrow beam (2)

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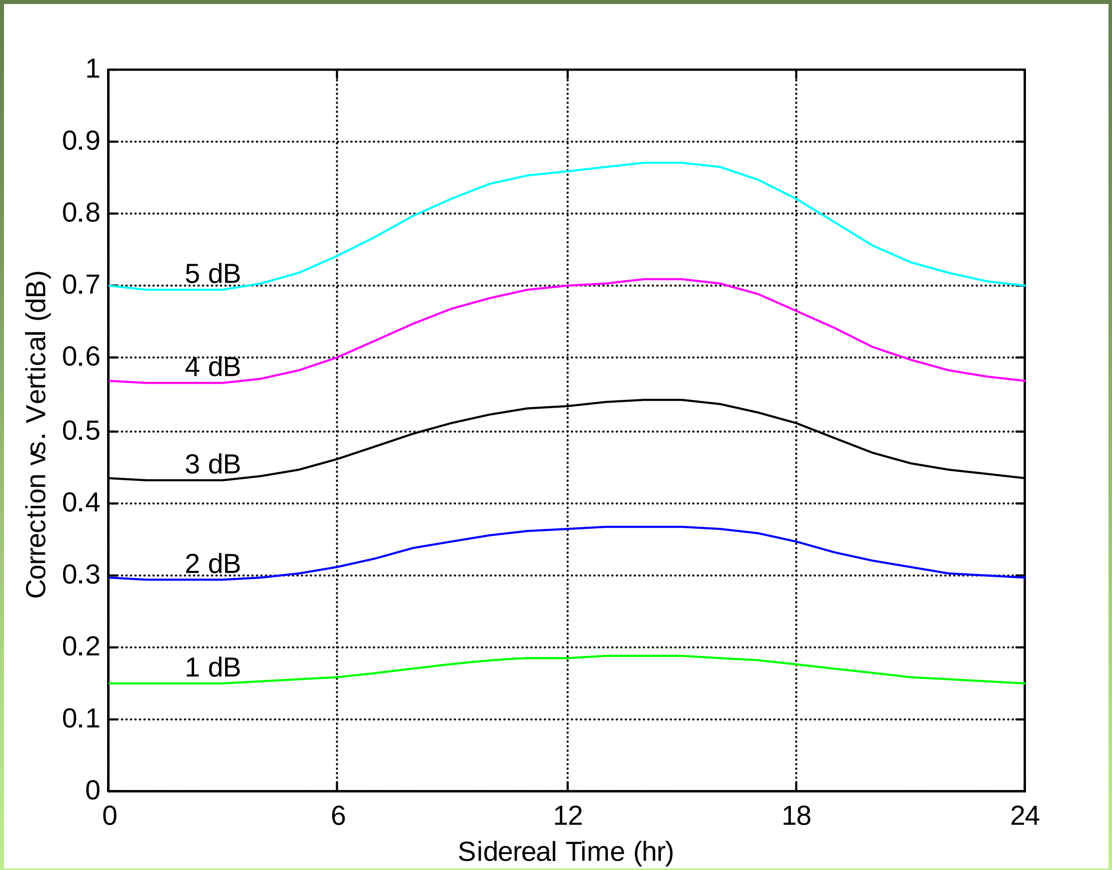
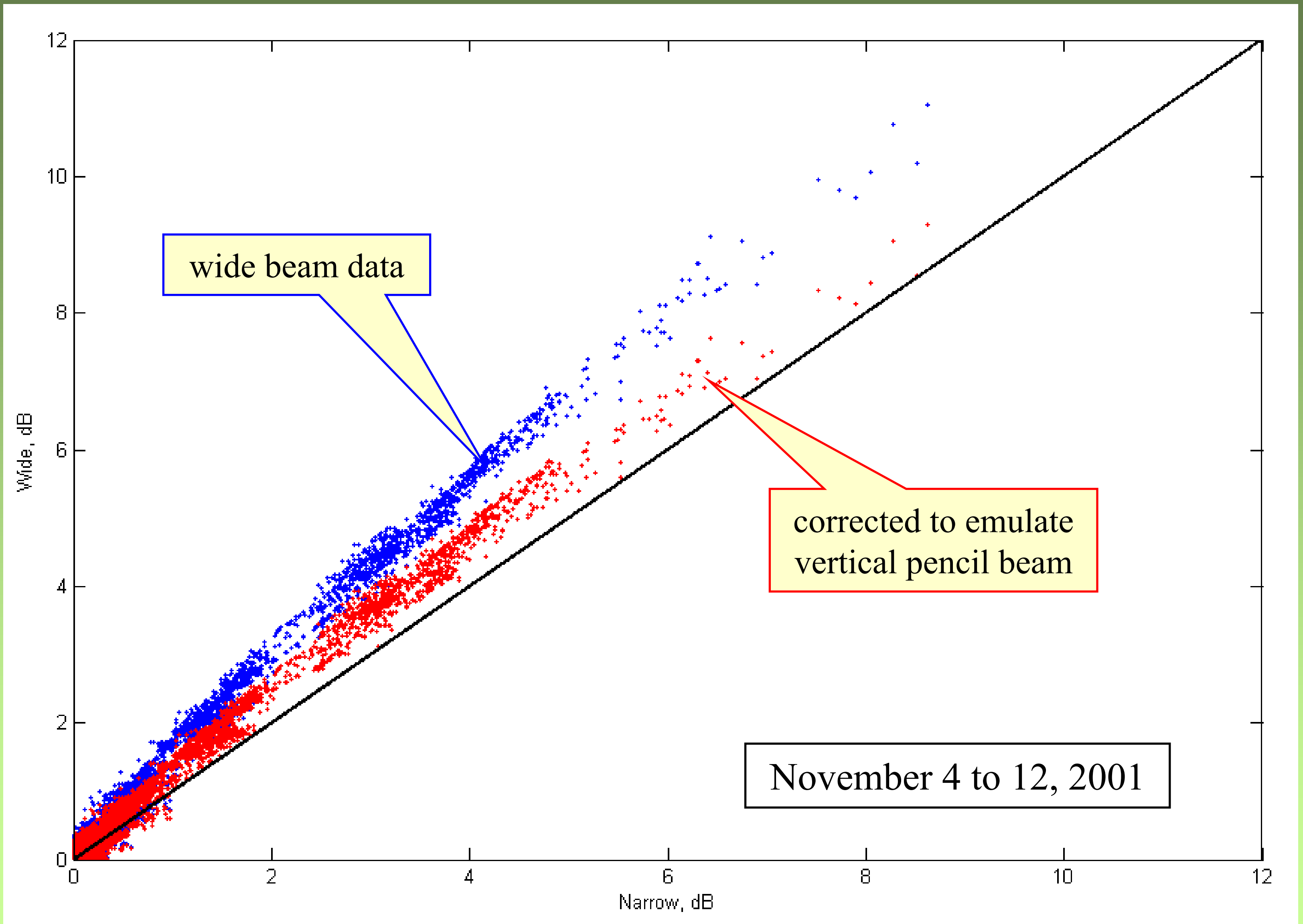


- additional absorption (<20 %) due to oblique noise contributions
- reduced effective opening angle for large absorption (collimation)

calculation for a ±30° antenna,
absorption at 90 km

All you should know about riometers



correction works to better than 20 %

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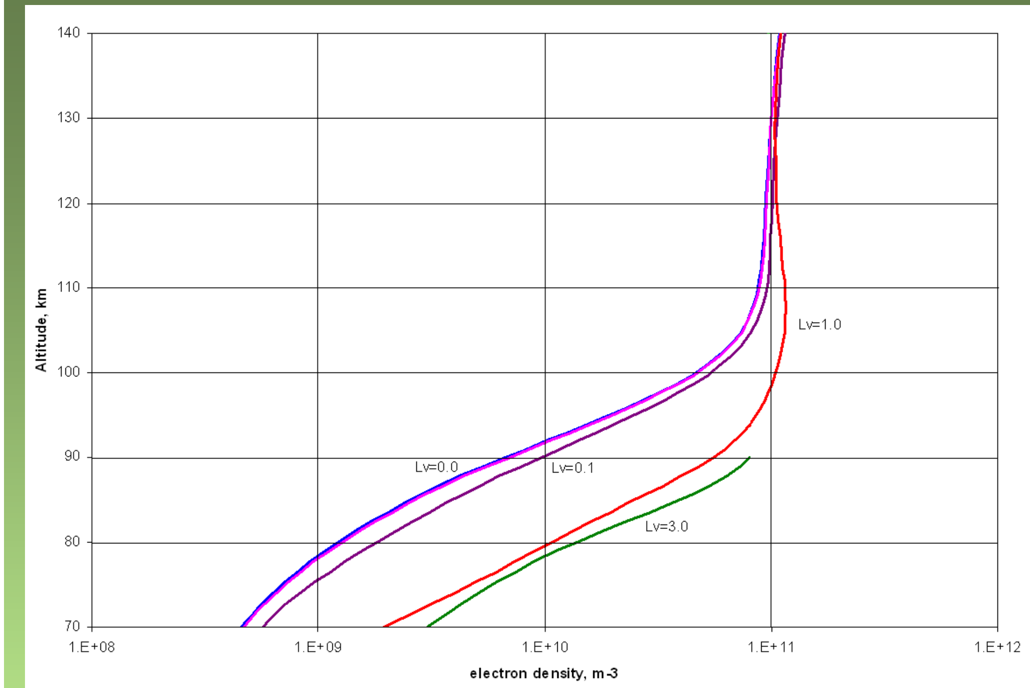
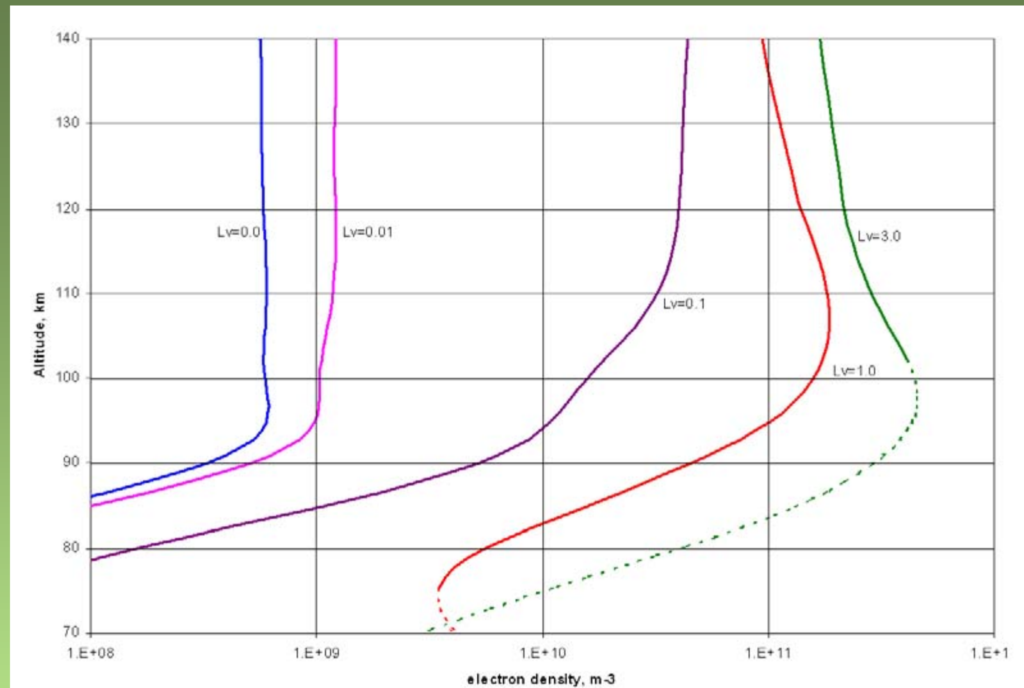


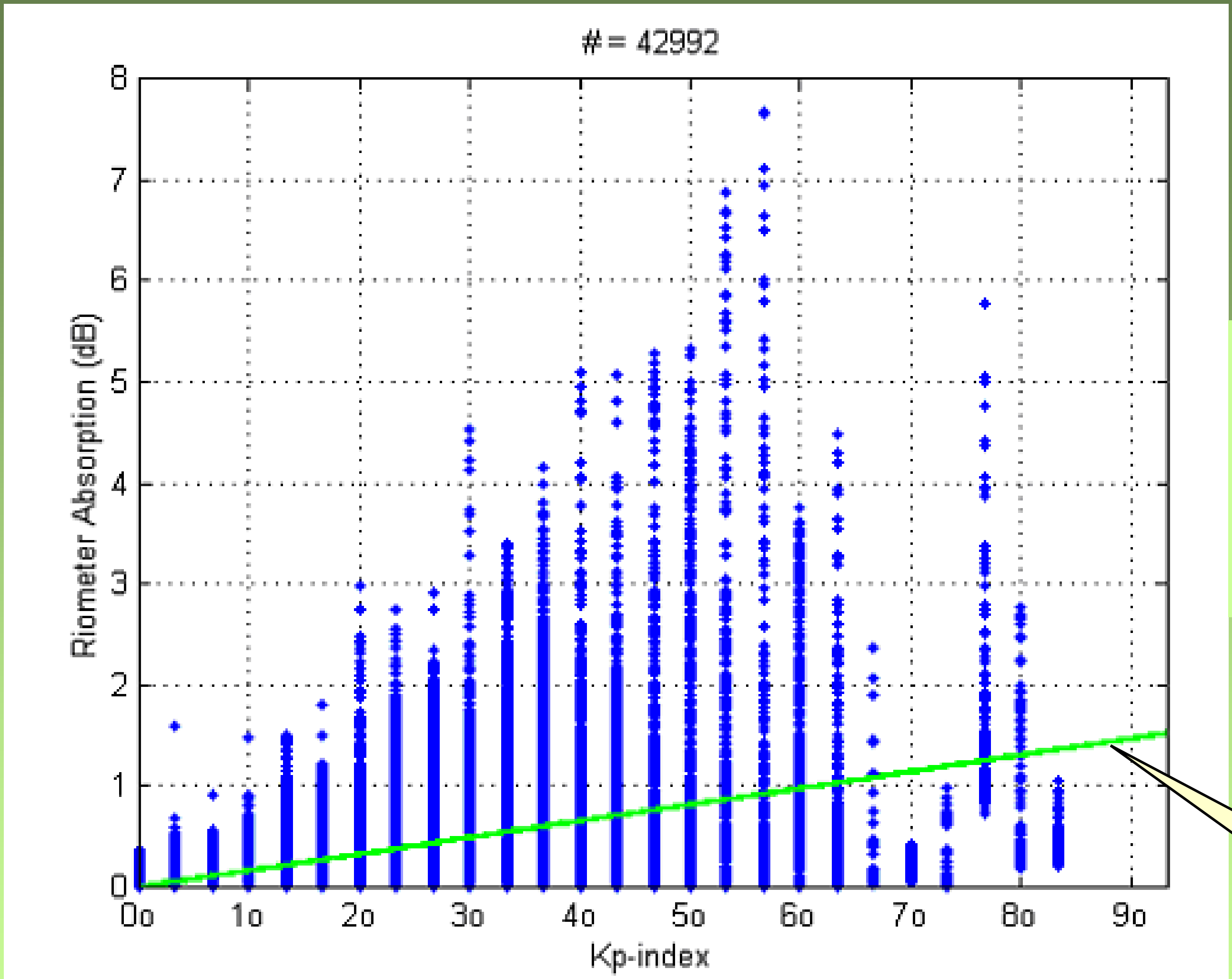


- L_R = 0.1 dB is significant at night (*i.e.*, 93·L_i, *vs*. only 1.8·L_i during the day)
- L_R not significant in the *E*-region (during the day)

median results of the empirical model IMAZ
(McKinnell and Friedrich, 2007)
K_p = 3, χ = 60°, 100°, local noon / mid-night, mid April

day & night

All you should know about riometers



- large L_R is always associated with high K_p,
- but high K_p can occur without large L_R.

best fit
(not a good fit!)

can L_R be replaced by K_p?

All you should know about riometers

- ⇒ for quantitative or synoptic studies (involving different riometers) check:
  - ⇒ *the operating frequencies*
  - ⇒ *the opening angles*
  - ⇒ *the mode (o-, x-, or both)*
- ⇒ can riometer absorption be replaced by a geomagnetic disturbance index?
  - ⇒ *definitely not*
- ⇒ does, *e.g.*, 0.1 dB mean a significantly different electron density?
  - ⇒ *yes at night, but not during the day*
- ⇒ can, say, 0.1 dB be measured?
  - ⇒ *it can be resolved, but not (reliably) measured (QDC!)*
- ⇒ is L_R a clue to the shape of the profile?
  - ⇒ *to some extent: larger* L_R *generally mean* N_e *bulges at lower altitudes*

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