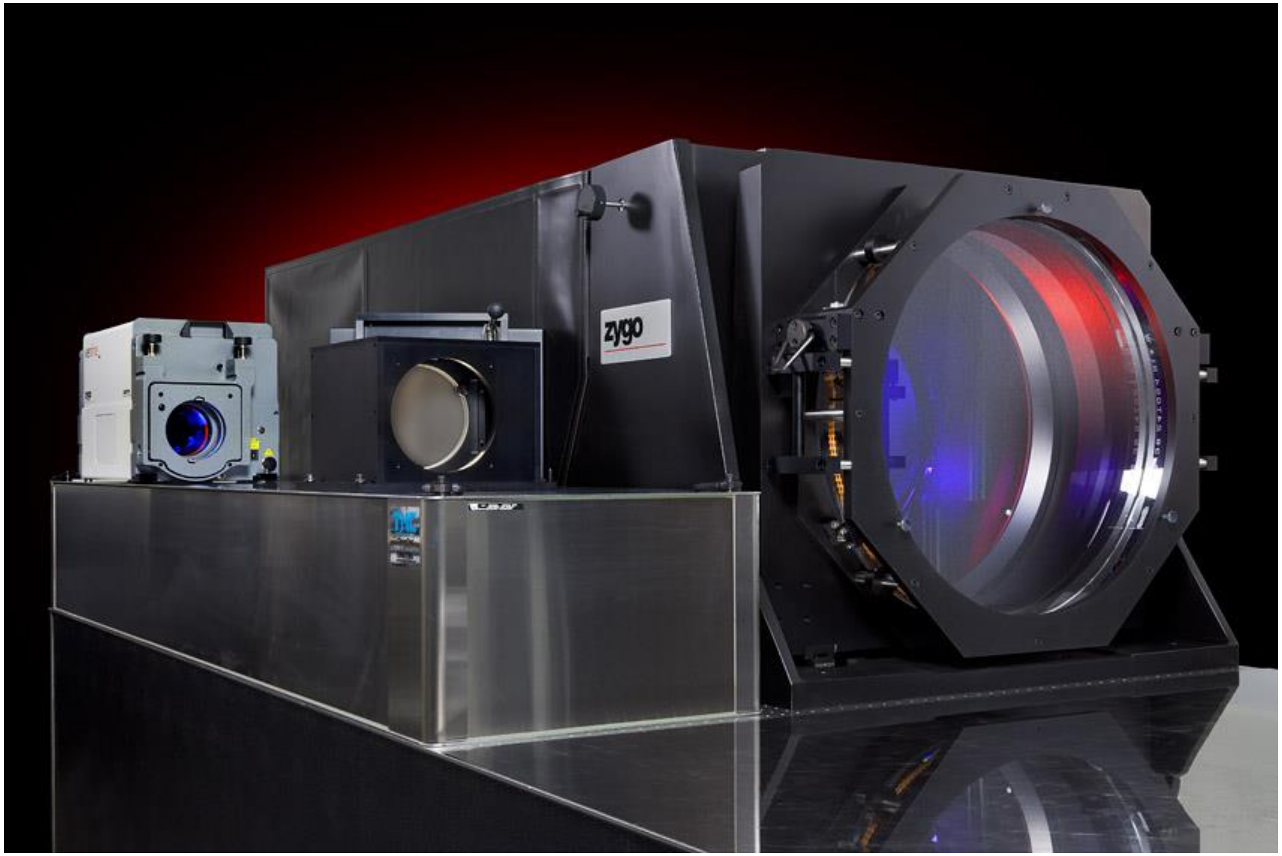
Compensation of thermal aberrations in high-precision wide-aperture interferometers

Dmitry Silin

Institute of Applied Physics of the Russian Academy of Sciences

Nizhny Novgorod, Russia

Commercial wide-aperture interferometers



Wyko, Zygo

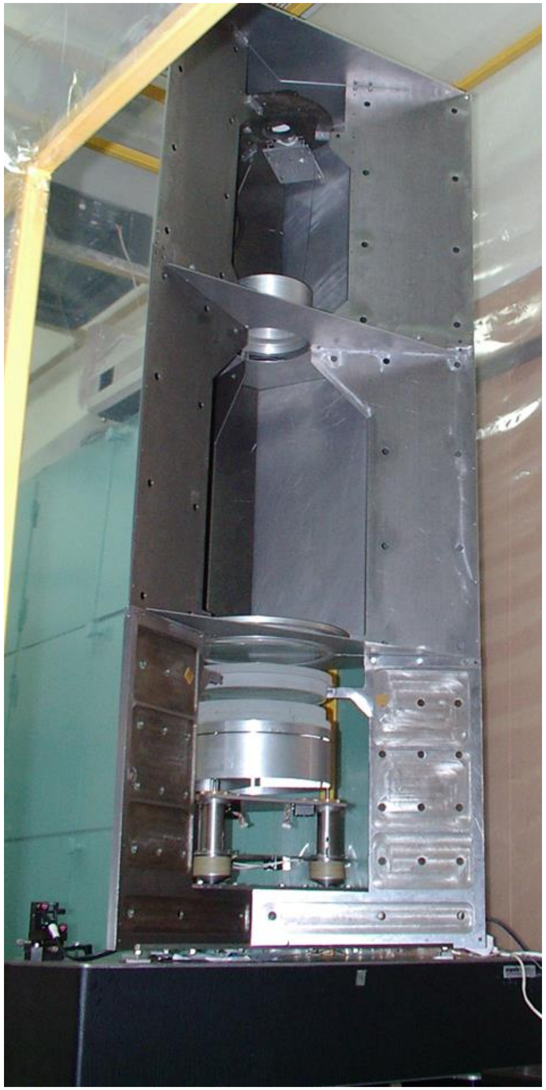
Apertures up to 810 mm

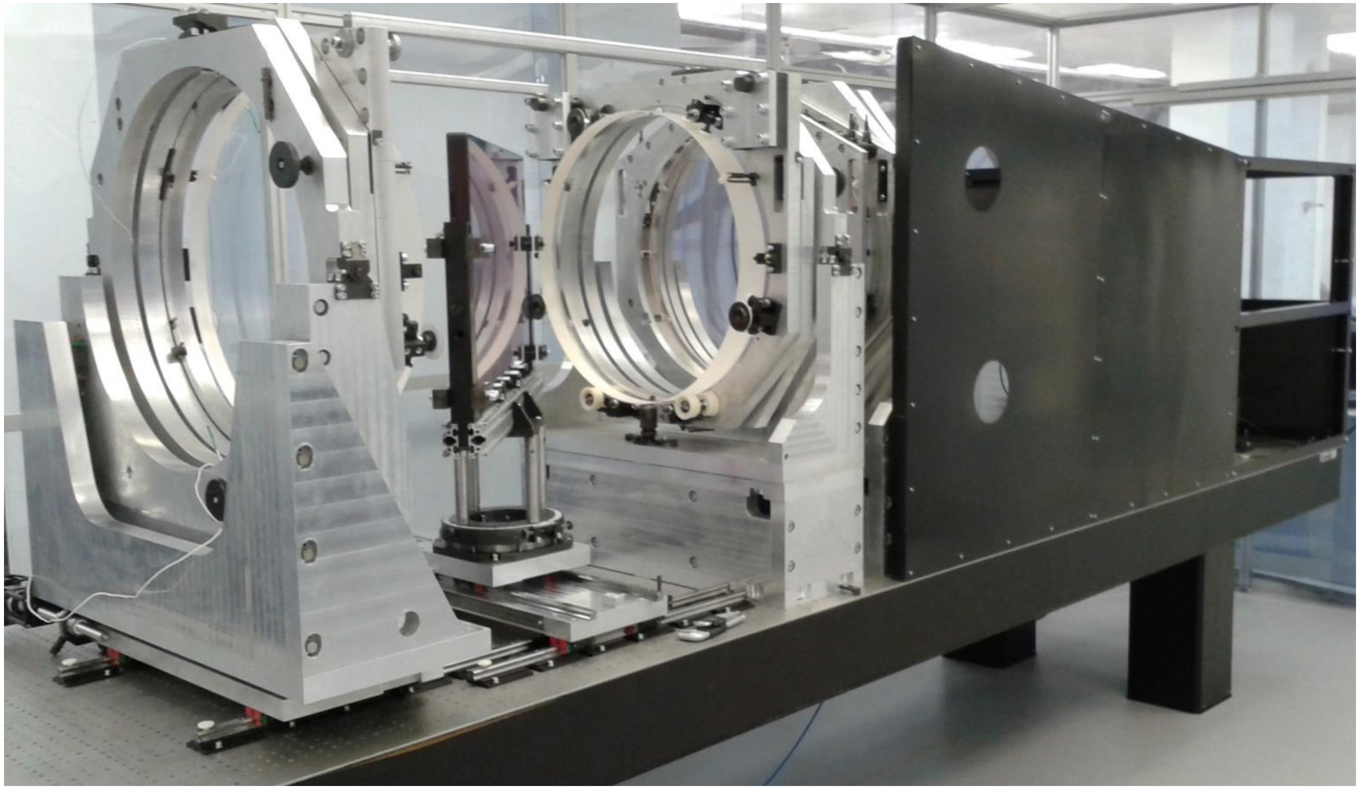
Measurement accuracy: ~ λ/40 - λ/50 (13-16 nm) RMS

Wide-aperture IAP RAS interferometers

Ø250 mm

Ø630 mm



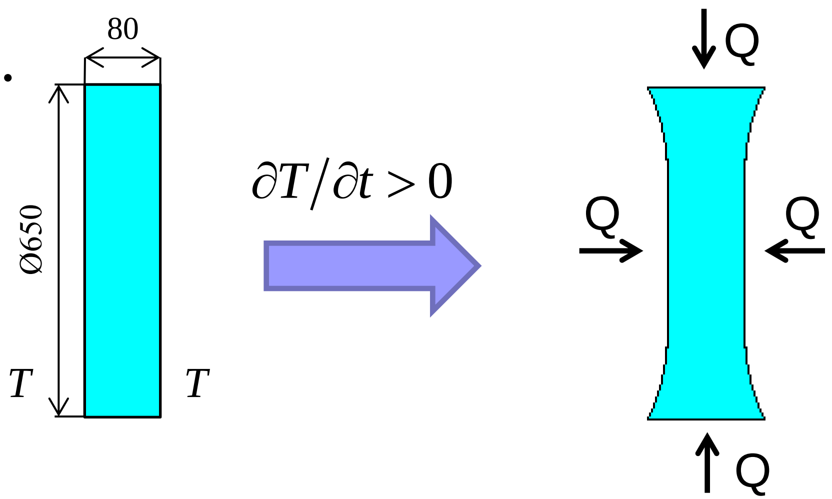


Fizeau interferometers

Measurement accuracy: λ/1000 (0.6 nm) RMS

Reasons of thermal aberrations

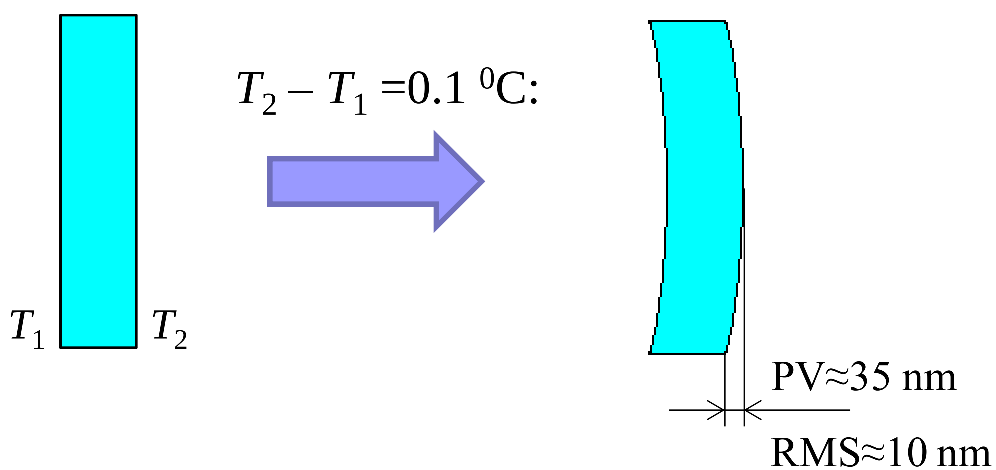
1.



Stability of the reference plate form with RMS≈0.6 nm requires:

$$\frac{\partial T}{\partial t} \sim 0.6\ ^0\mathrm{C/h}$$

2.



Stability of the reference plate form with RMS≈0.6 nm requires:

$$\frac{\partial T}{\partial t} \sim 0.009\ ^0\mathrm{C/h}$$

Ways to reduce thermal aberrations

1. Maintaining a stable room temperature

$$\frac{\partial T}{\partial t} \sim 0.009\ ^0\text{C/h} \text{ is required}$$

for accuracy λ/1000 on aperture Ø630 mm

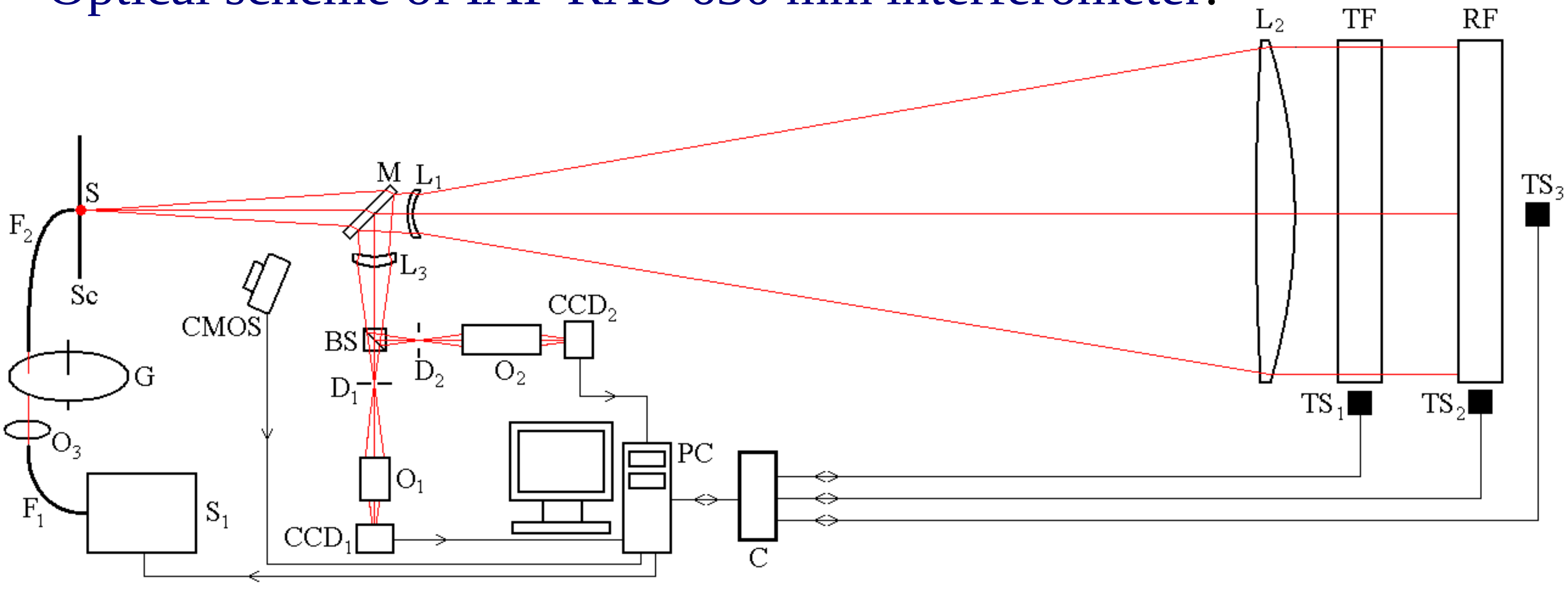
2. Using optical materials with a low coefficient of thermal expansion

3. Creation of a theoretical or an empirical model for predicting changes in the shape of the reference plate and the sample in time based on the results of measuring the air temperature

Location of temperature sensors

- Sensors cannot be located on the working surfaces of the reference plates
- The simplest variant was tested in which sensors were located in the air and only at those points where they do not impede the operation of the interferometer

Optical scheme of IAP RAS 630 mm interferometer:



Empirical model

T – average temperature from three sensors

The temperature T_{in} of the inner sides of both reference plates:

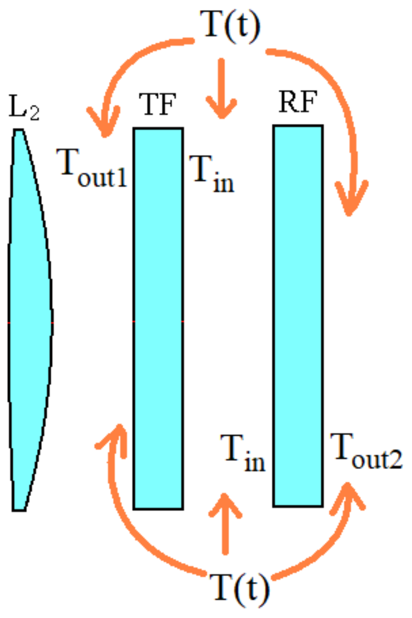
$$\boldsymbol{T_{in}(n) = T_{in}(n-1) + k_{in}\,[T(n) - T_{in}(n-1)]}$$

The temperature T_{out1} of the outer side of TF:

$$\boldsymbol{T_{out1}(n) = T_{out1}(n-1) + k_{out1}\,[T(n) - T_{out1}(n-1)]}$$

The temperature T_{out2} of the outer side of RF:

$$\boldsymbol{T_{out2}(n) = T_{out2}(n-1) + k_{out2}\,[T(n) - T_{out2}(n-1)]}$$



n - number of measurement, interval for taking temperatures from sensors: 1 minute

When the distance between the plates is 30 mm, the empirical values of the coefficients are:

k_{in}=1/95, k_{out1}=1/65, k_{out2}=1/95 for 250 mm interferometer

k_{in}=1/143, k_{out1}=1/133, k_{out2}=1/67 for 630 mm interferometer

Empirical model

$$\begin{cases} \dfrac{\partial T(\bar{r},t)}{\partial t} = a^2 \Delta T(\bar{r},t), \\ T(\bar{r}, t=0) = T_0, \\ T(\bar{r}_{in}, t) = T_{in}(t), \\ T(\bar{r}_{out}, t) = T_{out}(t) \end{cases}$$

→ $T(\bar{r},t)$ → *CAE system* → Plate deformations

Simple calculation:

Sag: $\boldsymbol{\Delta h = c\,(T_{\mathrm{in}} - T_{\mathrm{out}})}$

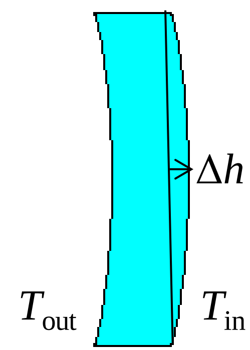
Consider round plates. In this case, the temperature deformations are spherical.

$$c = \frac{\alpha D^2}{8d}$$

α=0.54·10^{-6} for fused silica

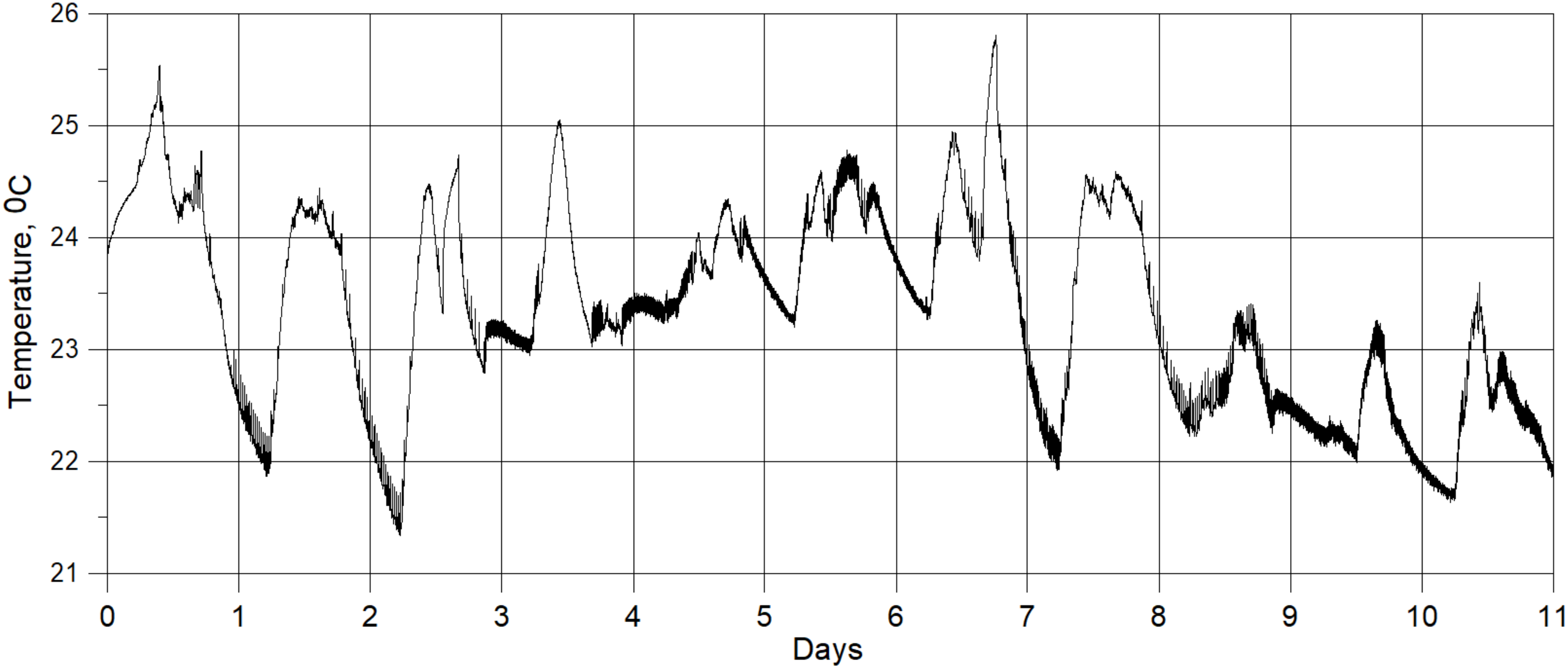
$c \approx 105$ nm for D=250 mm, d=40 mm

$c \approx 335$ nm for D=630 mm, d=80 mm



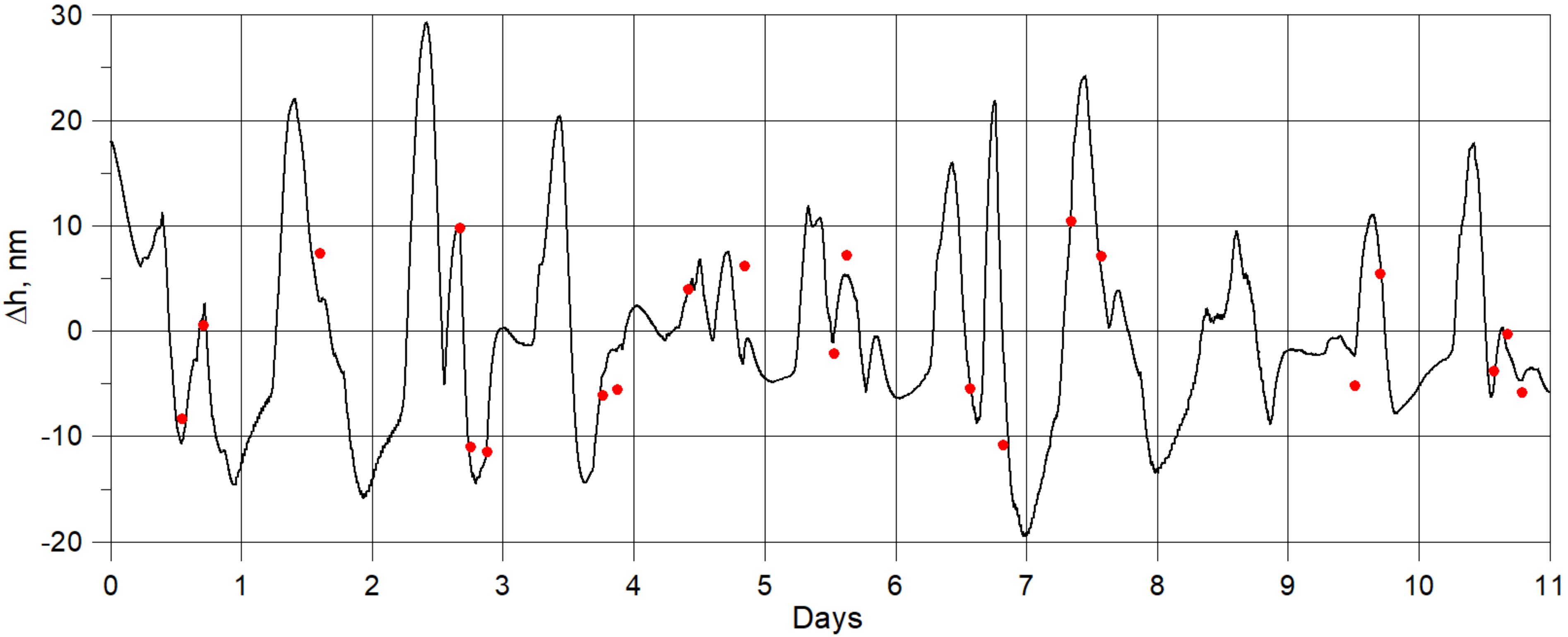
Thermal aberrations in 250 mm interferometer

The dependence of air temperature on time



Thermal aberrations in 250 mm interferometer

The total sag of surface deformations of two reference plates

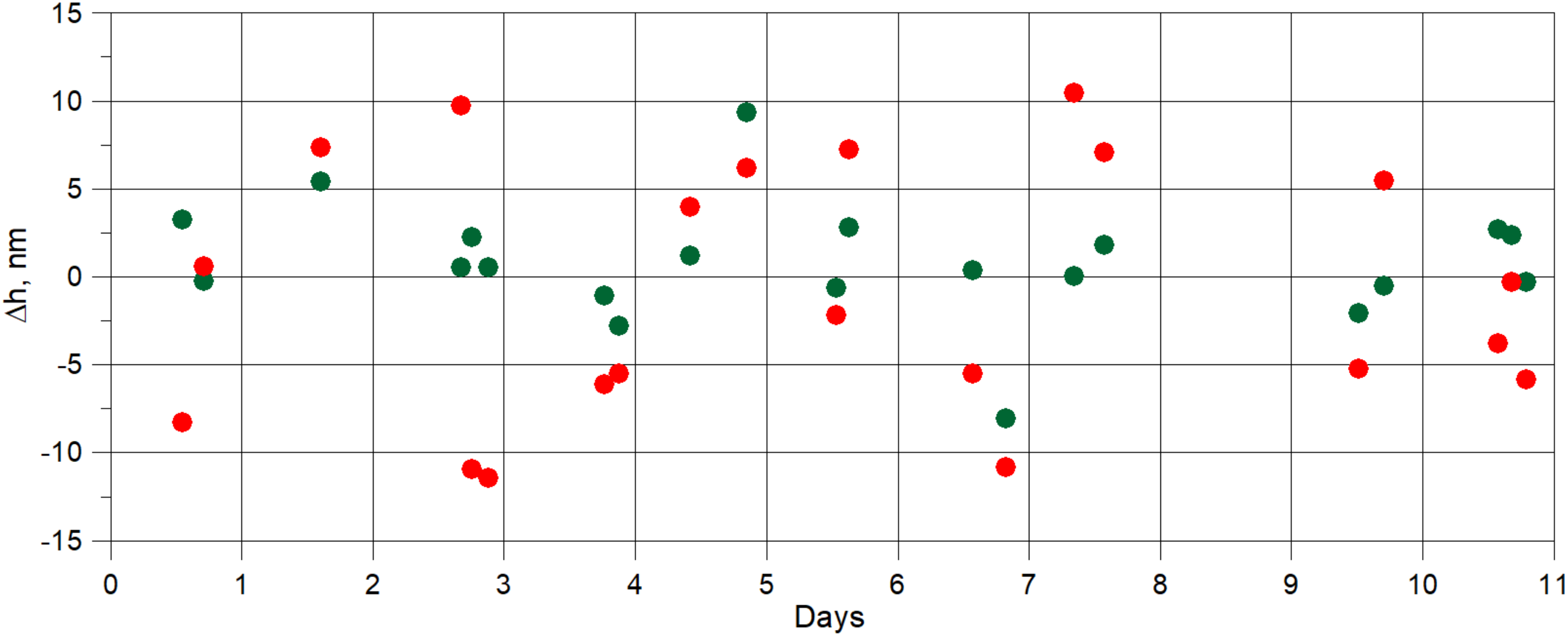


—— model

• • • • measurement results

Thermal aberrations in 250 mm interferometer

Errors caused by thermal deformations

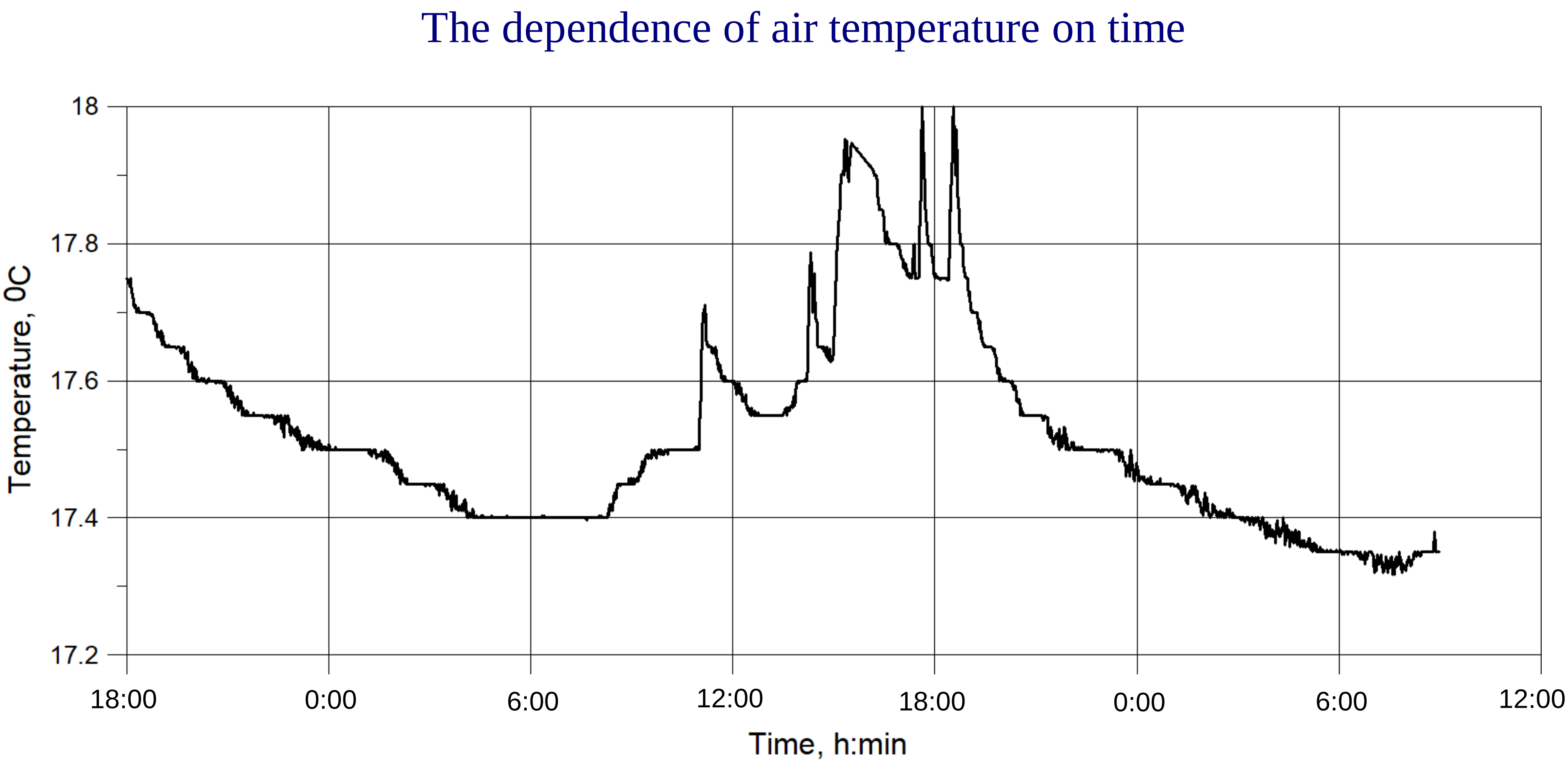


•••• errors without using the model

•••• errors after subtracting theoretical sag

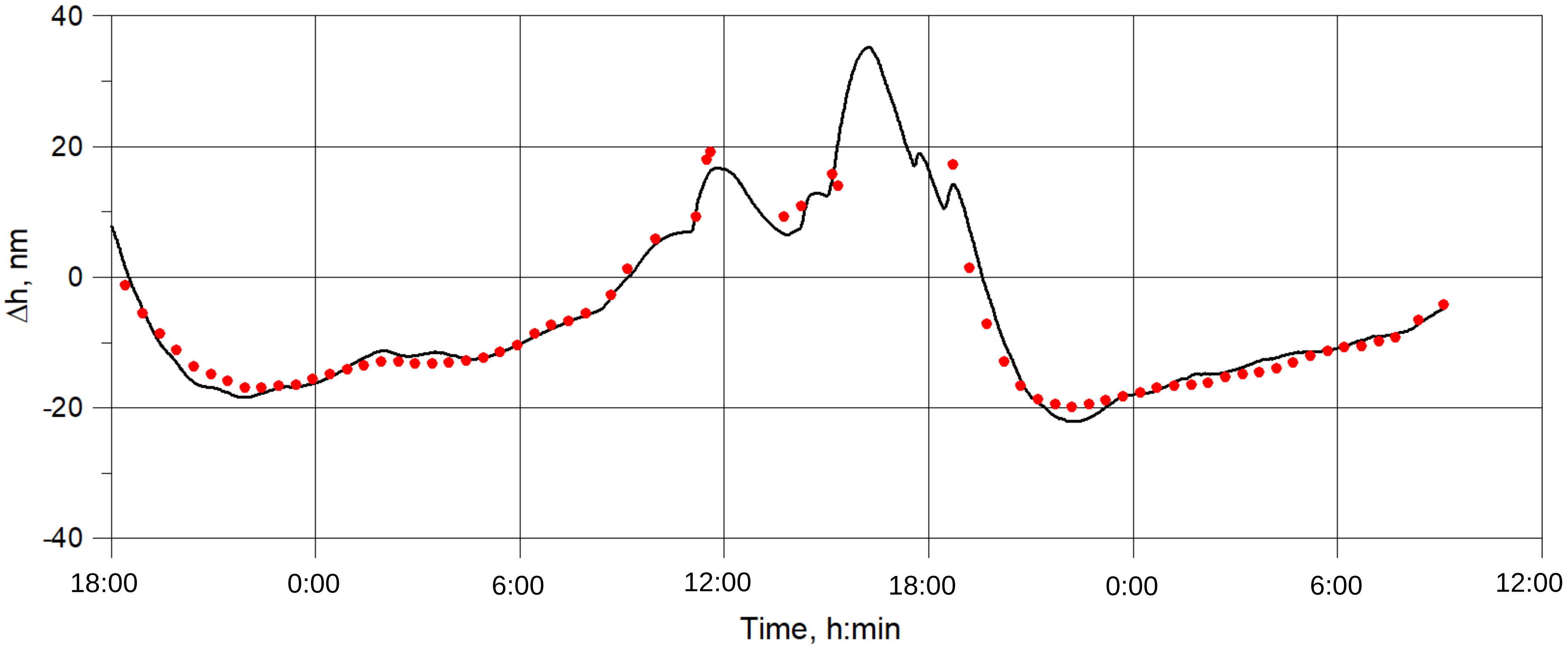
Thermal aberrations were reduced >2 times.

Thermal aberrations in 630 mm interferometer



Thermal aberrations in 630 mm interferometer

The total sag of surface deformations of two reference plates

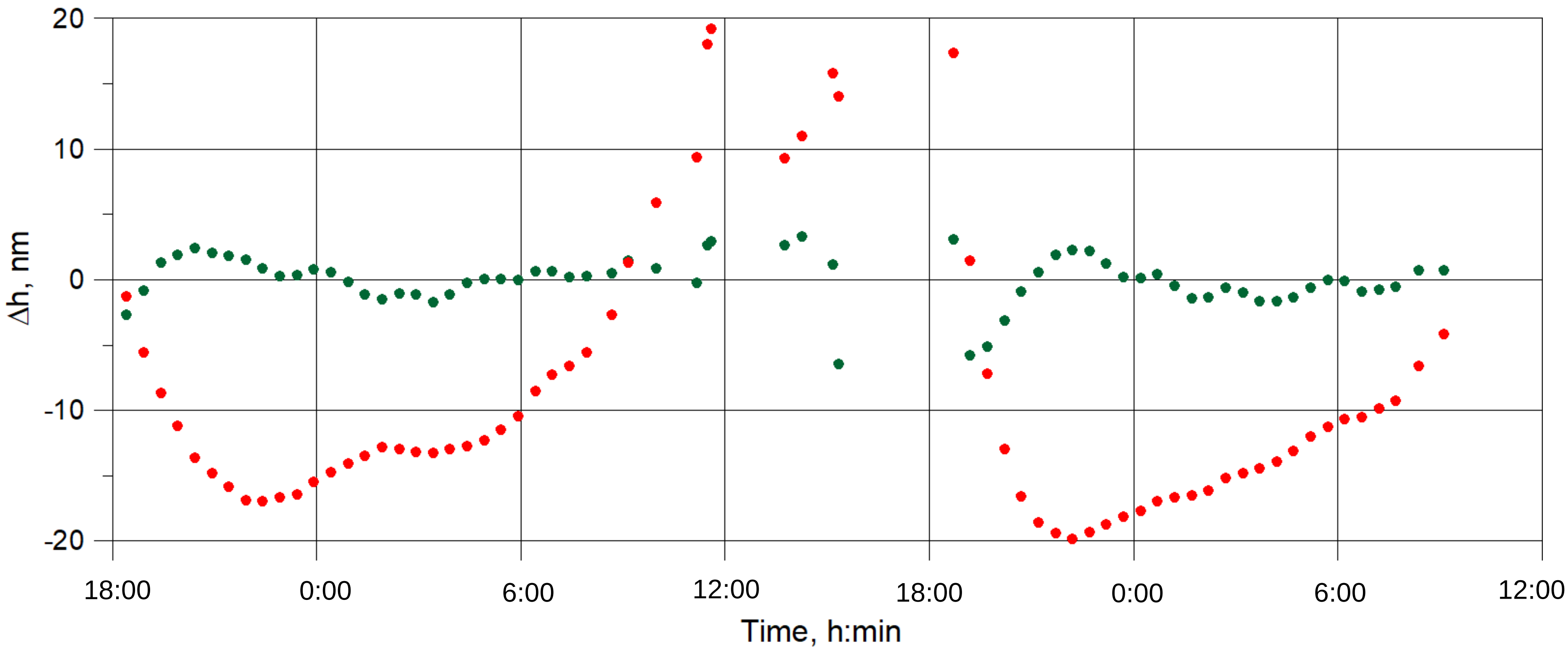


—— model

• • • • measurement results

Thermal aberrations in 630 mm interferometer

Errors caused by thermal deformations

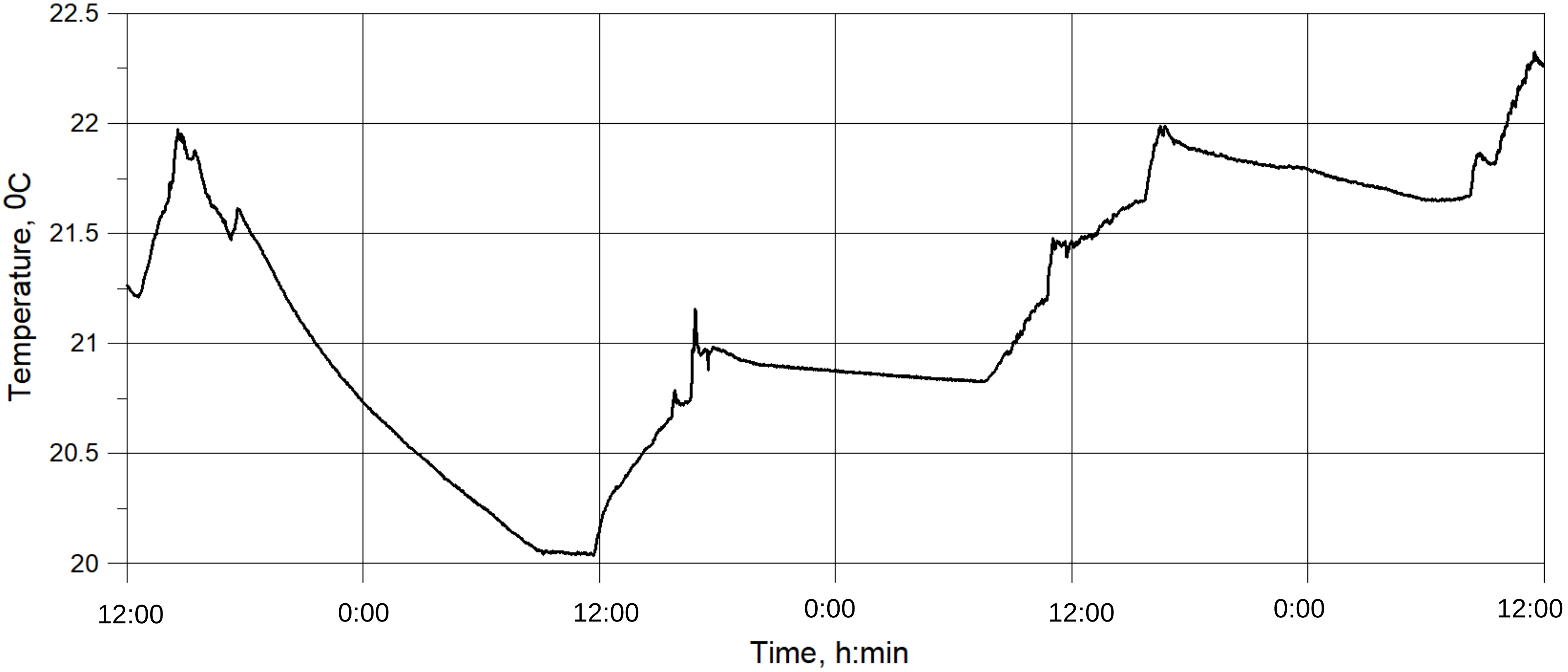


- errors without using the model
- errors after subtracting theoretical sag

Thermal aberrations were reduced ~7 times.

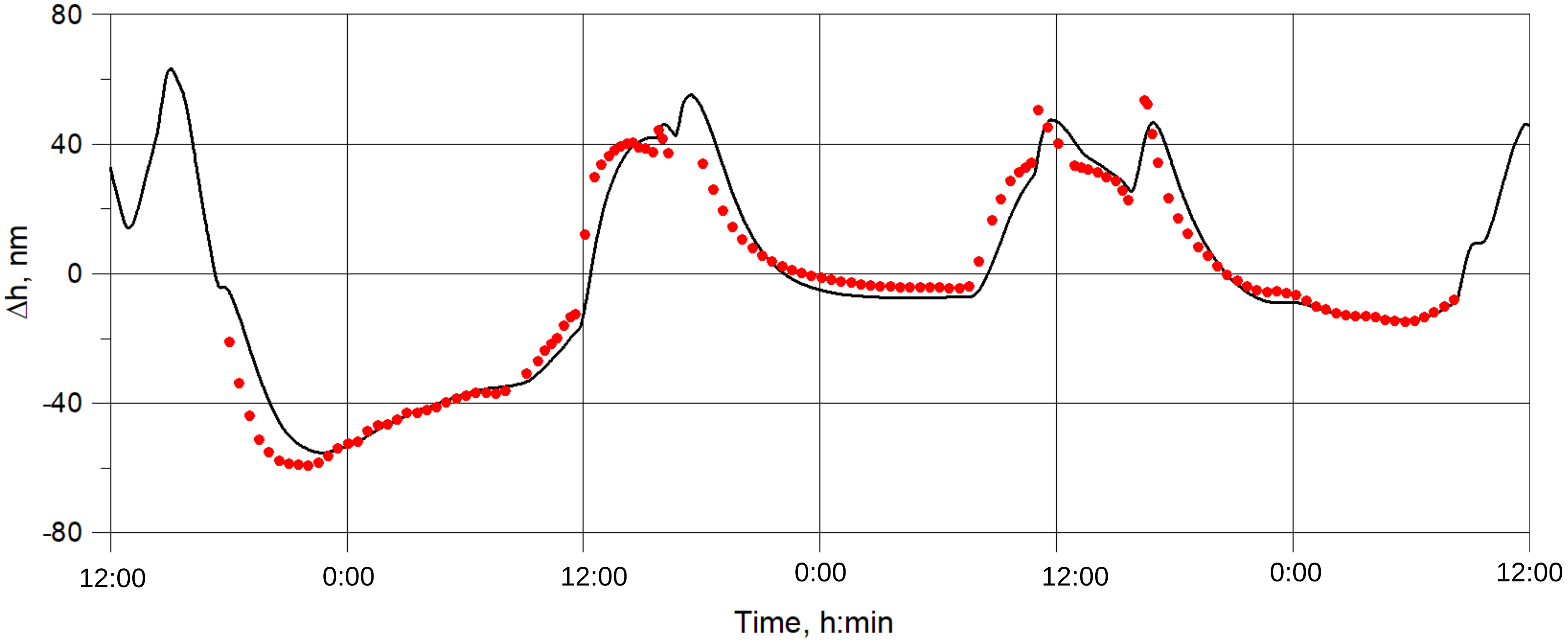
Thermal aberrations in 630 mm interferometer

The dependence of air temperature on time



Thermal aberrations in 630 mm interferometer

The total sag of surface deformations of two reference plates

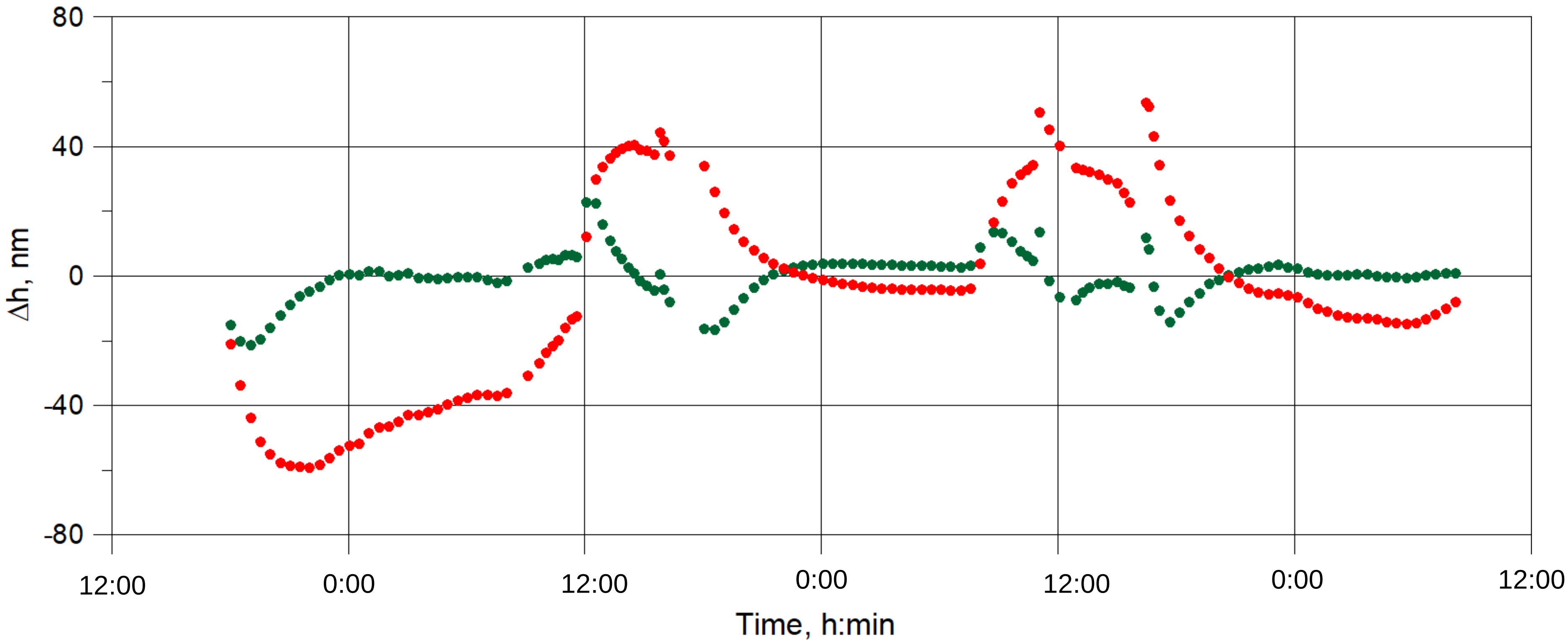


model

measurement results

Thermal aberrations in 630 mm interferometer

Errors caused by thermal deformations



• • • • errors without using the model

• • • • errors after subtracting theoretical sag

Thermal aberrations were reduced >4 times.

Conclusion

1. The empirical model was developed to predict the thermal deformations of the reference plates and samples based on the results of temperature measurements.

2. The developed model makes it possible to reduce the errors caused by thermal aberrations in wide-aperture interferometers.

3. The developed model reduces the requirements for air temperature stability for high-precision measurements.

Thank you for your attention!