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Atmospheric density, pressure and temperature profile reconstruction from refractive angle measurements in stellar occultation

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Introduction

- We have studied possibility of atmospheric density, pressure and temperature reconstruction from refractive angle measurements in stellar occultation
- Stellar occultation instruments have high pointing accuracy and they follow point−like sources ⇒ direct accurate measurements of the refractive angle
- Part of ESA project SARFOI ; FMI−SSF−ESA−TERMA
- Goals:
  - ➢ Development of model and inversion algorithm
  - ➢ Assessment of possible error sources and sensitivity of the retrieval to them
  - ➢ To derive pointing accuracy requirements for temperature profiling with accuracy 1−2 K and vertical resolution 1−2 km (for COALA instrument)
  - ➢ Analyze the accuracy attainable in temperature profiling with GOMOS instrument

Stellar occultation measurements

- Altitude range 120−10 km
- Reference point at the altitude ~ 120 km
- Pointing system: scanning mirror + star tracker
- Sampling frequency of refractive angle measurements ~ 100Hz
- Wavelength range photometers
  - *GOMOS 625−950 nm*
  - *COALA 675−775 nm*
- Instrumental noise
  - *Random component*
  - *Harmonic component*

	GOMOS	COALA
Instrumental noise at 2 Hz	2.75 μrad	1−2 μrad
Signal−to−noise ratio at 40 km	16.7	23−46

Forward model

density profile $\Rightarrow$ ***refractive angle***

Assumptions:

- Dependence of the refractive index on the wavelength (Edlen formula)

$$n = 1 + C(\lambda)\frac{\rho}{\rho_0}$$

- Spherical symmetry assumption

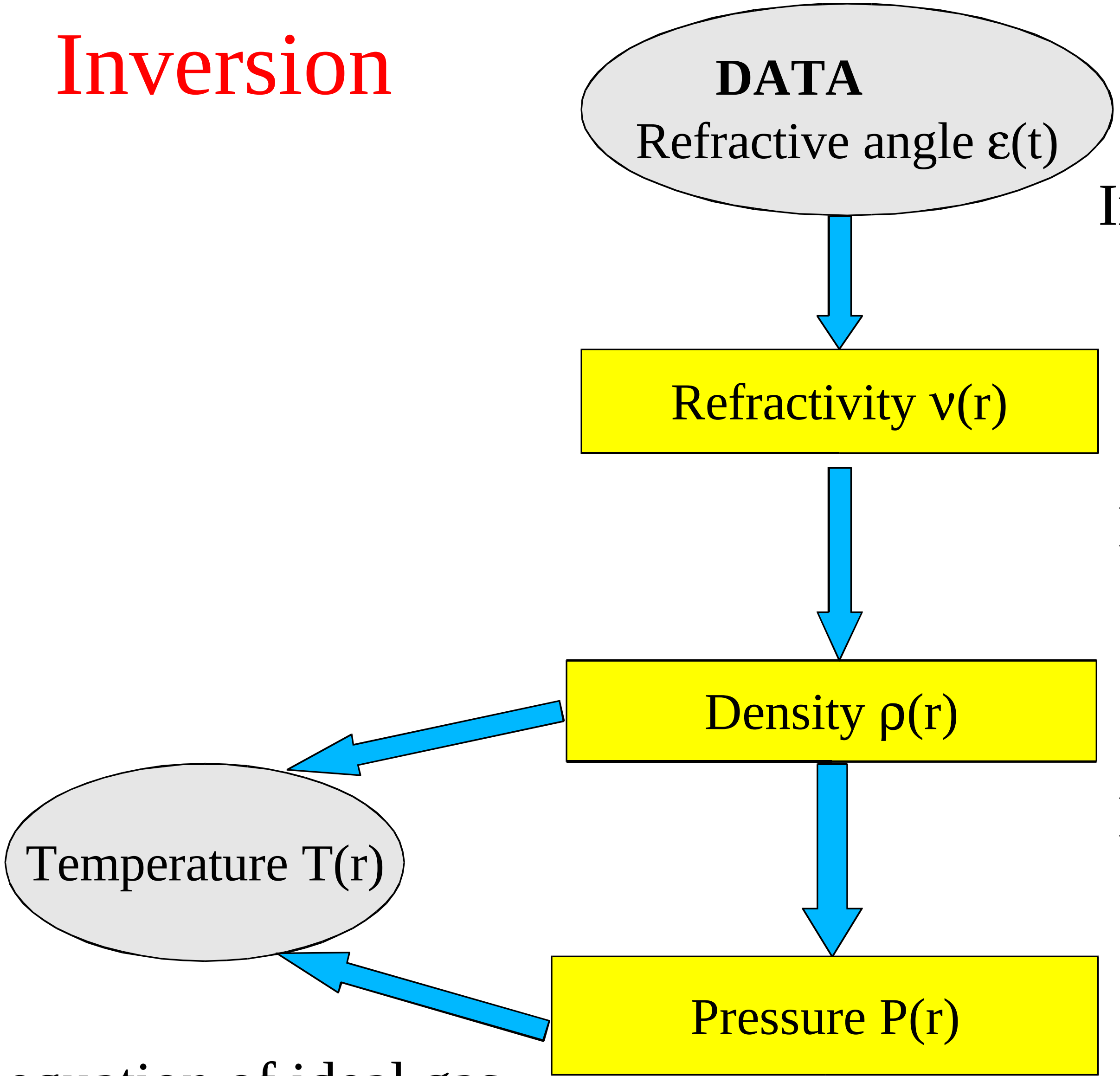
Refractive angle

$$\varepsilon = -2\int_{r_t}^{\infty}\frac{d(\ln n)}{dr}\frac{a\,dr}{\sqrt{n^2r^2 - a^2}}$$

Error of forward model

< 0.1 K in temperature reconstruction

Inversion



Inverse Abel transform

$$\varepsilon(a) = -\int_a^{\infty} \frac{2a \ln(n(z))' dz}{\sqrt{z^2 - a^2}}$$

Edlen formula

$$\rho(r) = \frac{\rho_0}{C(\lambda)}(n(r) - 1)$$

Hydrostatic equation

$$P(r) = \int_r^{\infty} g(x)\,\rho(x)\,dx$$

State equation of ideal gas

$$T(r) = k\frac{P(r)}{\rho(r)}$$

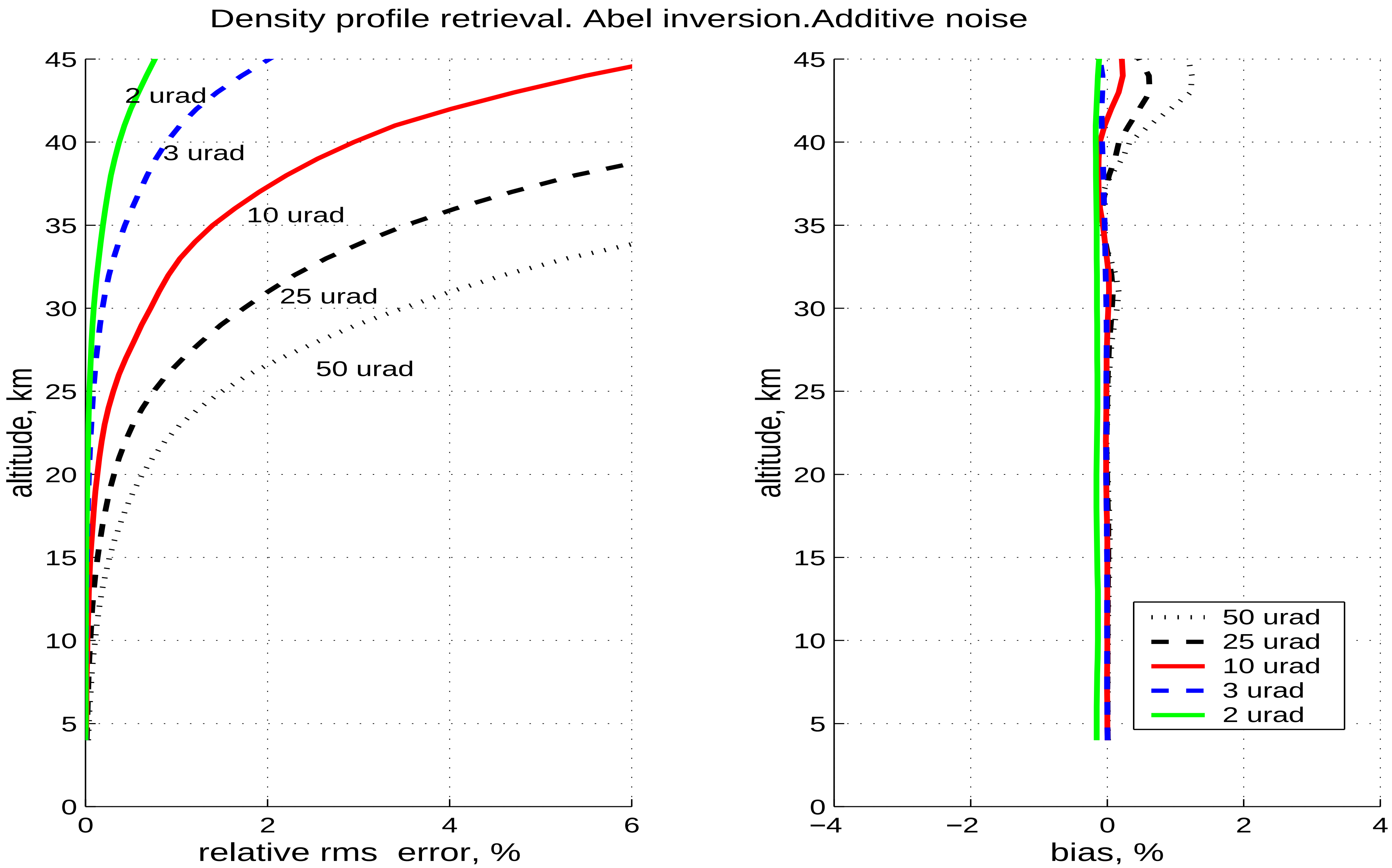
Error analysis

- Error analysis: Monte−Carlo simulation
- Instrumental noise : additive Gaussian noise
- Inversion statistics:
  - *rms error (from true value)*
  - *bias*

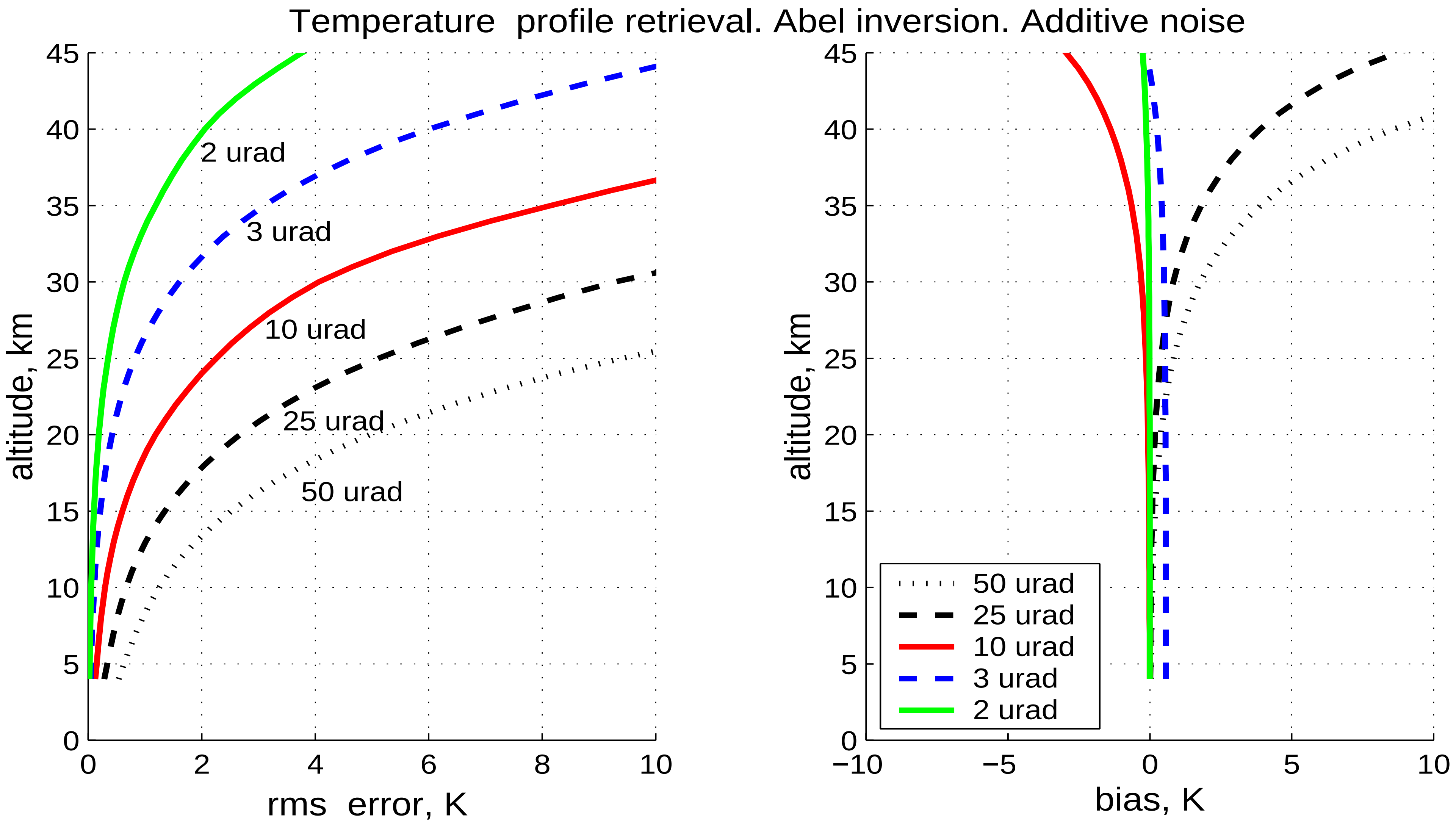
Error sources

- Instrumental error
- Sampling frequency of measurements
  - *vertical resolution*
  - *accuracy of retrieval*
- Chromatic smoothing < 0.01 K
- Scintillation effect < 0.1 K

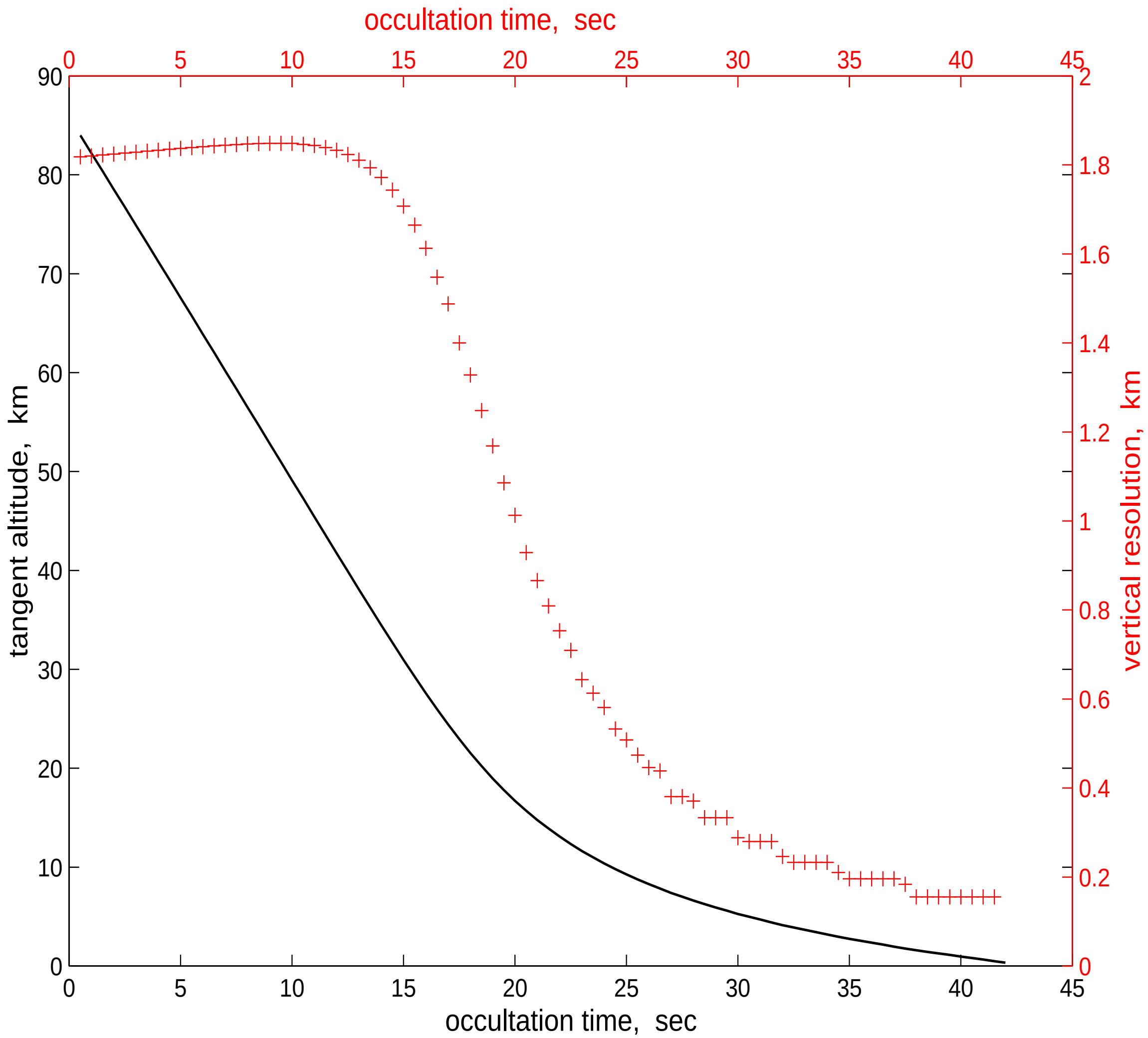
Instrumental error. Density profile retrieval



Instrumental error.Temperature profile retrieval



Sampling frequency of measurements. Vertical resolution



Sampling frequency	*Vertical sampling resolution*	
	High altitudes	*Mean*
200 Hz	18.4 m	**11.4 m**
100 Hz	37 m	**23 m**
50 Hz	74 m	**46 m**
20 Hz	185 m	**114 m**
10 Hz	369 m	**228 m**
2 Hz (0.5s)	1.8 km	**1.14 km**

The effect of smoothing before inversion

Considered cases

- 21 µrad at 100 Hz
- 3 µrad at 2 Hz
- 3 µrad at 100 Hz

Questions

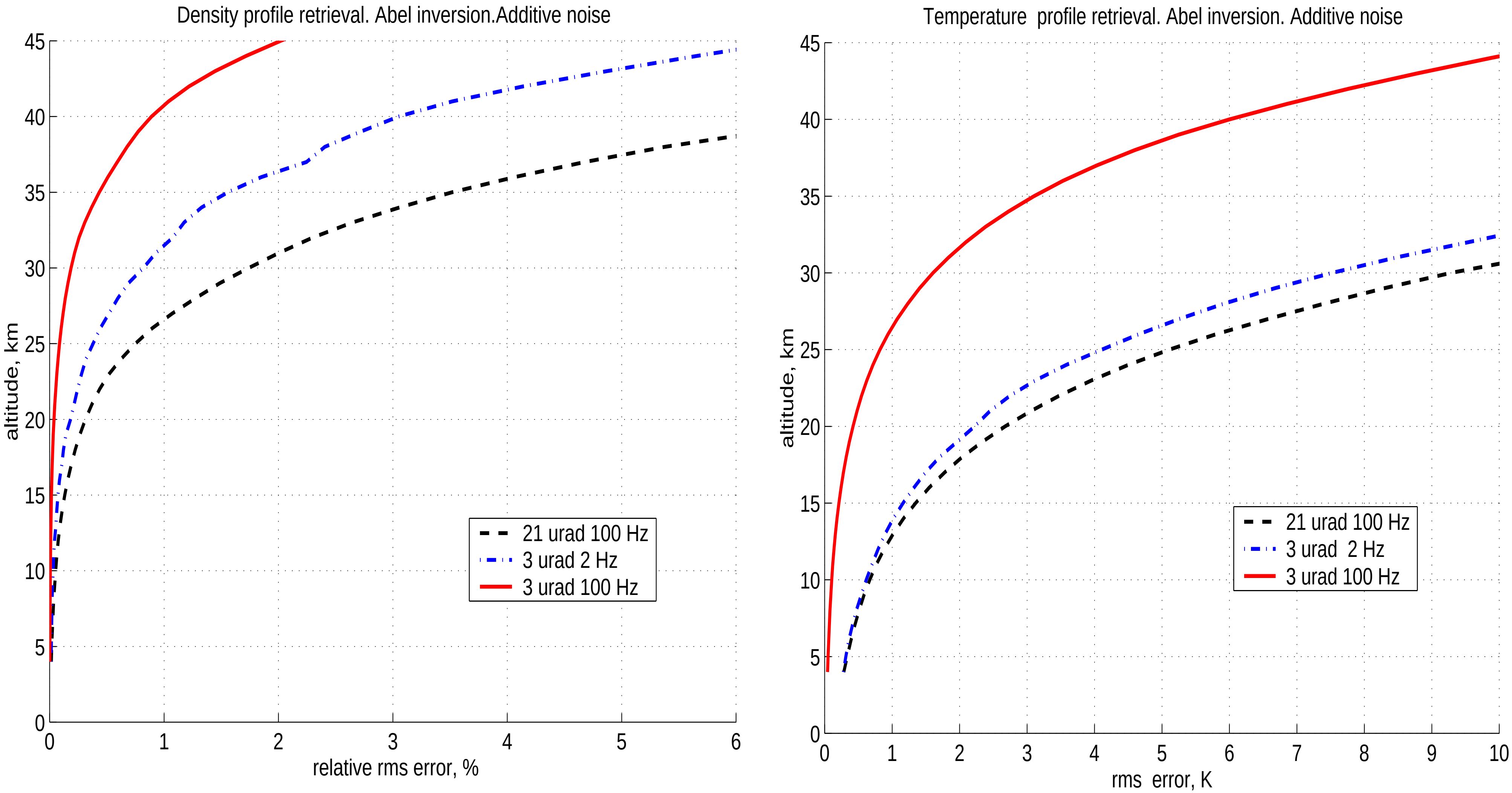
- An advantage of smoothing prior to the inversion (compare cases

21 µrad @ 100Hz and 3 µrad@2 Hz)

- Smoothing properties of the inversion procedure

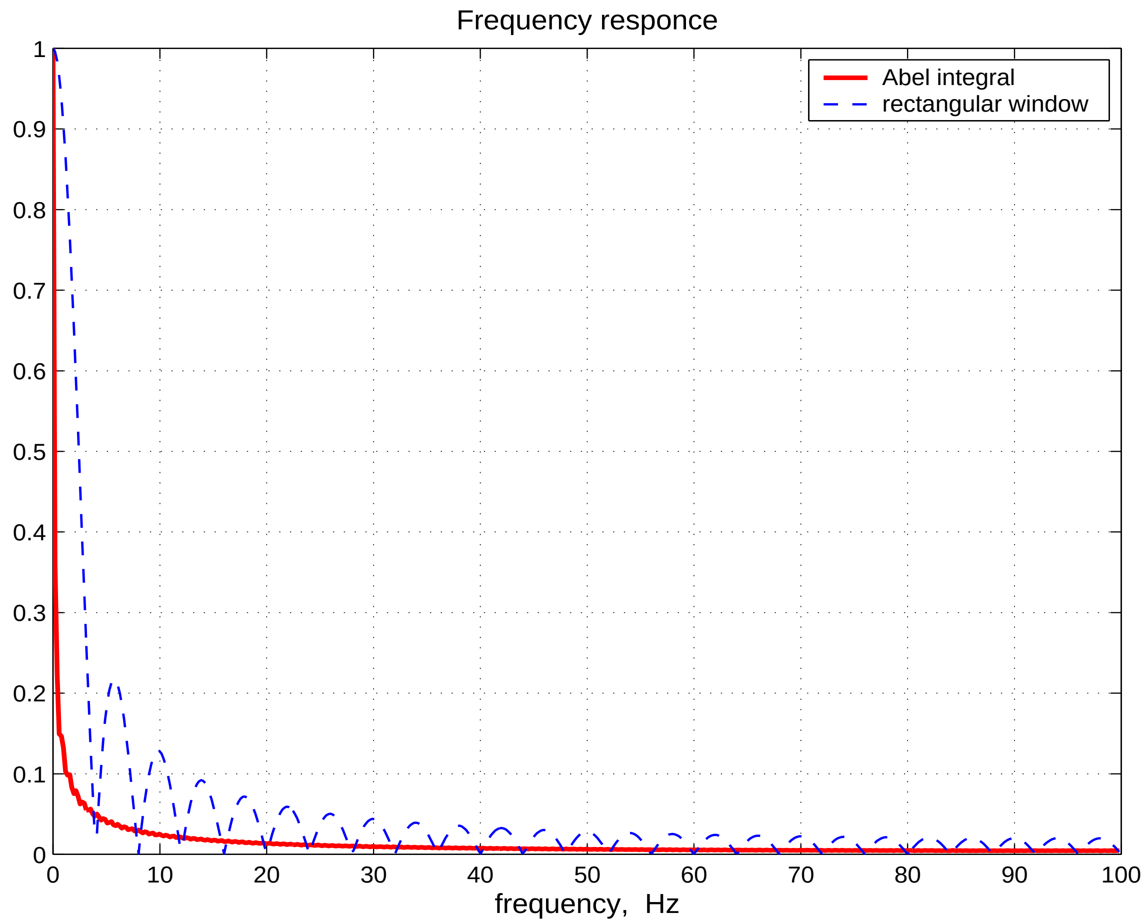
(cases 3 µrad @2 Hz and 3 µrad @ 100 Hz)

The effect of smoothing prior to inversion



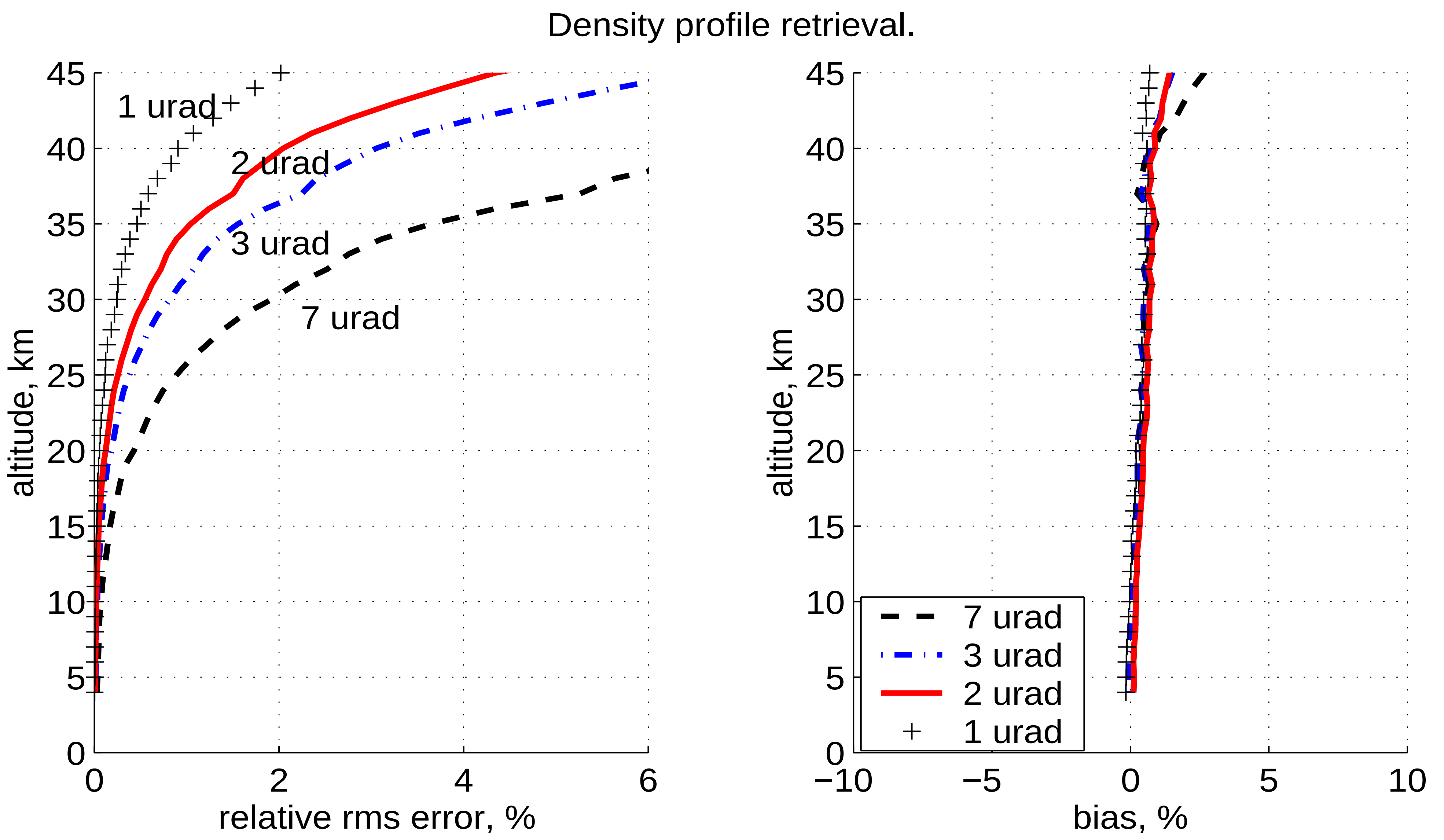
Smoothing properties of inversion

- Temperature reconstruction contains two smoothing procedures
  - *Abel inversion*
  - *integration in the pressure reconstruction*

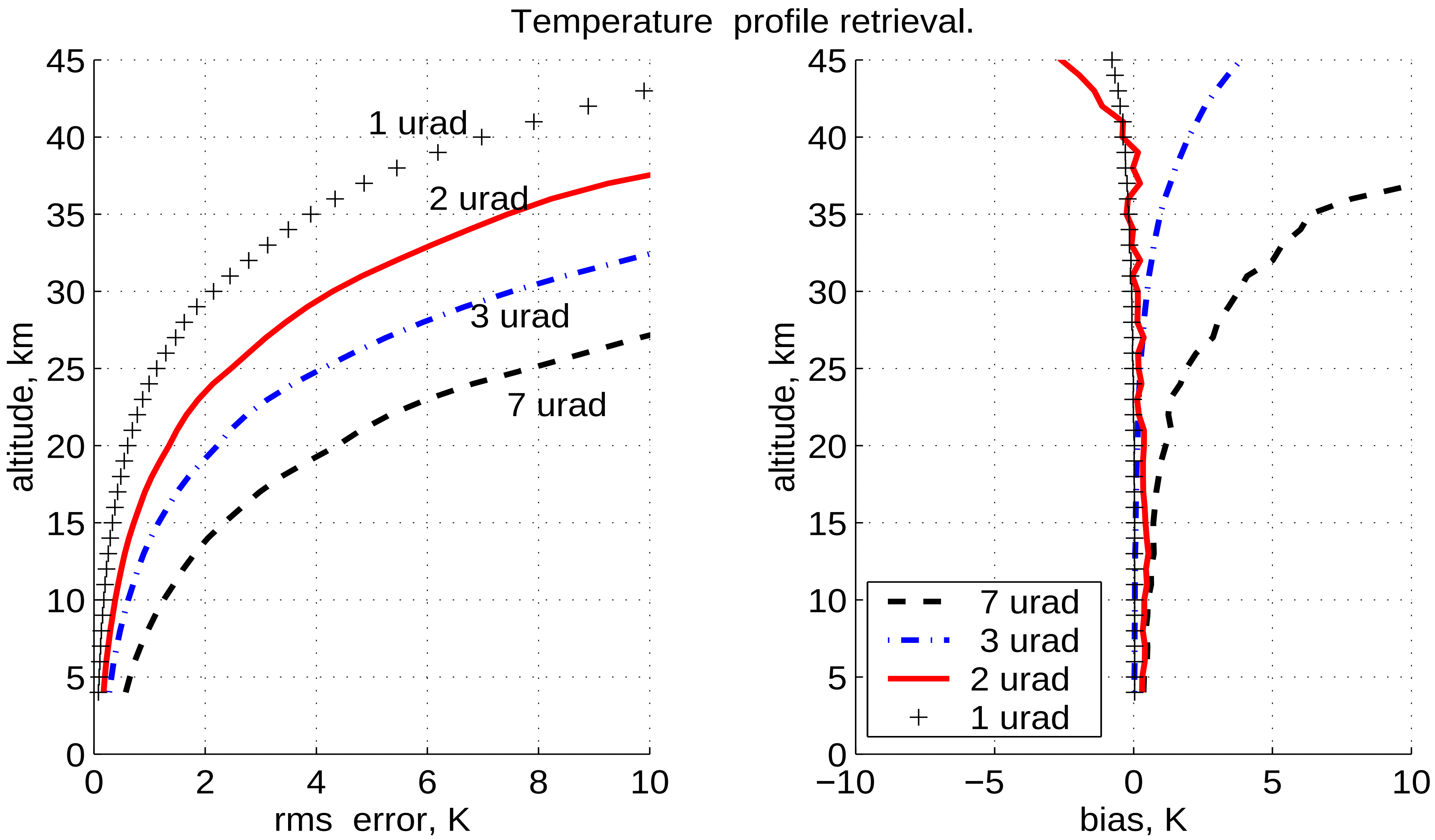


Frequency response of Abel integral

Accuracy of density retrieval at 2 Hz sampling frequency



Accuracy of temperature retrieval at 2 Hz sampling frequency



Summary

- The main source of error in temperature and density retrieval is the non−accurate measurements of the refractive angle.
- Both instrument noise level and sampling frequency of measurements are very important for retrieval.
- In order to obtain the temperature profile with accuracy of 1−2 K and vertical resolution 1−2 km for altitudes up to 35−40 km the refractive angle should be measured with accuracy better than

1 μrad at 2 Hz sampling frequency

- Reality for stellar occultation : temperature profiling with accuracy 2 K up to
  - GOMOS: 22 km
  - COALA: 30 km