Observation and Analysis of Deep Radio Occultation Signals in COSMIC

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Deep Occultation with GRAS:
[Marquqard et al., FORMOSAT-3/COSMIC User Workshop, Taipei, Apr.13-15, 2011]
Atmospheric RO signals are observed "down to -200km SLTA, everything below are PRN cross-correlations (or so weak that they cannot be observed by GRAS)"

COSMIC was set to track down to -350km on FM1 in tropics (-30 +30 deg lat.) on October 5-6, 2010. Goal: observations of deep RO signals.

This study:

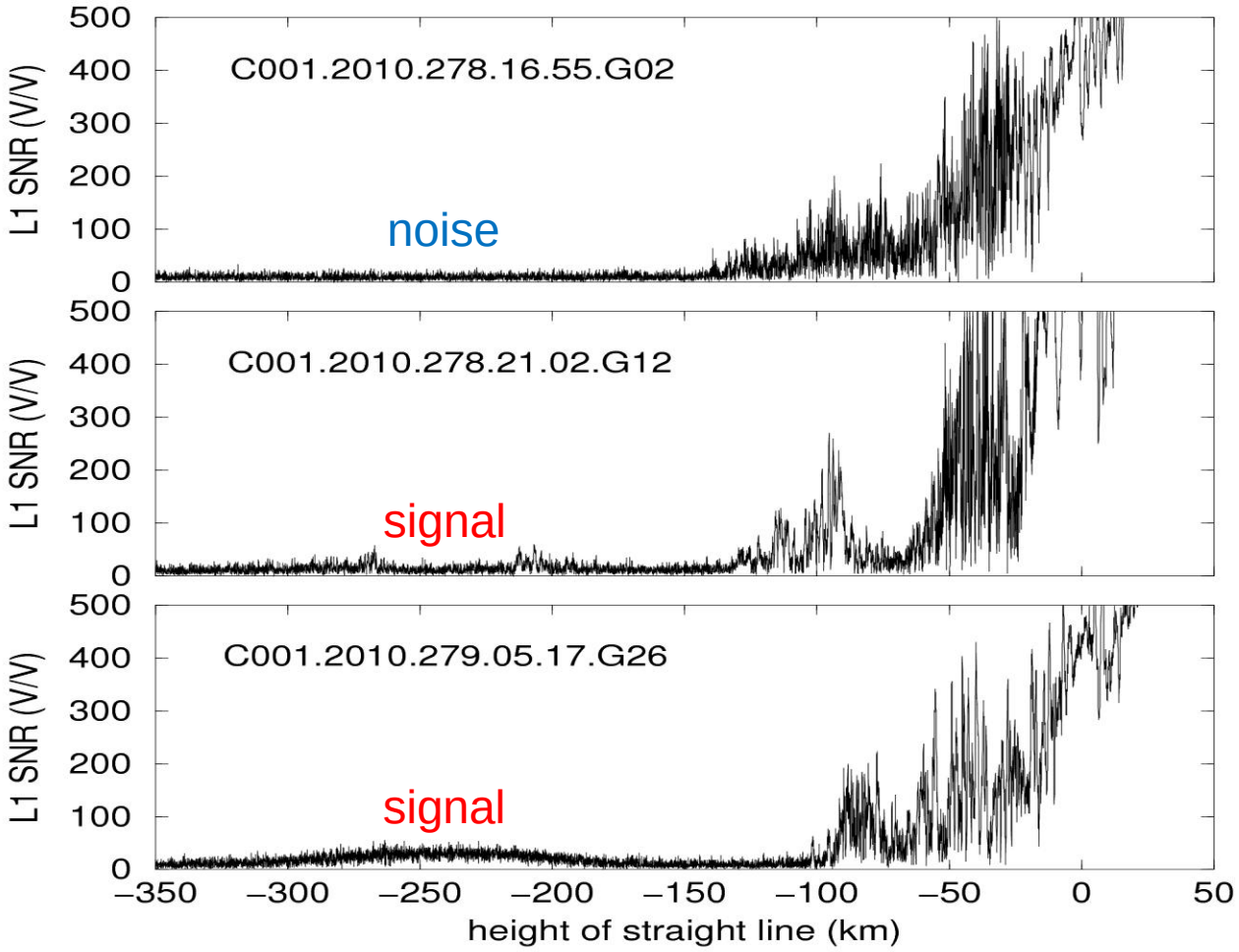
- Investigation of the information contained in deep RO signals
- Investigation of the effect of PRN cross-correlations on inversions

Selection criteria (important: NOT based on the structure of RO signals):

- setting occultations
- tracked to HSL<-350km
- Doppler miss-modeling < 10 Hz (loss < 0.6 dB)
- range miss-modeling < 50 m (loss < 0.8 dB)

Passed: 20 occultations

Examples of RO signals (amplitudes) from FM1, October 5-6, 2010



Amplitude is insufficient to understand the structure of RO signal, spectrogram is needed (also concluded by Marquardt et al., 2011)

Spectrograms of the selected RO signals

- 50 Hz sampling band does not allow to see the spectrum as well as 1 kHz

- multipath in all signals except #1, #12, #13, #19

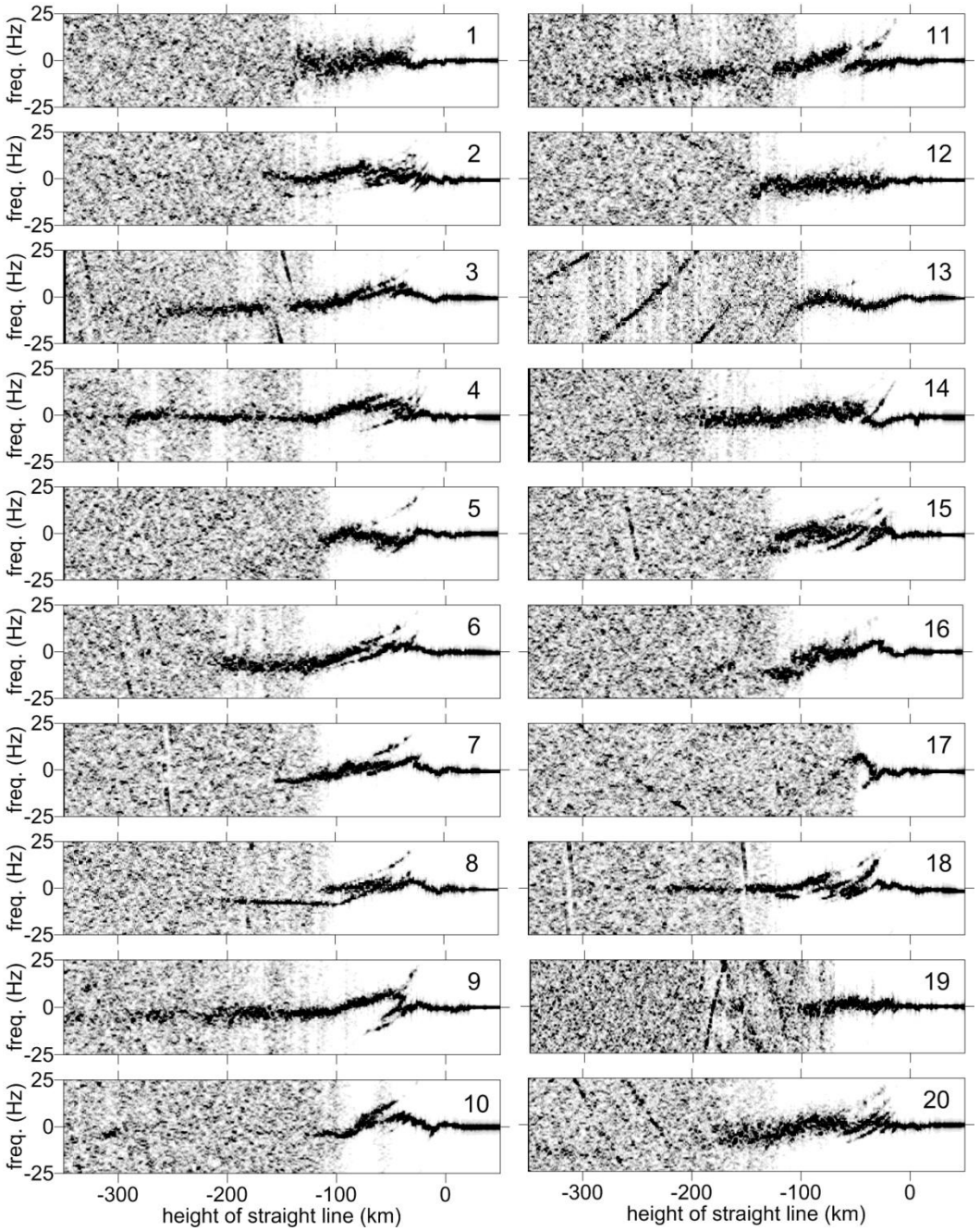
- deep atmospheric signals (-200 km or lower) in 8 occultations

- the deepest signal -300 km #4 (maybe -350 km ? #9)

- sub-refraction #14

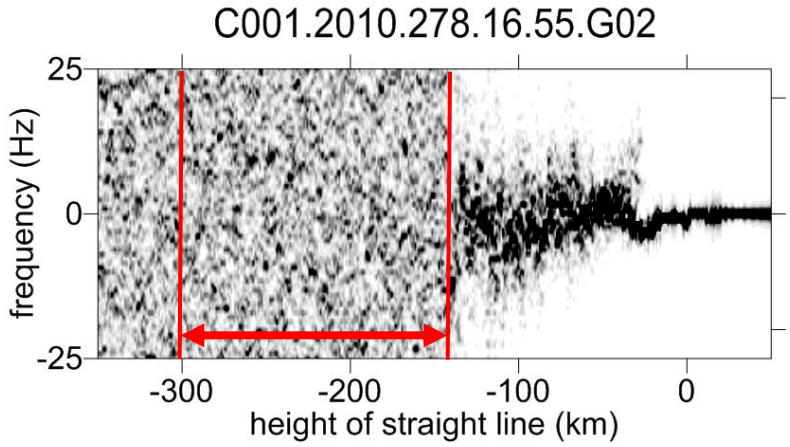
- interfering signals (start and end outside 50 Hz band) in 8 (10?) occultations

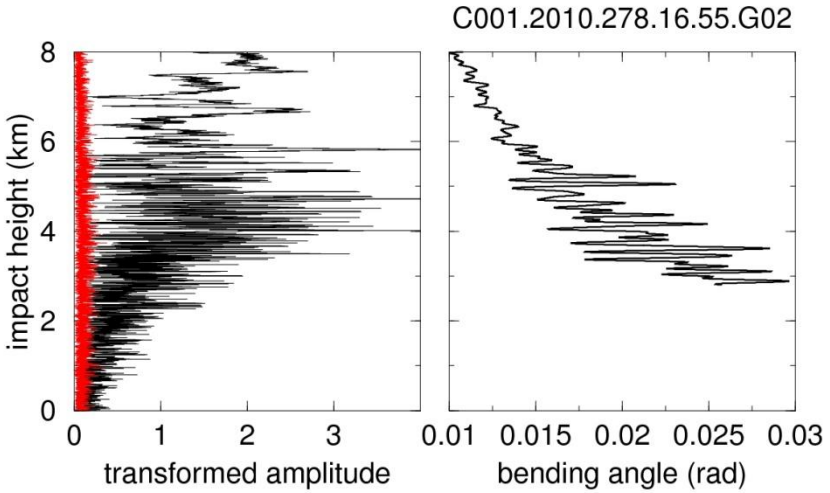
with 50 Hz sampling PRN cross-tracks must be invisible unless data modulation is removed

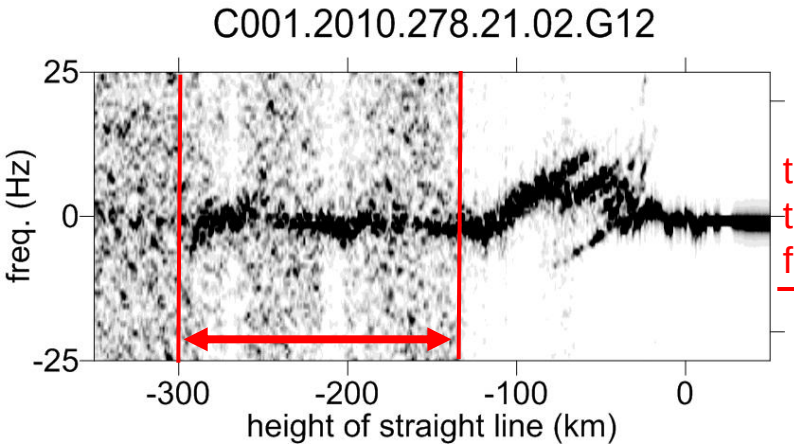


From what impact height the deep signals are arriving?

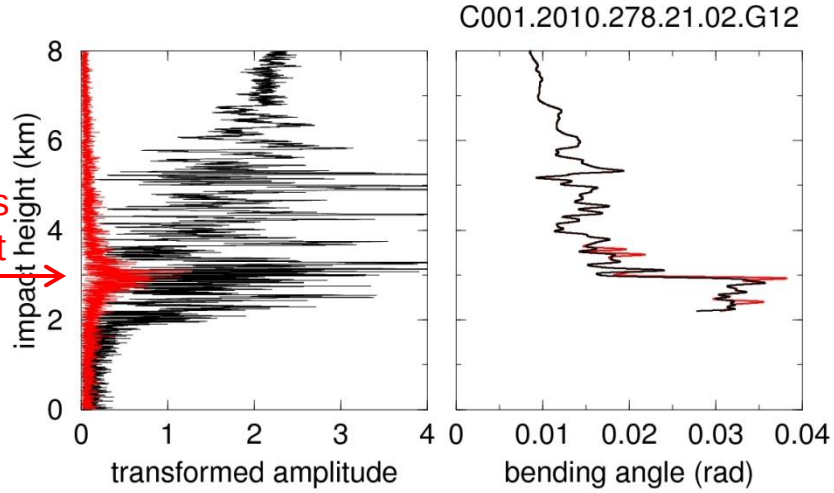
Wave optics transforms of the full RO signal and the "tail" only



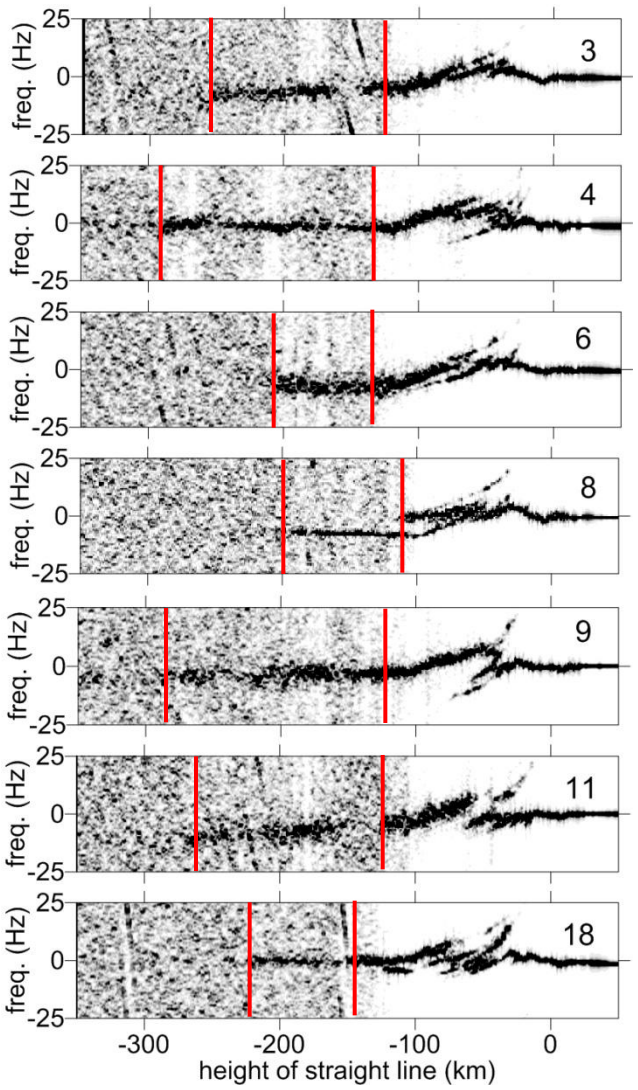


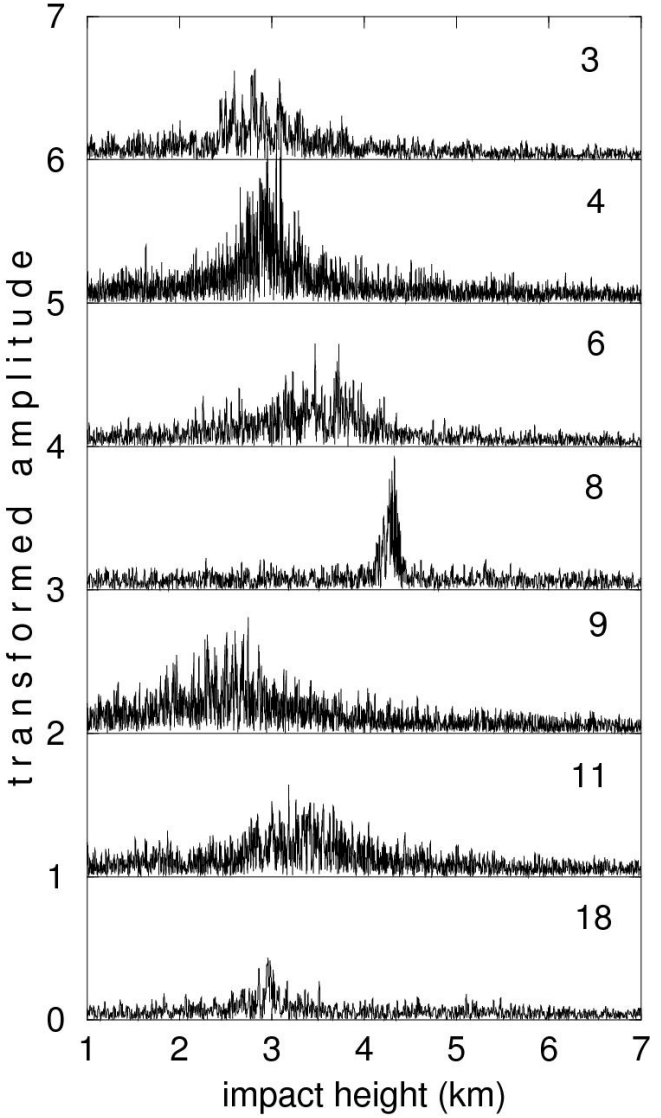


the signal from the "tail" arrives from this height



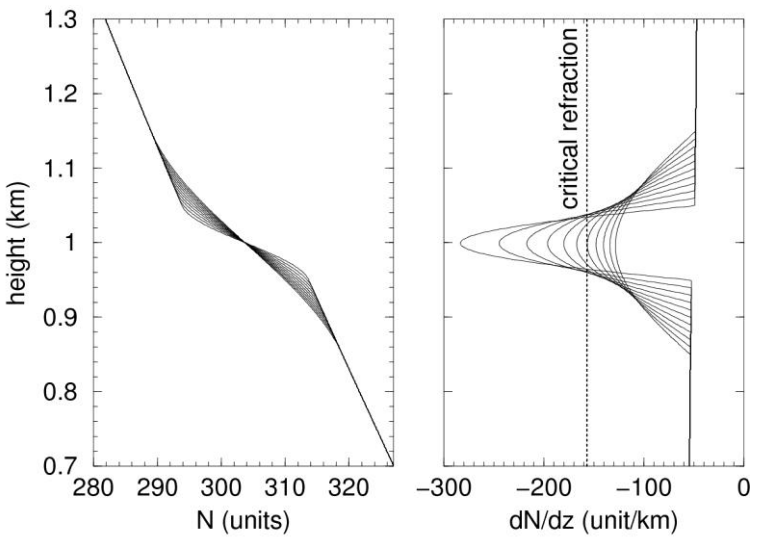
Impact heights of the deep RO signal "tails" observed down to -200 km and below

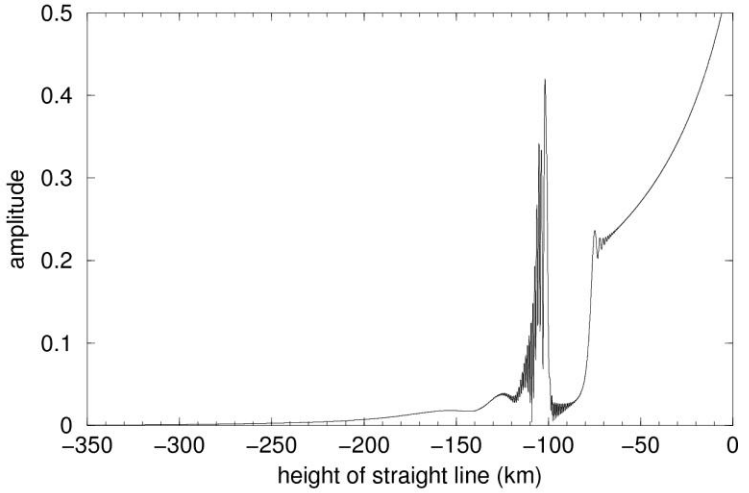


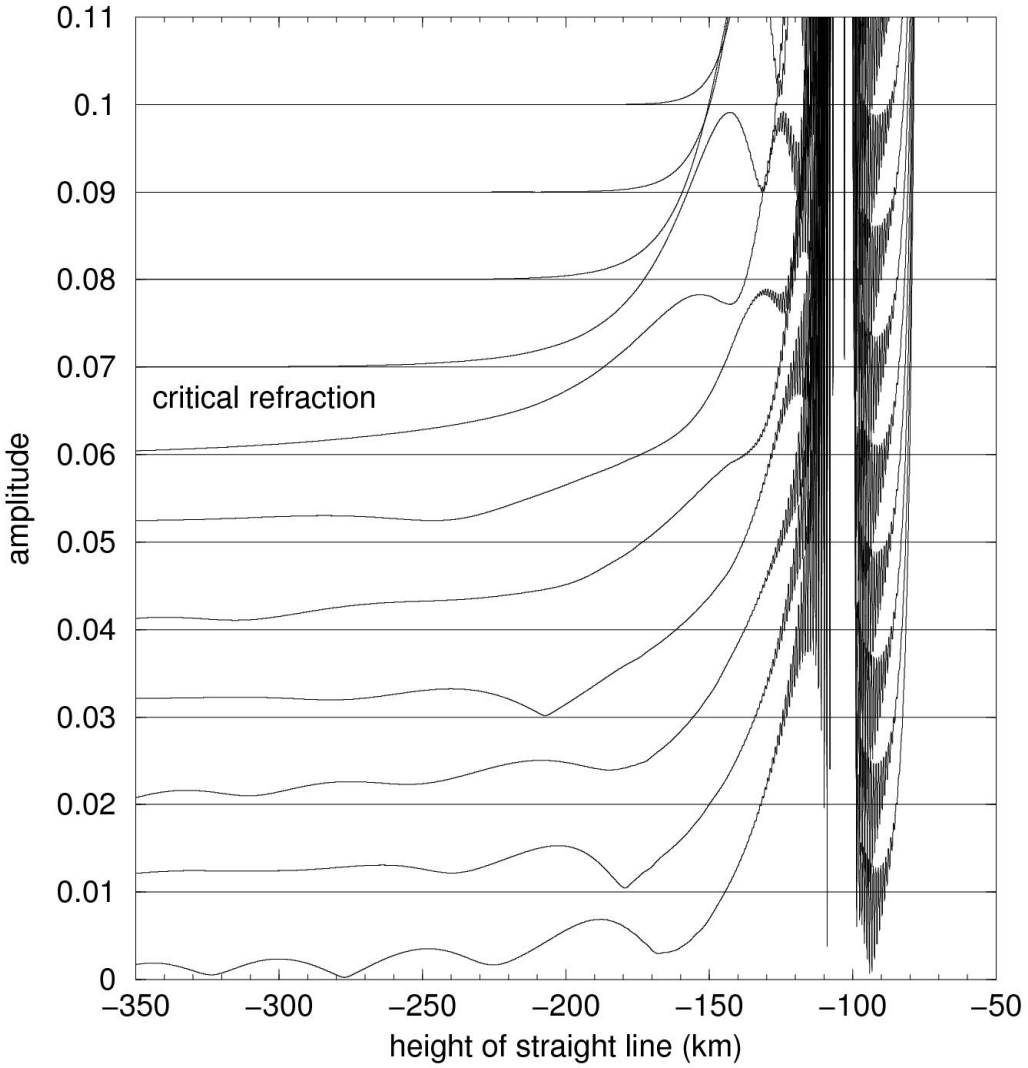


Wave optics modeling of RO signal in the presence of strong inversion layer

- when N-gradient exceeds critical, the deep "tail" of RO signal appears
- this can be used as the indicator of super-refraction
- for reliable detection requires 1-Hz SNR~2000 V/V

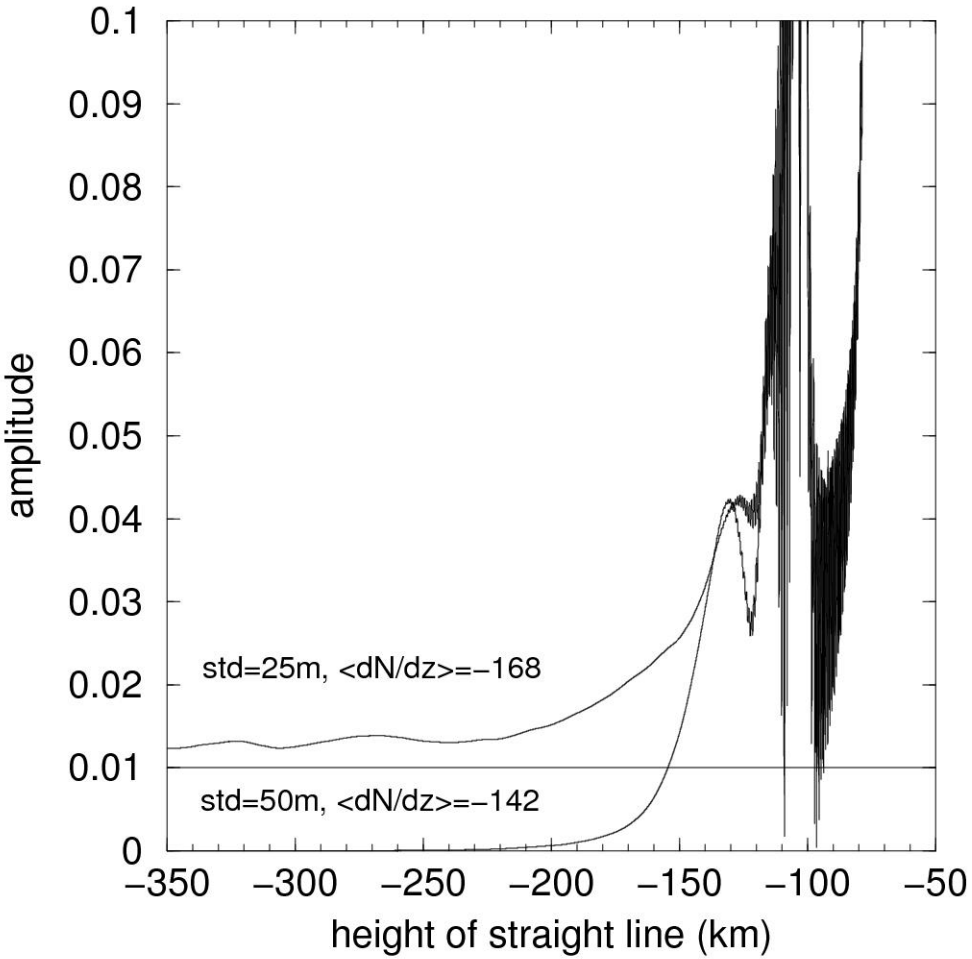


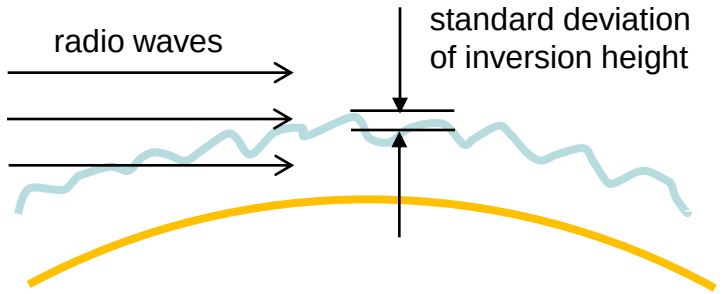


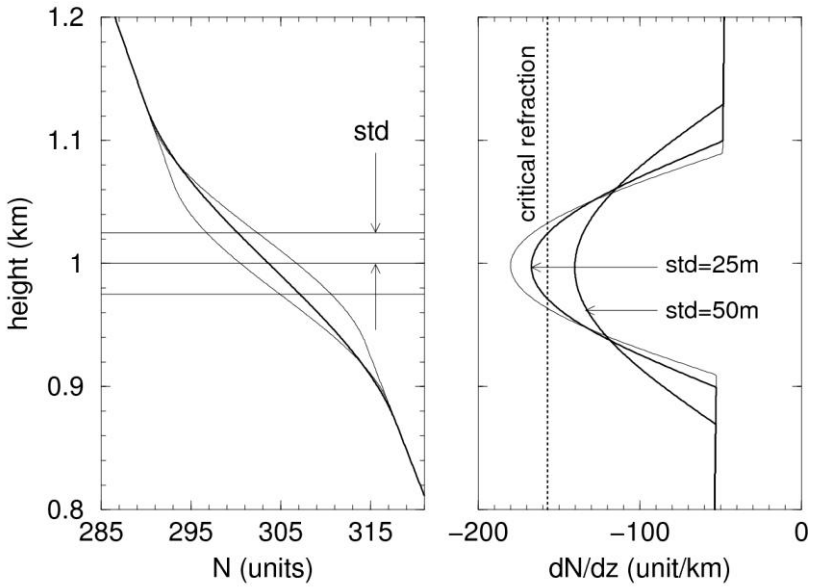


Effect of "bumpiness" of the inversion layer on deep RO signal "tail"

- the local N-gradient in inversion layer may exceed critical
- fluctuation of the inversion height reduces the mean N-gradient
- if the mean N-gradient **>** critical, then "tail" exists
- if the mean N-gradient **<** critical, then no "tail"

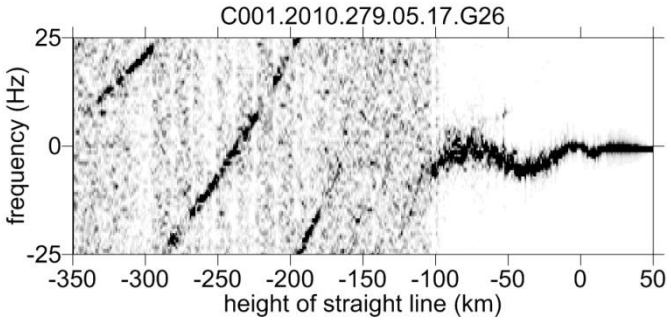


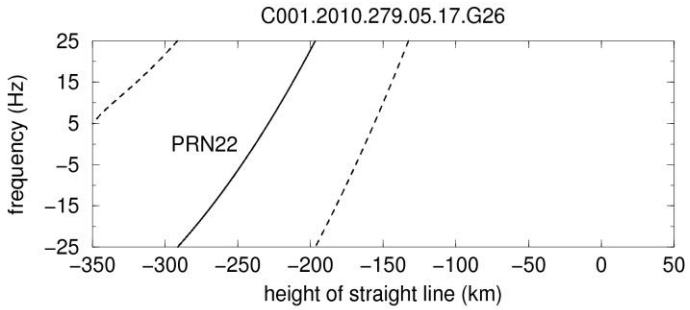


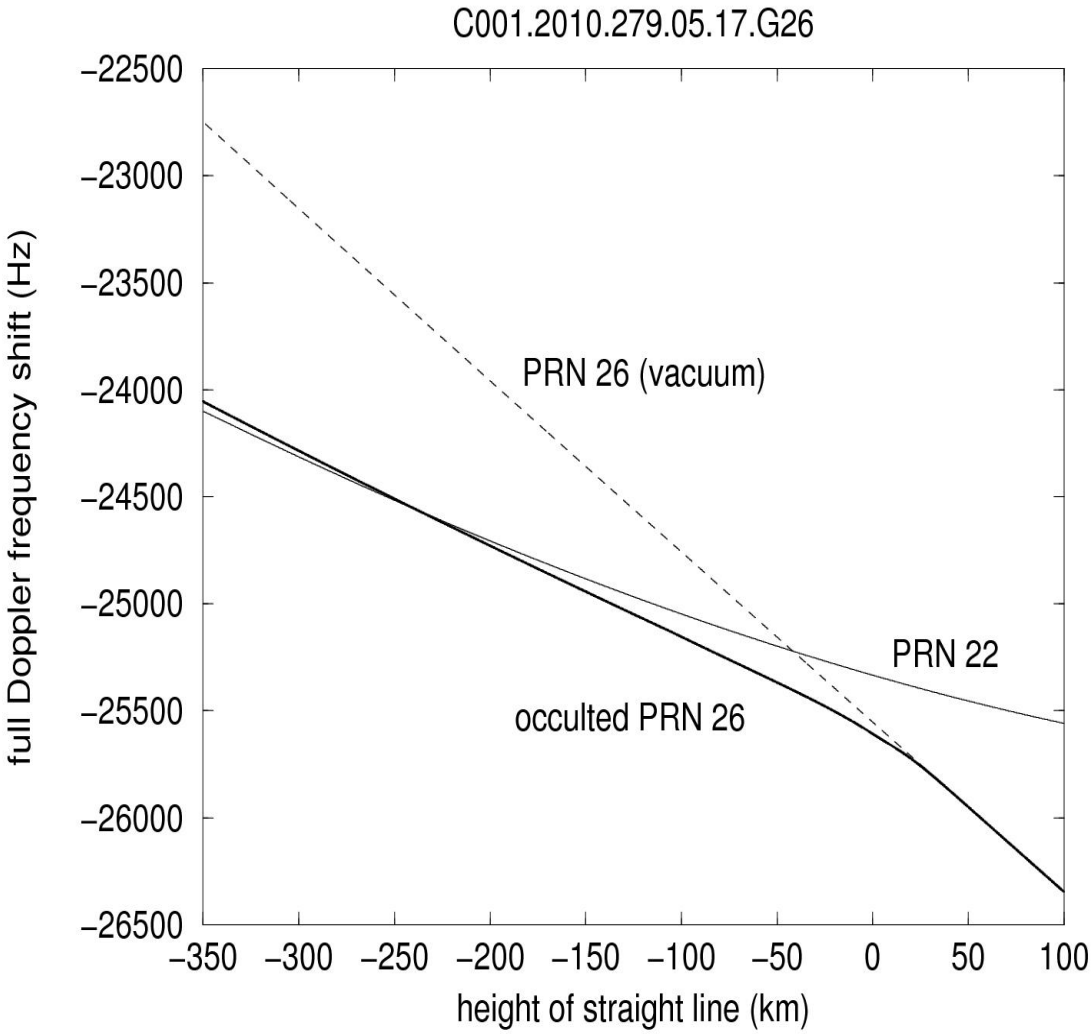


Interfering signals

- signals from non-occulted PRN are about -24dB (C/A code cross-correlation)
- non-occulted PRN cross-tracks are invisible in 50Hz RO spectrograms unless data modulation is correlated with the occulted PRN (spectrum is de-spread)
- for all selected occultations Doppler tracks for all PRN were calculated
- only one interfering signal was identified as the PRN cross-track







Interfering signals (cont.)

Mapping of RO signal from
time - frequency to
bending angle - impact parameter
representations (geometric optics):

$$f_d = (\vec{k}_2\vec{v}_2 - \vec{k}_1\vec{v}_1)/2\pi$$

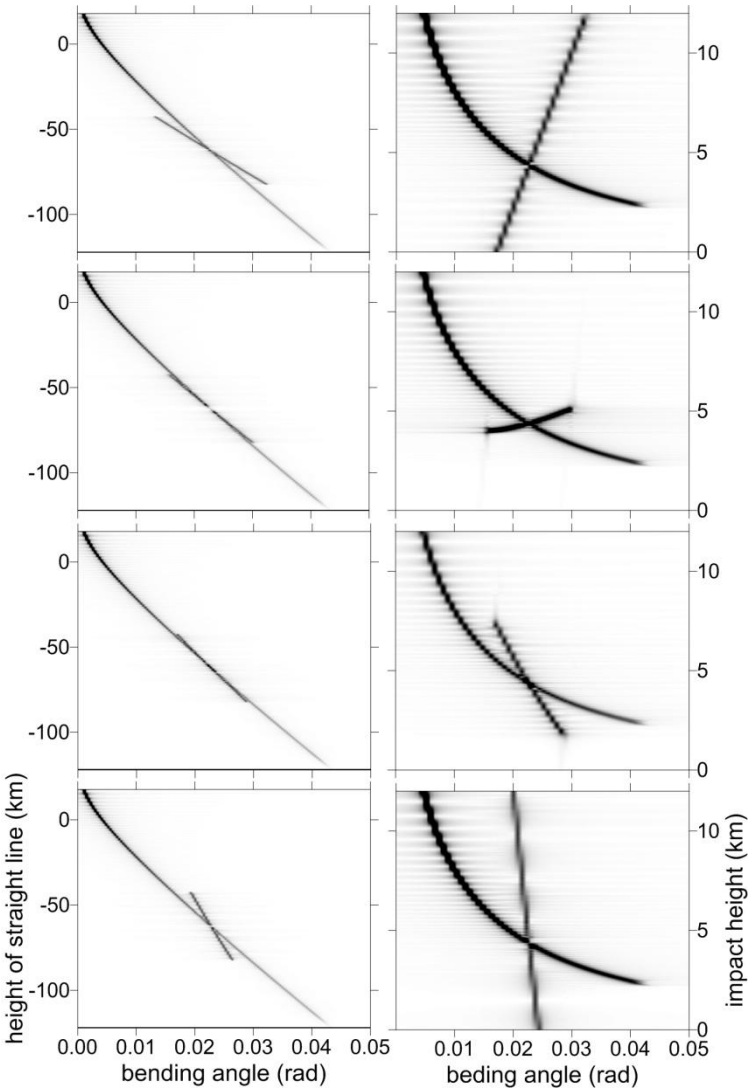
$$a = r_1 \sin\phi_1 = r_2 \sin\phi_2$$

$$\alpha = \phi_1 + \phi_2 + \theta - \pi$$

Special case: plane wave,
straight-line orthogonal
observation trajectory

$$f_d = f_c v c^{-1} \sin\alpha$$

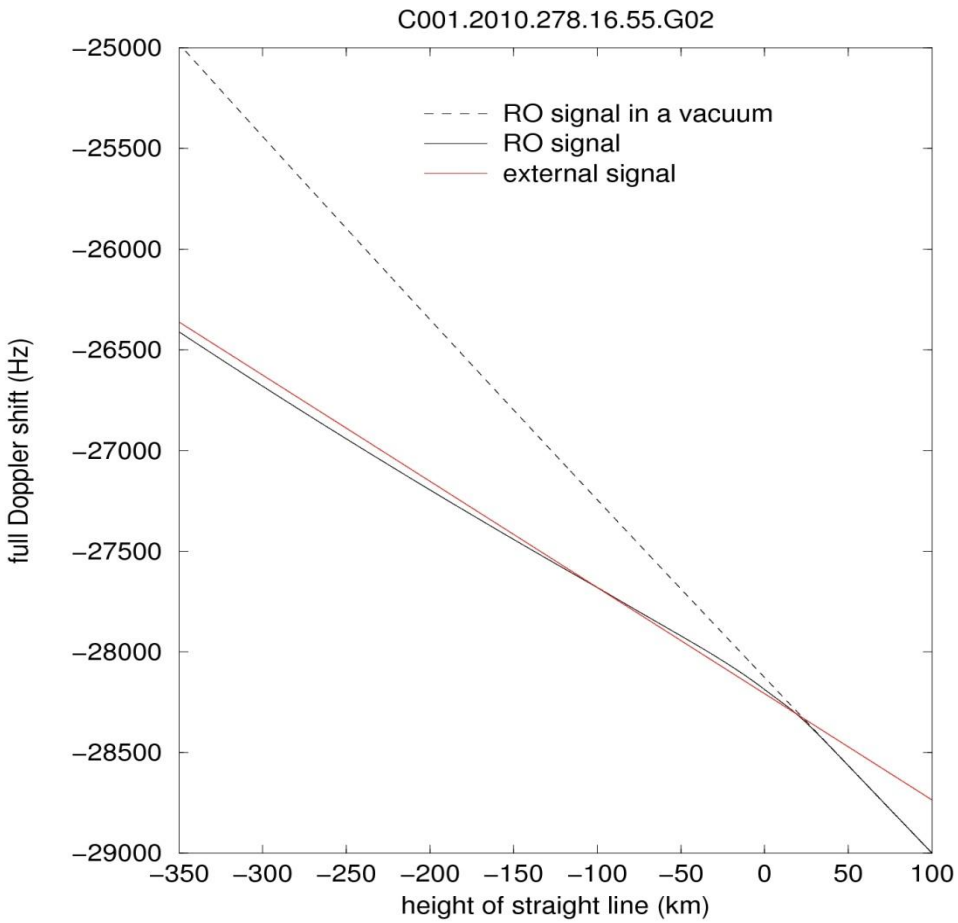
$$a = r\sin(\psi + \alpha)$$

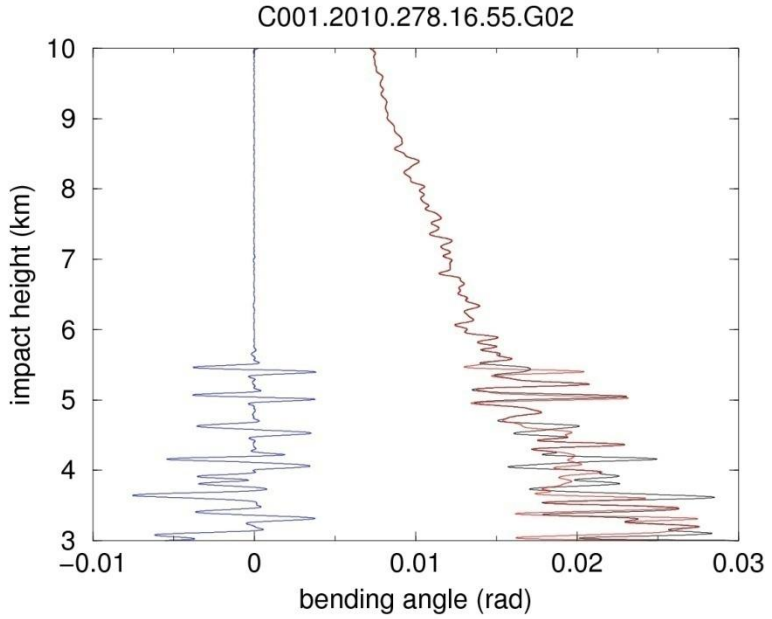


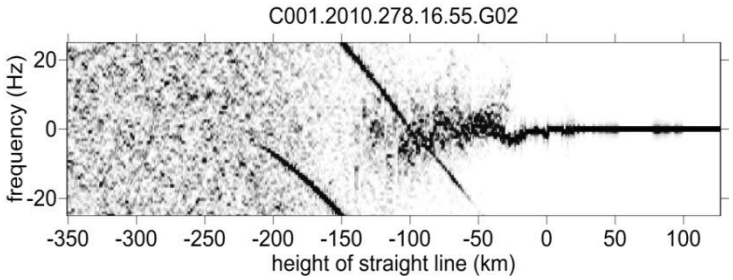
RO inversion errors introduced by interfering signals from other PRN

may happen when:

- the spectrum of WO-transformed RO signal is broad (tropics, convection)
- the interfering signal stays close in frequency in the interval corresponding to propagation in LT (the interval of max. convexity of the full RO Doppler)
- the data modulations on occulted and interfering signals are correlated
- can this probability be significant?







Summary

1) With COSMIC receiver (phase & delay in open loop mode) and antenna, deep RO signals in tropics were observed down to -300 km (in 40% cases: down to or below -200 km).

2) Signals induced by tropospheric propagation are clearly distinguished from interfering signals in the spectrograms.

3) Deep "tails" of RO signals can be used as an indicator of the super-refraction, an important QC flag for data assimilation. For reliable detection of the deep RO signals, the SNR of ~2000 V/V is needed.

4) Interfering signals from other PRNs (-24dB) may introduce significant inversion errors in the tropical occultations with spread spectrum, if they stay close in frequency for extended time and have same or correlated data modulation.

5) One interfering signal was identified as PRN cross-correlation; other signals not identified - this needs further investigation.