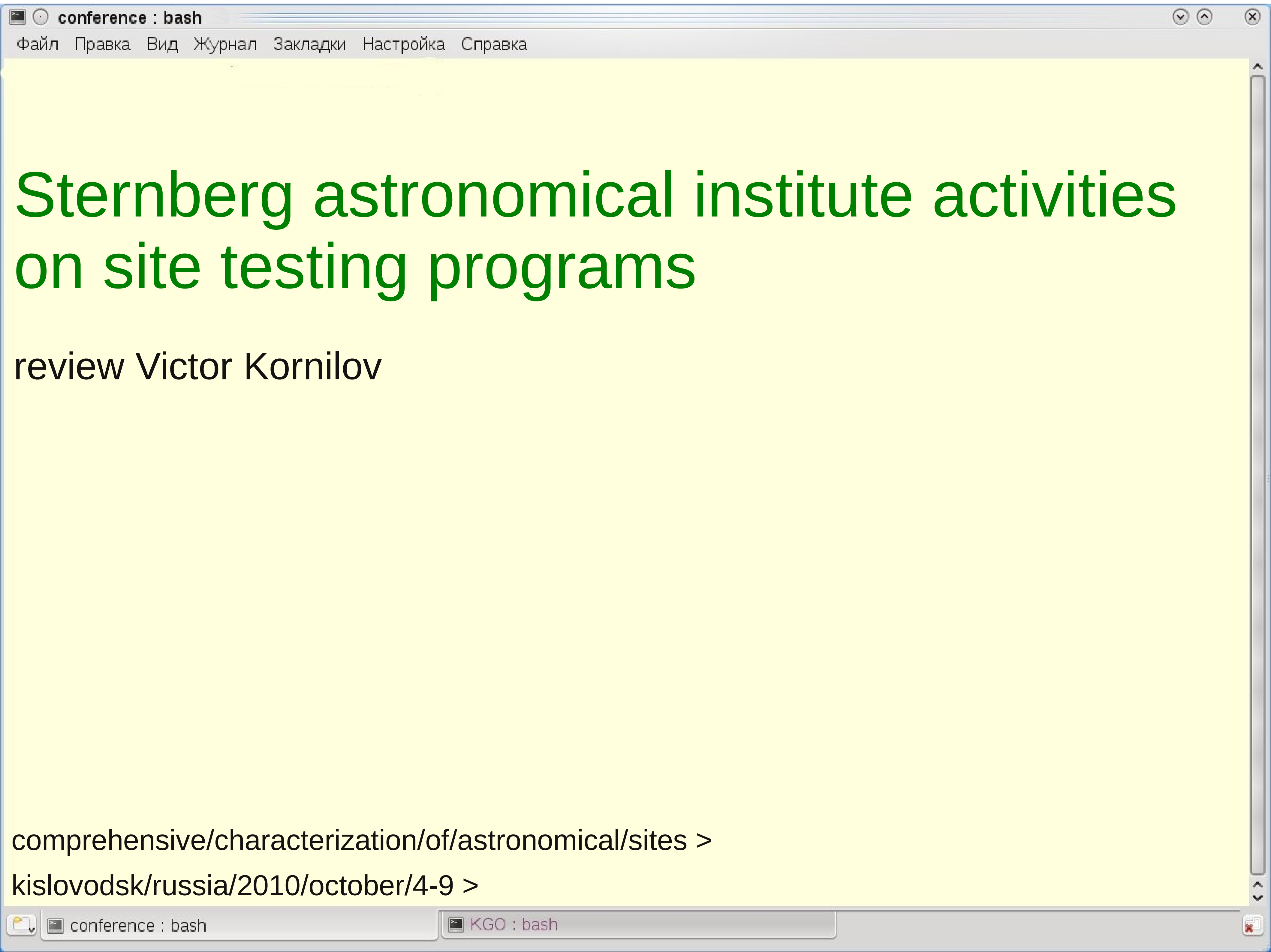

Sternberg astronomical institute activities on site testing programs

review Victor Kornilov

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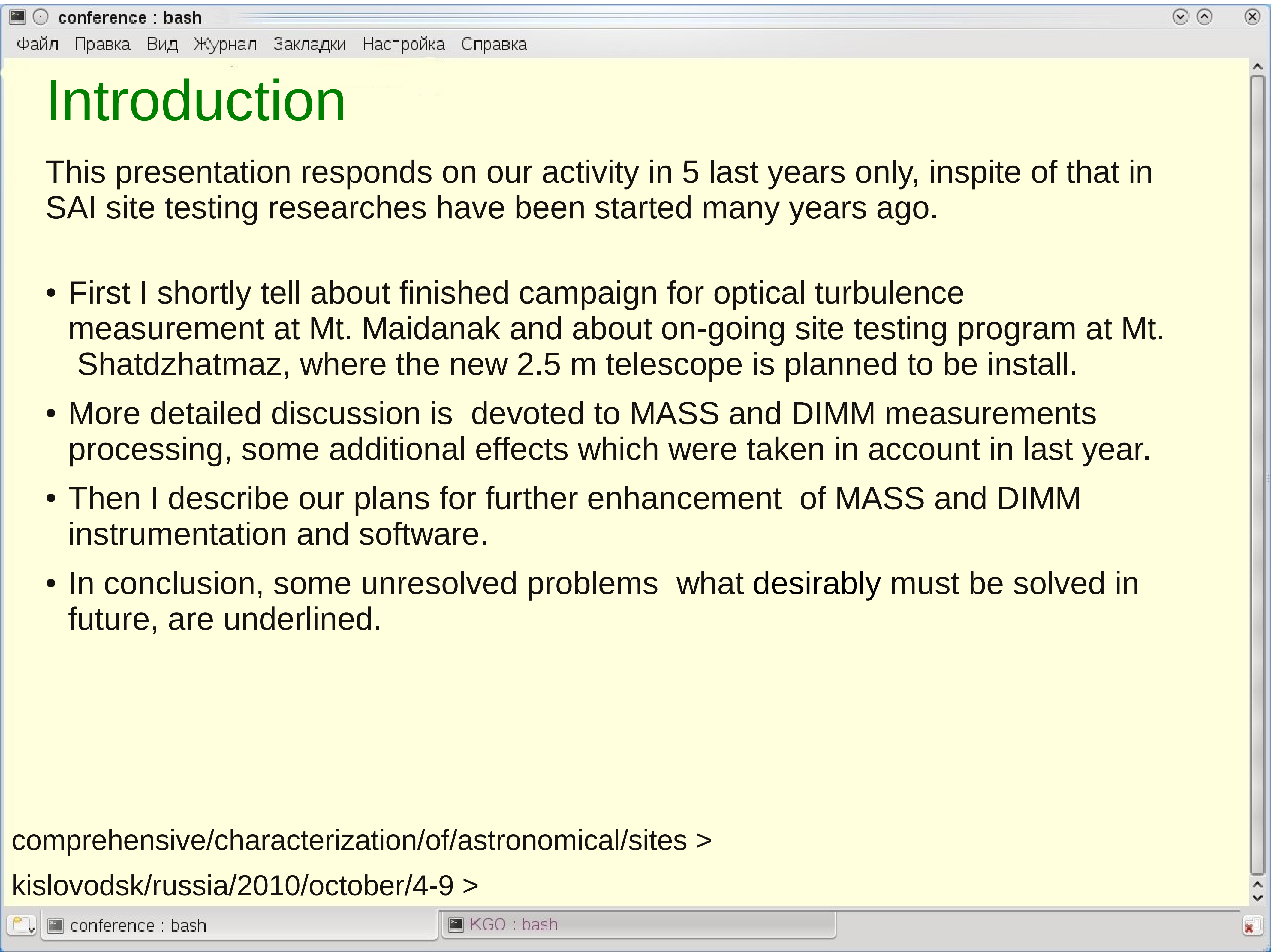

Introduction

This presentation responds on our activity in 5 last years only, inspite of that in SAI site testing researches have been started many years ago.

- First I shortly tell about finished campaign for optical turbulence measurement at Mt. Maidanak and about on-going site testing program at Mt. Shatdzhatmaz, where the new 2.5 m telescope is planned to be install.
- More detailed discussion is devoted to MASS and DIMM measurements processing, some additional effects which were taken in account in last year.
- Then I describe our plans for further enhancement of MASS and DIMM instrumentation and software.
- In conclusion, some unresolved problems what desirably must be solved in future, are underlined.

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Our website http://curl.sai.msu.ru/mass

In the work took part

Nicolai Shatsky
Olga Voziakova
Sergey Potanin
Boris Safonov
Matwey Kornilov

All they are here

On the site a lot of documents related to the MASS and DIMM instruments ans corresponding software can be found

О проекте / About MASS Project

Многоапертурный детектор атмосферных мерцаний (MASS) разработан для продолжительного мониторинга параметров оптической турбулентности в свободной атмосфере на существующих обсерваториях и при выборе мест для новых обсерваторий. Инструмент позволяет измерить изопланатический и изокинетический углы, интегральное качество изображение в свободной атмосфере, характерные высоты и вертикальный профиль турбулентности с разрешением порядка dh ~ 0.5h. Широкое распространение этой технологии (в настоящее время в мире действует около 15 таких приборов) позволяет аккумулировать большой объем данных о верхней атмосфере, так необходимой для поиска новых мест, проектированию и эксплуатации систем адаптивной оптики и для понимания атмосферных процессов, влияющих на астрономические наблюдения.

The Multi-Aperture Scintillation Sensor (MASS) is intended for continuous monitoring of free atmosphere parameters at different observatories and potential observational sites. MASS measures isoplanatic and isokinetic angles, integral seeing produced by the free atmosphere, characteristic altitudes and strengths of a few dominating turbulence layers with crude resolution about dh ~ 0.5h. Wide implementation of this technology (now, about 15 devices are in use in the world) permits to collect the data on upper atmosphere needed so much for site testing, adaptive optics systems and for further understanding of influence of atmosphere on astronomical observations.

Об этом сайте / About This Site

Подробную информацию о теоретических основах проекта, особенностях инструмента MASS, текущем состоянии исследований, проводимых разными группами на разных обсерваториях, вы можете узнать **на сайте А.Токовинина**. Наш сайт является сайтом технической поддержки проекта MASS и предназначен, главным образом, для внутреннего использования MASS-группой ГАИШ МГУ. Здесь

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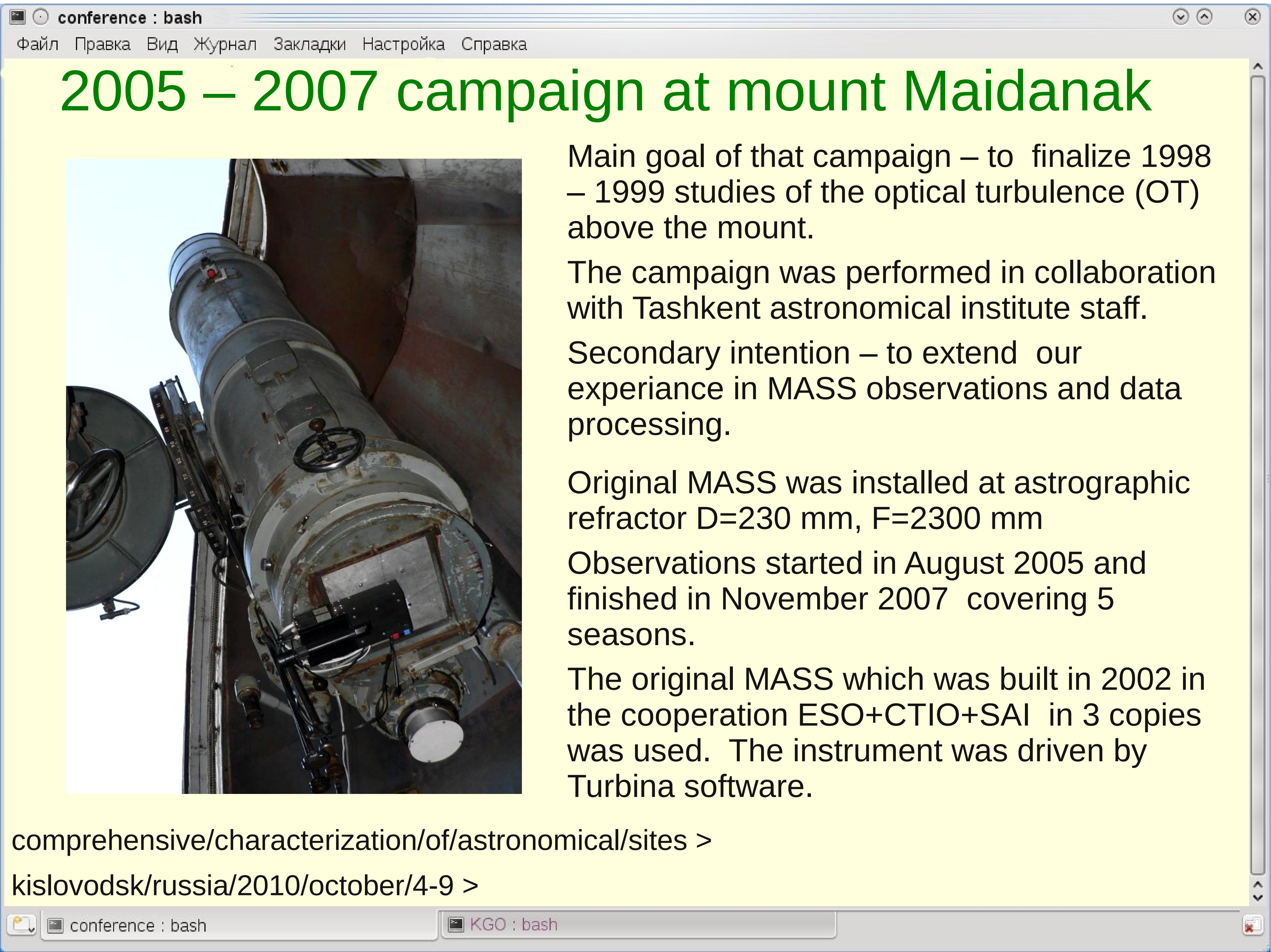

2005 – 2007 campaign at mount Maidanak

Main goal of that campaign – to finalize 1998 – 1999 studies of the optical turbulence (OT) above the mount.

The campaign was performed in collaboration with Tashkent astronomical institute staff.

Secondary intention – to extend our experiance in MASS observations and data processing.

Original MASS was installed at astrographic refractor D=230 mm, F=2300 mm

Observations started in August 2005 and finished in November 2007 covering 5 seasons.

The original MASS which was built in 2002 in the cooperation ESO+CTIO+SAI in 3 copies was used. The instrument was driven by Turbina software.

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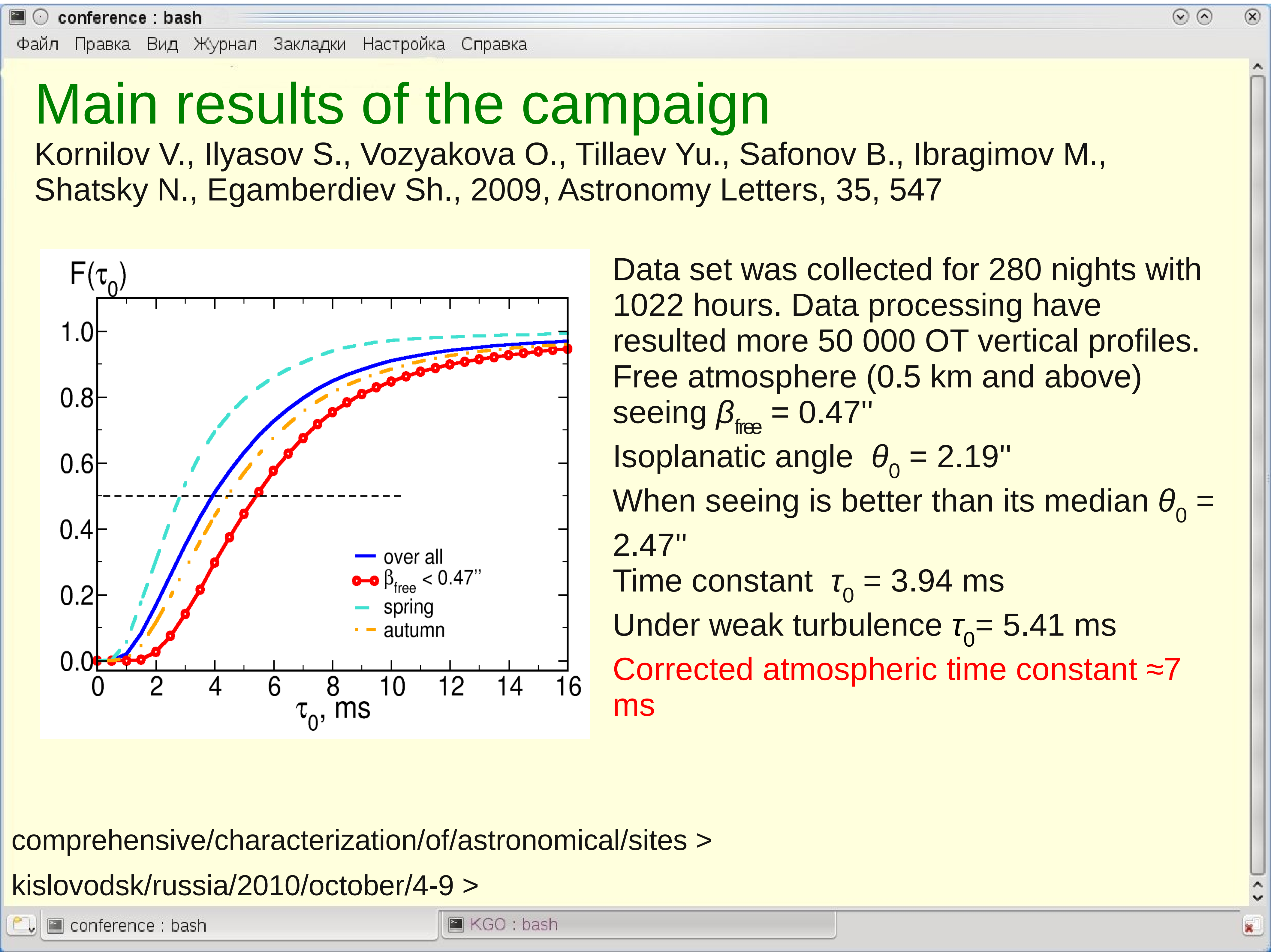

Main results of the campaign

Kornilov V., Ilyasov S., Vozyakova O., Tillaev Yu., Safonov B., Ibragimov M., Shatsky N., Egamberdiev Sh., 2009, Astronomy Letters, 35, 547

Data set was collected for 280 nights with 1022 hours. Data processing have resulted more 50 000 OT vertical profiles.

Free atmosphere (0.5 km and above) seeing β_{free} = 0.47''

Isoplanatic angle θ_0 = 2.19''

When seeing is better than its median θ_0 = 2.47''

Time constant τ_0 = 3.94 ms

Under weak turbulence τ_0= 5.41 ms

Corrected atmospheric time constant ≈7 ms

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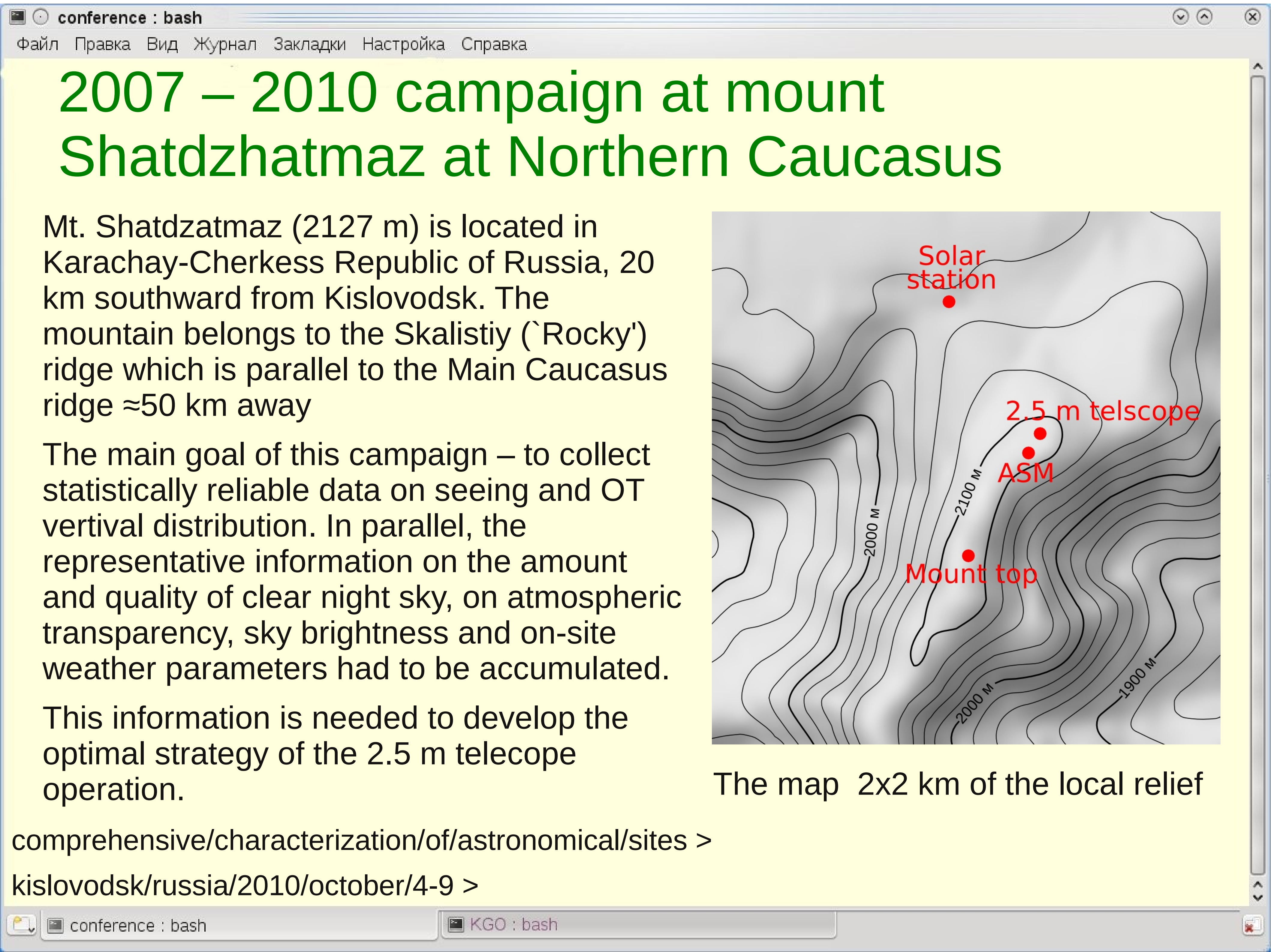

2007 – 2010 campaign at mount Shatdzhatmaz at Northern Caucasus

Mt. Shatdzatmaz (2127 m) is located in Karachay-Cherkess Republic of Russia, 20 km southward from Kislovodsk. The mountain belongs to the Skalistiy (`Rocky') ridge which is parallel to the Main Caucasus ridge ≈50 km away

The main goal of this campaign – to collect statistically reliable data on seeing and OT vertival distribution. In parallel, the representative information on the amount and quality of clear night sky, on atmospheric transparency, sky brightness and on-site weather parameters had to be accumulated.

This information is needed to develop the optimal strategy of the 2.5 m telecope operation.

The map 2x2 km of the local relief

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Automatic site monitor at mount Shatdzhatmaz

ASM tower is installed 40 m to SW from the spot reserved for the 2.5-m telescope.
ASM telescope tube is at 6-m elevation above the ground.

July 2008, night

January 2009, day

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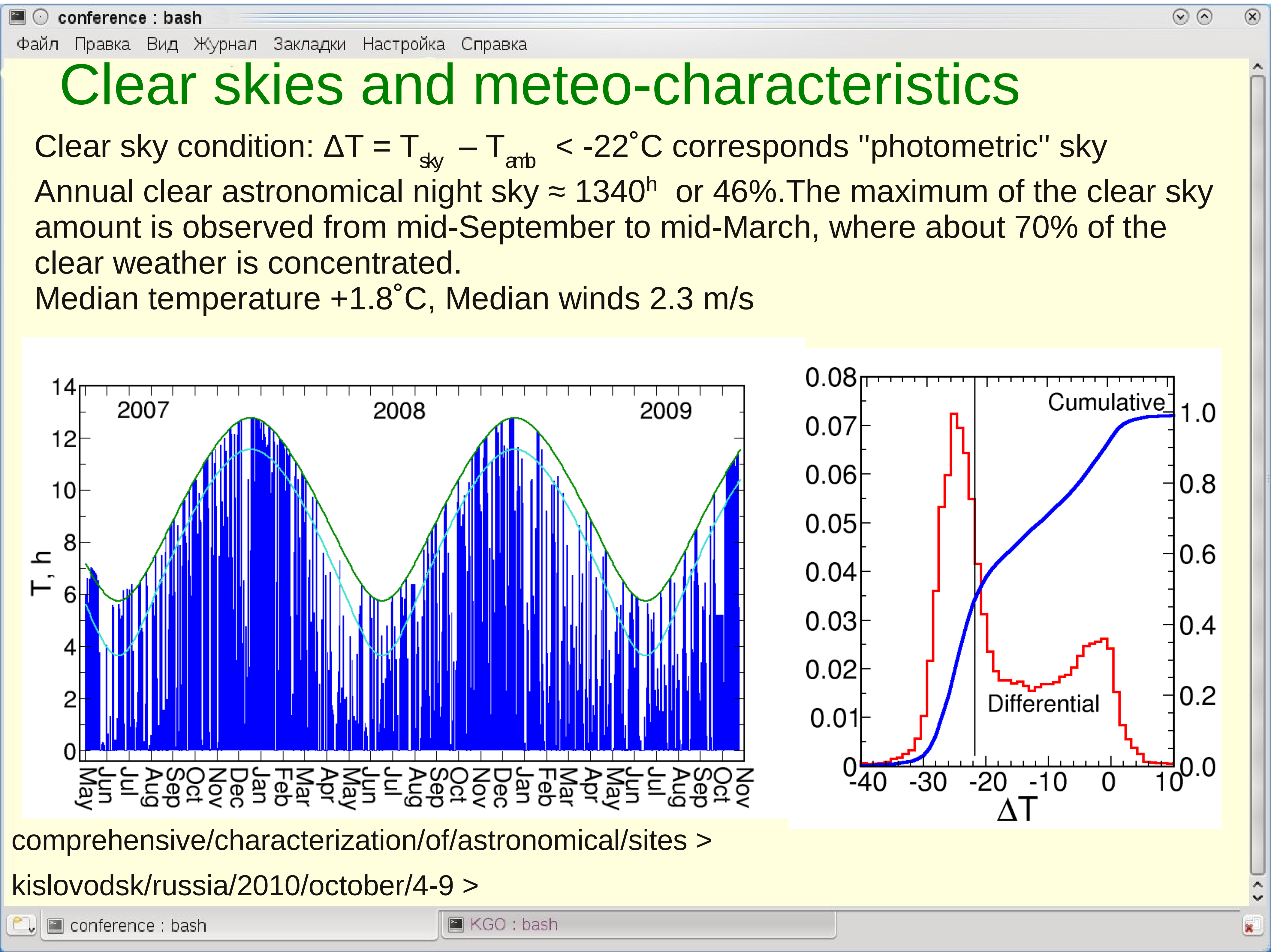
Instrumentation

- Telescope Meade RCX400 12"
- MASS/DIMM device
- CCD finder/guider
- Control computer
- Automated enclosure
- Wind, temperature, humidity sensors
- Boltwood clouds sensor
- Two web-cameras
- Power supply
- Service computer
- WiFi bridge to Solar station
- Main sofware: *mass, dimm, rcx_scope, monitor, dome*

MASS/DIMM instrument installed on Meade telescope. The DIMM camera is Prosilica EC650. Telescope CCD finder/guider is seen on the right side.



Clear skies and meteo-characteristics

Clear sky condition: $\Delta T = T_{sky} - T_{amb} < -22^{\circ}C$ corresponds "photometric" sky

Annual clear astronomical night sky ≈ 1340^{h} or 46%.The maximum of the clear sky amount is observed from mid-September to mid-March, where about 70% of the clear weather is concentrated.
Median temperature +1.8°C, Median winds 2.3 m/s

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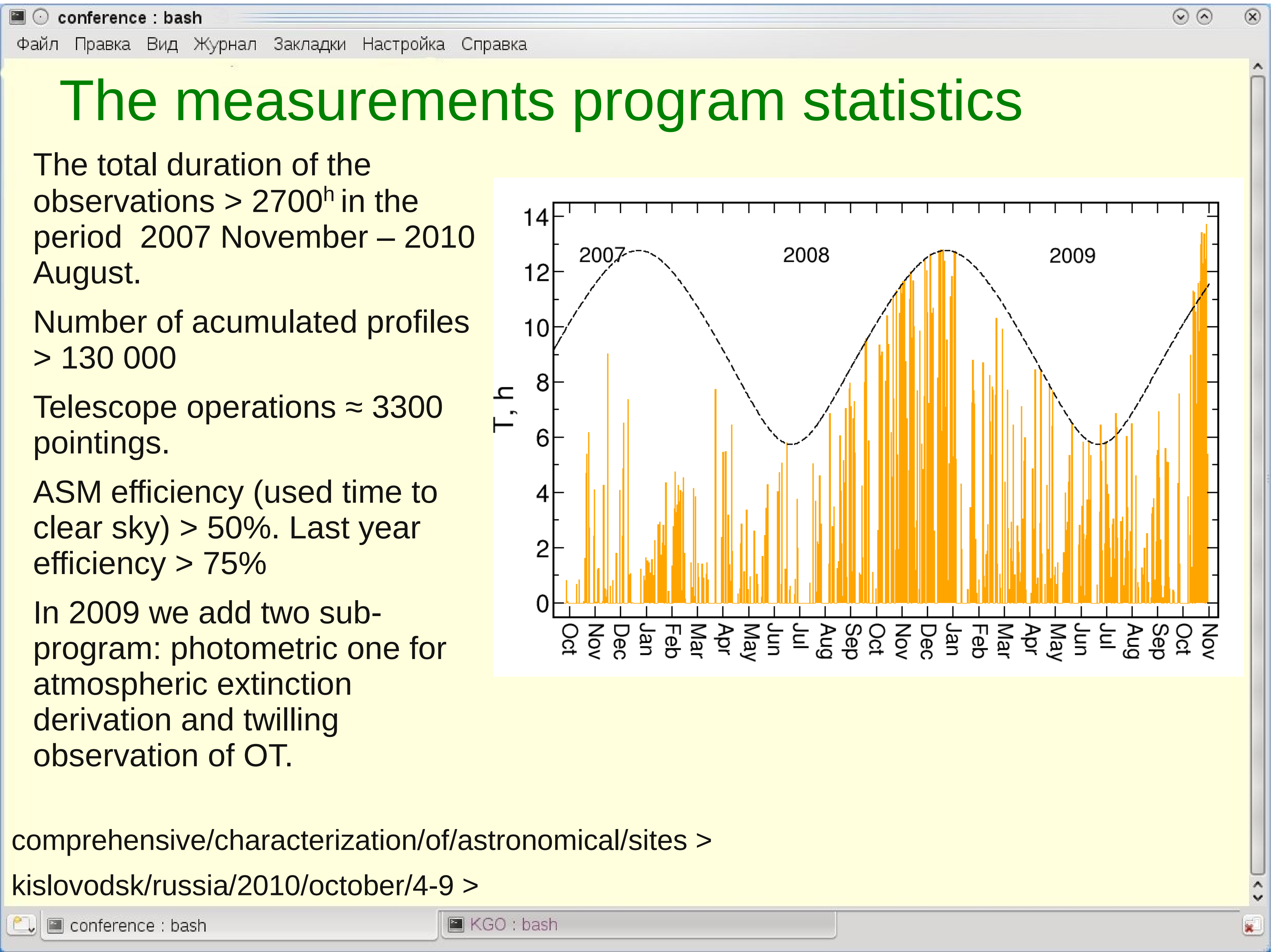

The measurements program statistics

The total duration of the observations > 2700^h in the period 2007 November – 2010 August.

Number of acumulated profiles > 130 000

Telescope operations ≈ 3300 pointings.

ASM efficiency (used time to clear sky) > 50%. Last year efficiency > 75%

In 2009 we add two sub-program: photometric one for atmospheric extinction derivation and twilling observation of OT.

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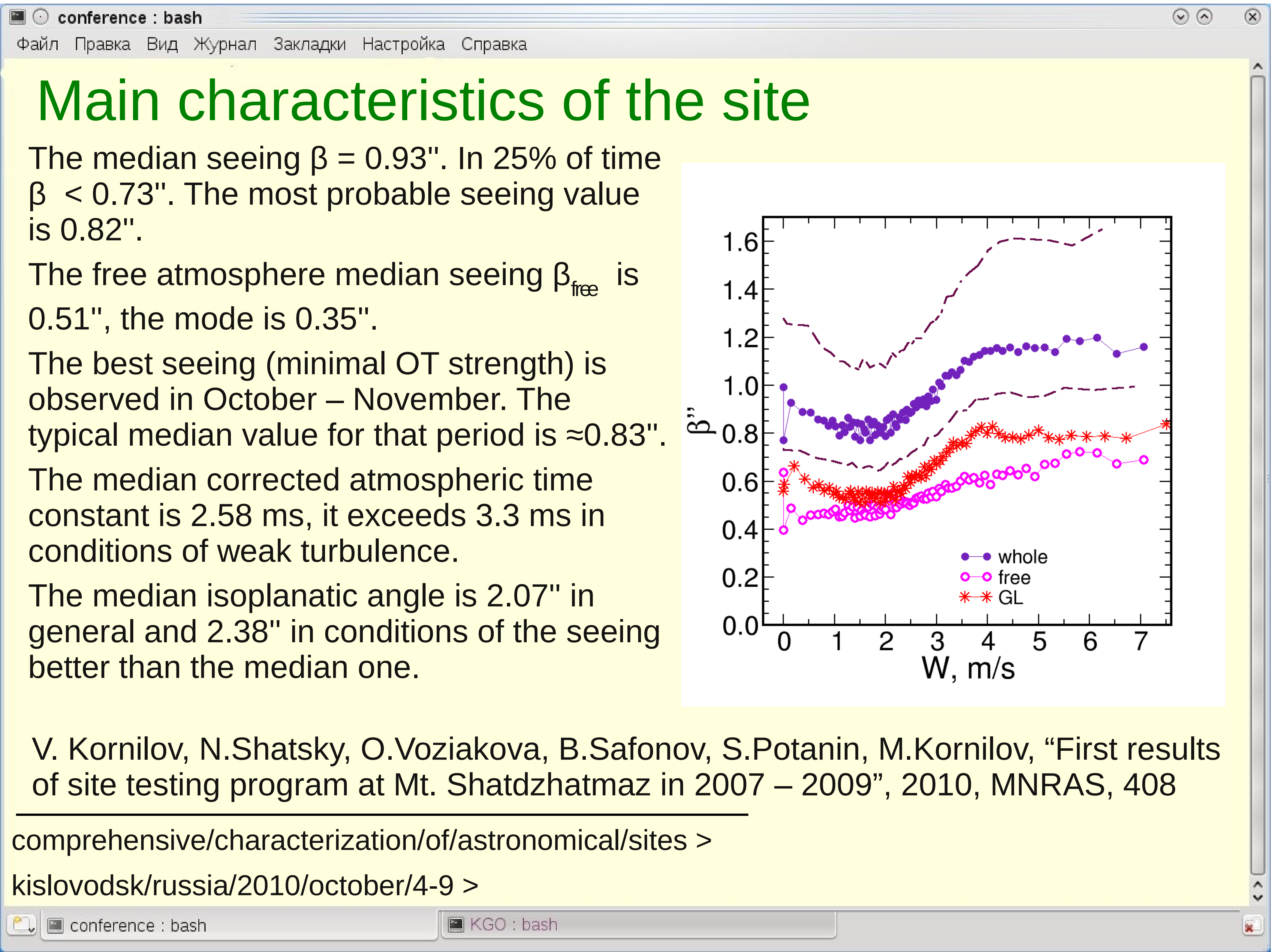


Main characteristics of the site

The median seeing β = 0.93''. In 25% of time β < 0.73''. The most probable seeing value is 0.82''.

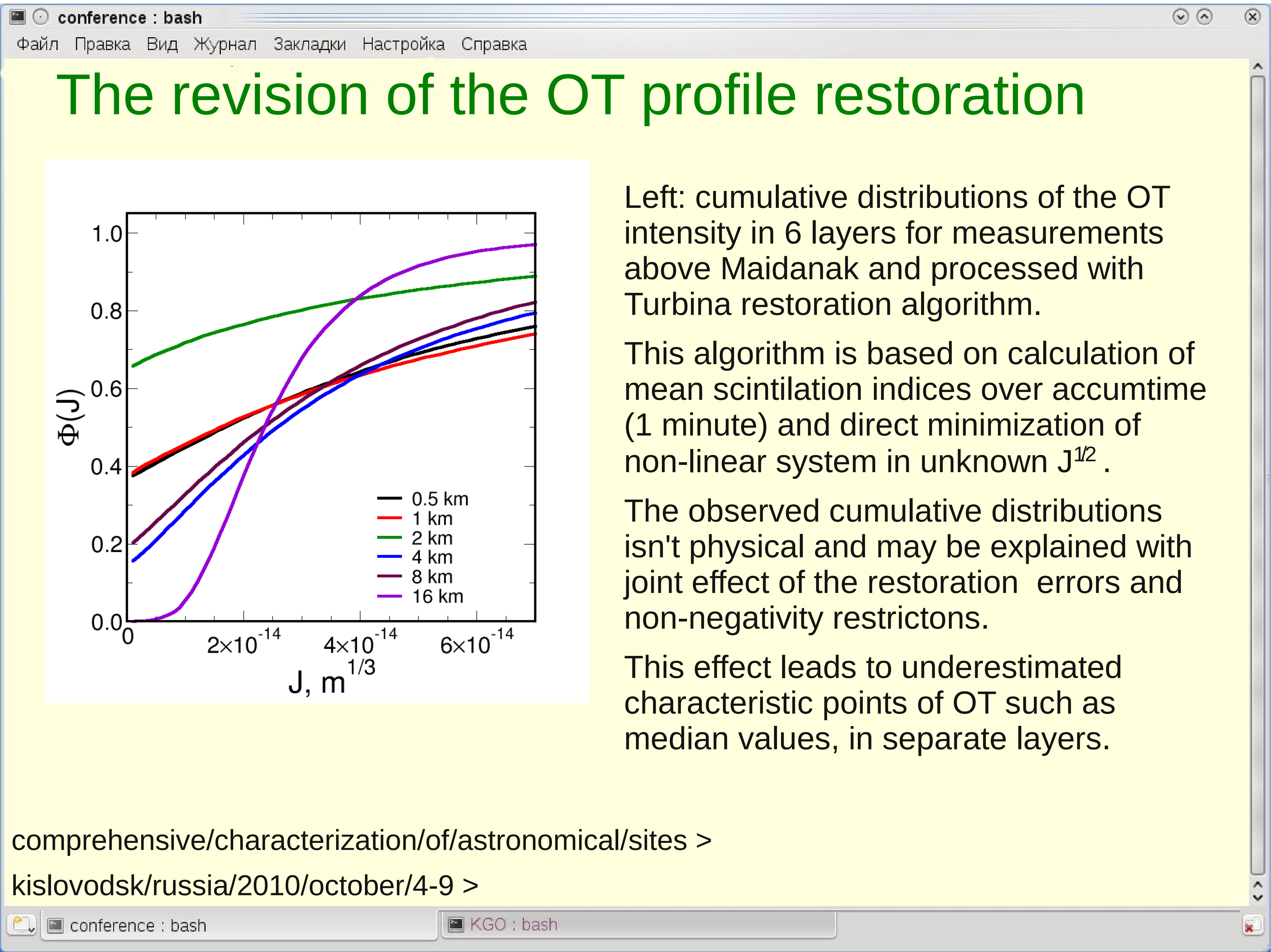
The free atmosphere median seeing β_{free} is 0.51'', the mode is 0.35''.

The best seeing (minimal OT strength) is observed in October – November. The typical median value for that period is ≈0.83''.

The median corrected atmospheric time constant is 2.58 ms, it exceeds 3.3 ms in conditions of weak turbulence.

The median isoplanatic angle is 2.07'' in general and 2.38'' in conditions of the seeing better than the median one.

V. Kornilov, N.Shatsky, O.Voziakova, B.Safonov, S.Potanin, M.Kornilov, “First results of site testing program at Mt. Shatdzhatmaz in 2007 – 2009”, 2010, MNRAS, 408



The revision of the OT profile restoration

Left: cumulative distributions of the OT intensity in 6 layers for measurements above Maidanak and processed with Turbina restoration algorithm.

This algorithm is based on calculation of mean scintilation indices over accumtime (1 minute) and direct minimization of non-linear system in unknown $J^{1/2}$.

The observed cumulative distributions isn't physical and may be explained with joint effect of the restoration errors and non-negativity restrictons.

This effect leads to underestimated characteristic points of OT such as median values, in separate layers.

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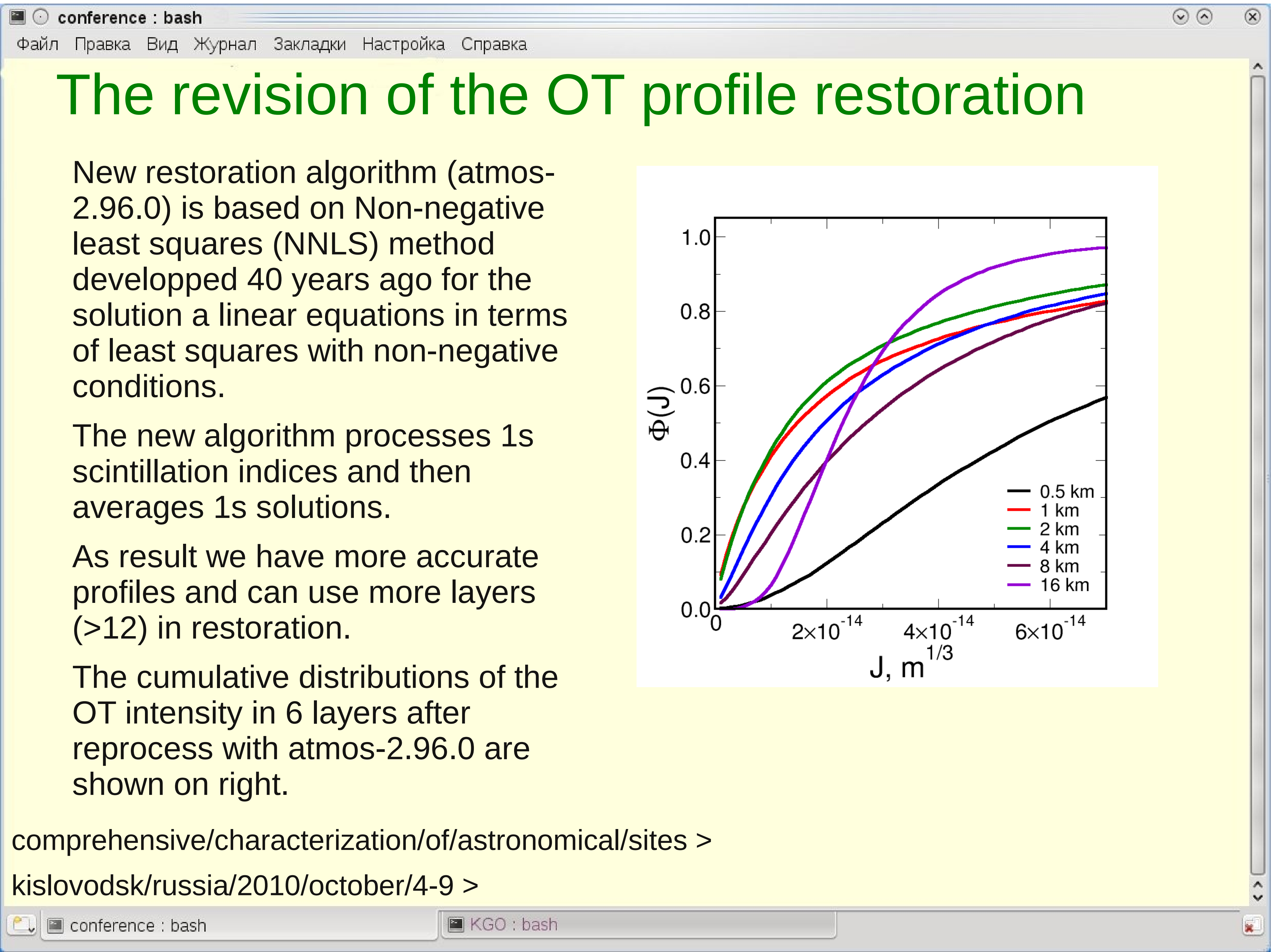

The revision of the OT profile restoration

New restoration algorithm (atmos-2.96.0) is based on Non-negative least squares (NNLS) method developped 40 years ago for the solution a linear equations in terms of least squares with non-negative conditions.

The new algorithm processes 1s scintillation indices and then averages 1s solutions.

As result we have more accurate profiles and can use more layers (>12) in restoration.

The cumulative distributions of the OT intensity in 6 layers after reprocess with atmos-2.96.0 are shown on right.

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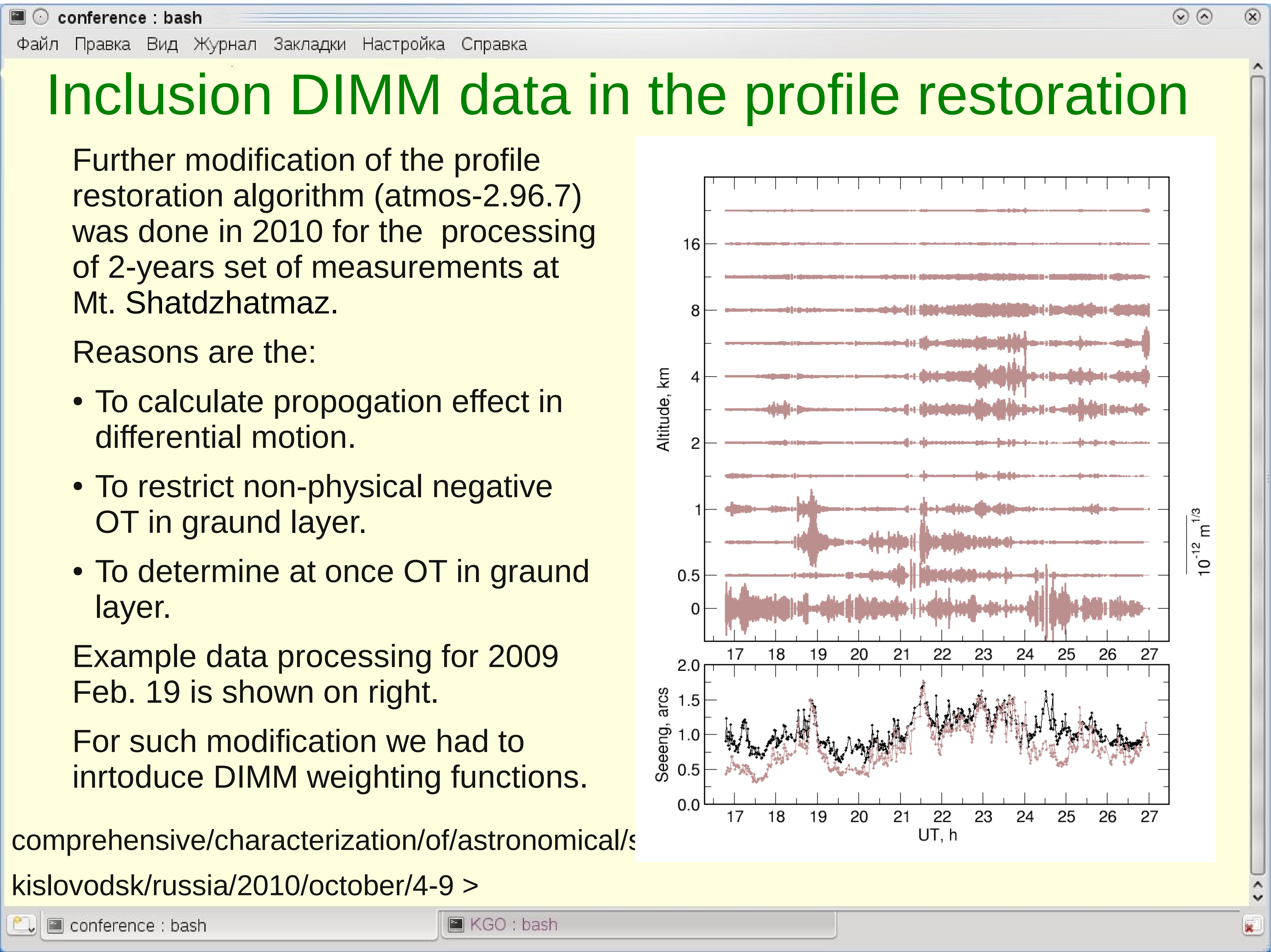

Inclusion DIMM data in the profile restoration

Further modification of the profile restoration algorithm (atmos-2.96.7) was done in 2010 for the processing of 2-years set of measurements at Mt. Shatdzhatmaz.

Reasons are the:

- To calculate propogation effect in differential motion.
- To restrict non-physical negative OT in graund layer.
- To determine at once OT in graund layer.

Example data processing for 2009 Feb. 19 is shown on right.

For such modification we had to inrtoduce DIMM weighting functions.

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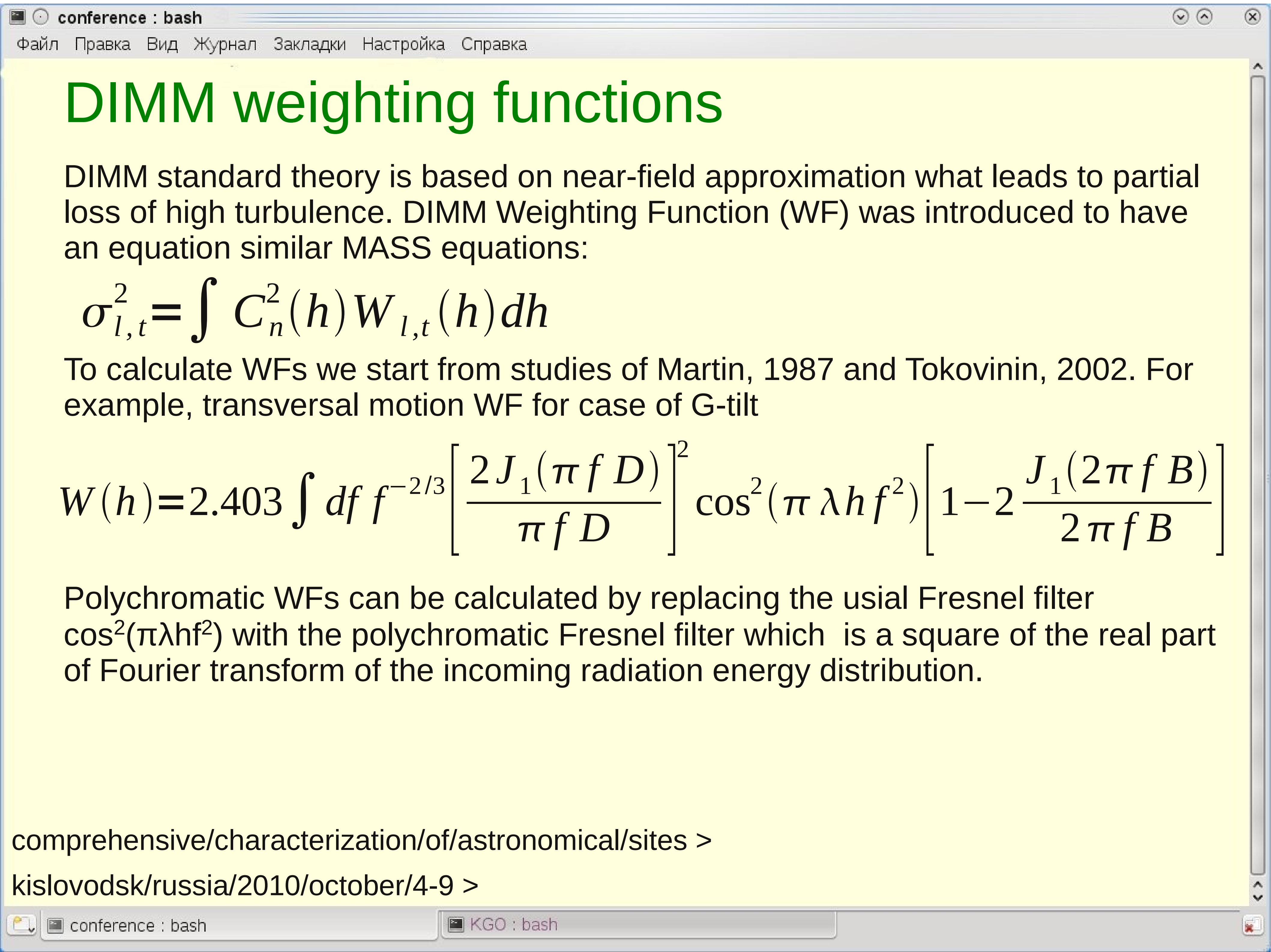

DIMM weighting functions

DIMM standard theory is based on near-field approximation what leads to partial loss of high turbulence. DIMM Weighting Function (WF) was introduced to have an equation similar MASS equations:

$$\sigma^2_{l,t} = \int C_n^2(h)\, W_{l,t}(h)\, dh$$

To calculate WFs we start from studies of Martin, 1987 and Tokovinin, 2002. For example, transversal motion WF for case of G-tilt

$$W(h) = 2.403 \int df\, f^{-2/3} \left[\frac{2 J_1(\pi f D)}{\pi f D} \right]^2 \cos^2(\pi \lambda h f^2) \left[1 - 2 \frac{J_1(2\pi f B)}{2 \pi f B} \right]$$

Polychromatic WFs can be calculated by replacing the usial Fresnel filter $\cos^2(\pi\lambda h f^2)$ with the polychromatic Fresnel filter which is a square of the real part of Fourier transform of the incoming radiation energy distribution.

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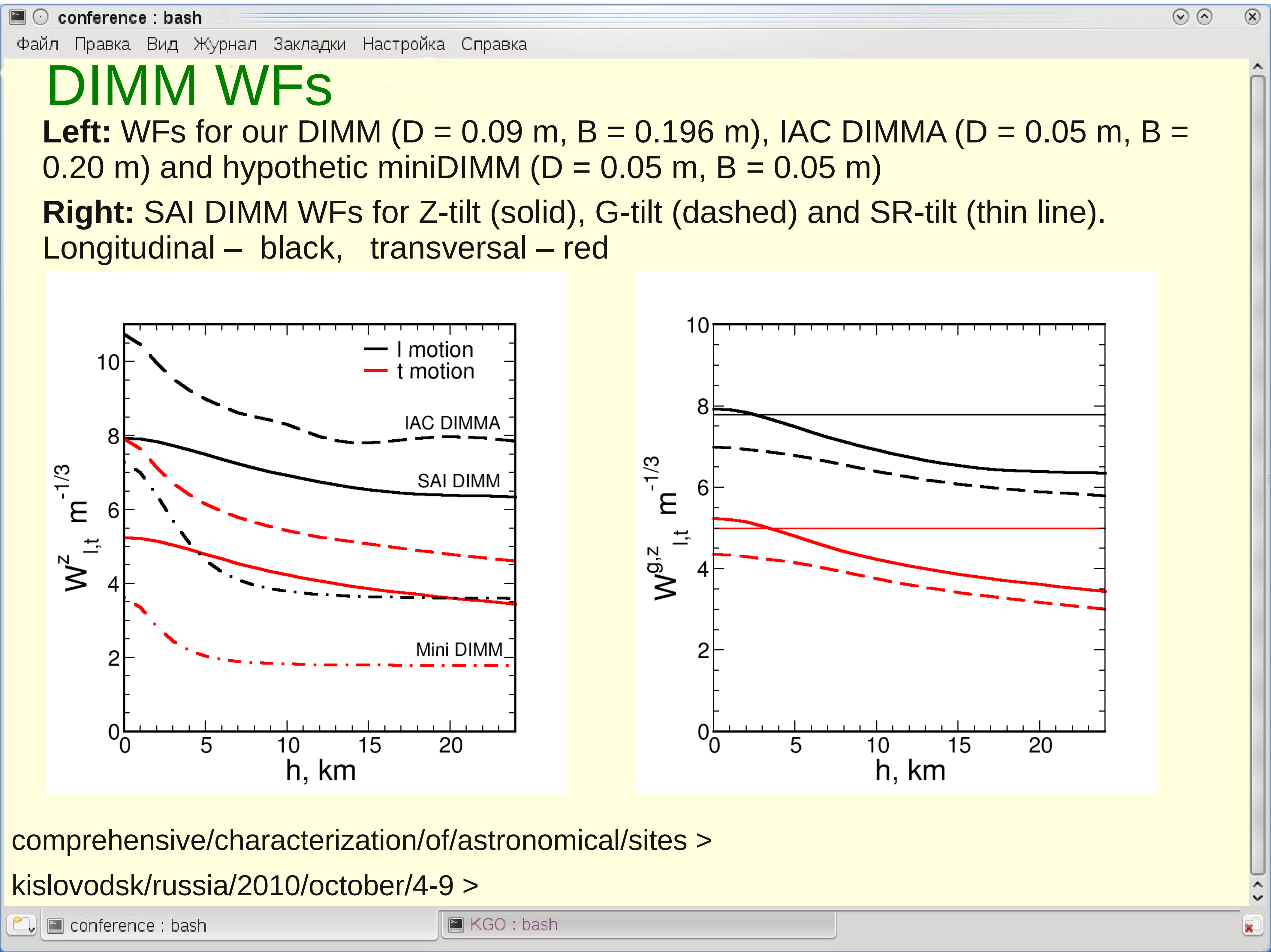

DIMM WFs

Left: WFs for our DIMM (D = 0.09 m, B = 0.196 m), IAC DIMMA (D = 0.05 m, B = 0.20 m) and hypothetic miniDIMM (D = 0.05 m, B = 0.05 m)

Right: SAI DIMM WFs for Z-tilt (solid), G-tilt (dashed) and SR-tilt (thin line). Longitudinal – black, transversal – red

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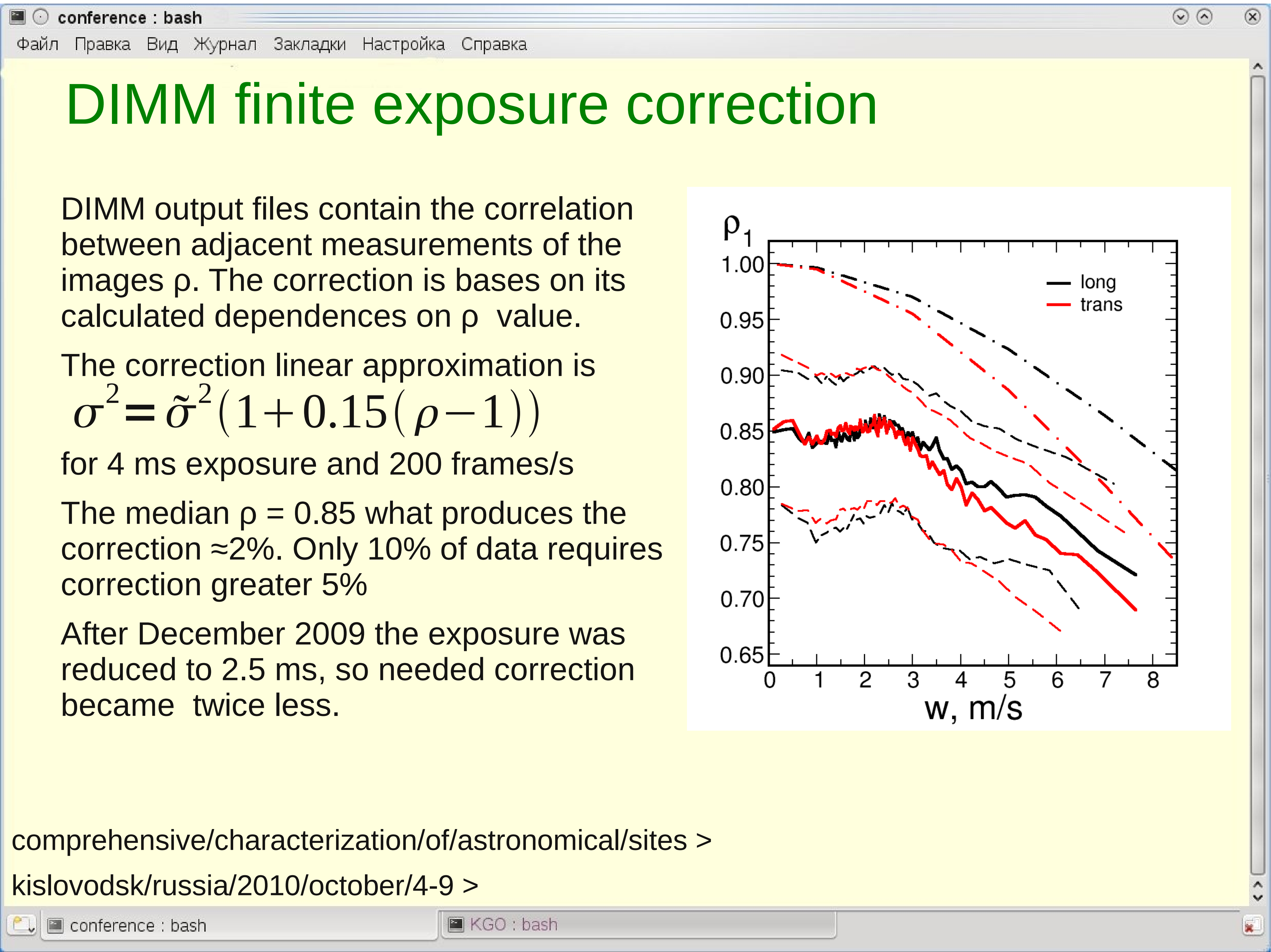

DIMM finite exposure correction

DIMM output files contain the correlation between adjacent measurements of the images ρ. The correction is bases on its calculated dependences on ρ value.

The correction linear approximation is

$$\sigma^2 = \tilde{\sigma}^2(1+0.15(\rho-1))$$

for 4 ms exposure and 200 frames/s

The median ρ = 0.85 what produces the correction ≈2%. Only 10% of data requires correction greater 5%

After December 2009 the exposure was reduced to 2.5 ms, so needed correction became twice less.

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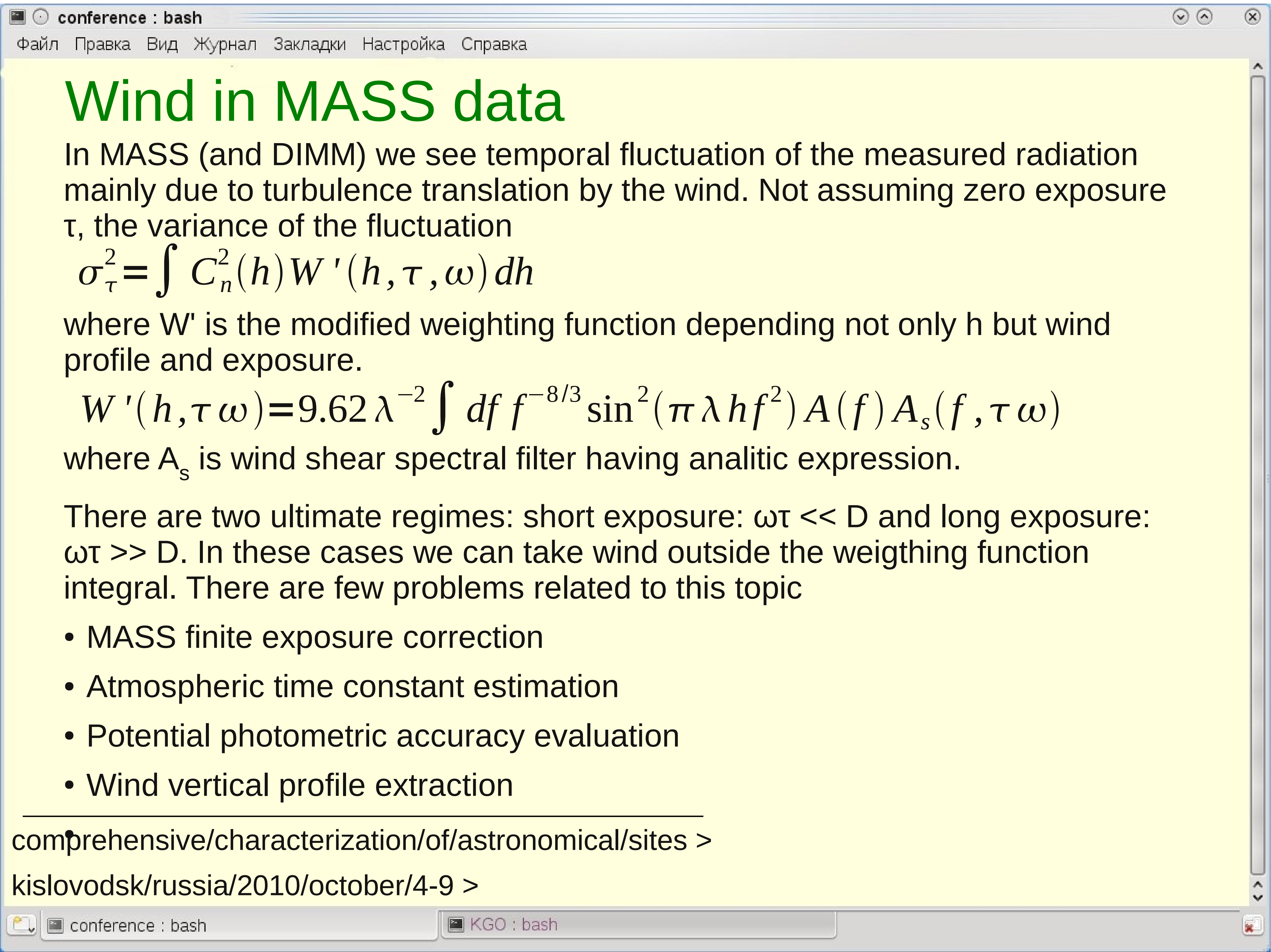

Wind in MASS data

In MASS (and DIMM) we see temporal fluctuation of the measured radiation mainly due to turbulence translation by the wind. Not assuming zero exposure τ, the variance of the fluctuation

$$\sigma_\tau^2 = \int C_n^2(h)\, W'(h,\tau,\omega)\, dh$$

where W' is the modified weighting function depending not only h but wind profile and exposure.

$$W'(h,\tau\omega) = 9.62\,\lambda^{-2} \int df\, f^{-8/3} \sin^2(\pi\lambda h f^2)\, A(f)\, A_s(f,\tau\omega)$$

where A_s is wind shear spectral filter having analitic expression.

There are two ultimate regimes: short exposure: ωτ << D and long exposure: ωτ >> D. In these cases we can take wind outside the weigthing function integral. There are few problems related to this topic

- MASS finite exposure correction
- Atmospheric time constant estimation
- Potential photometric accuracy evaluation
- Wind vertical profile extraction

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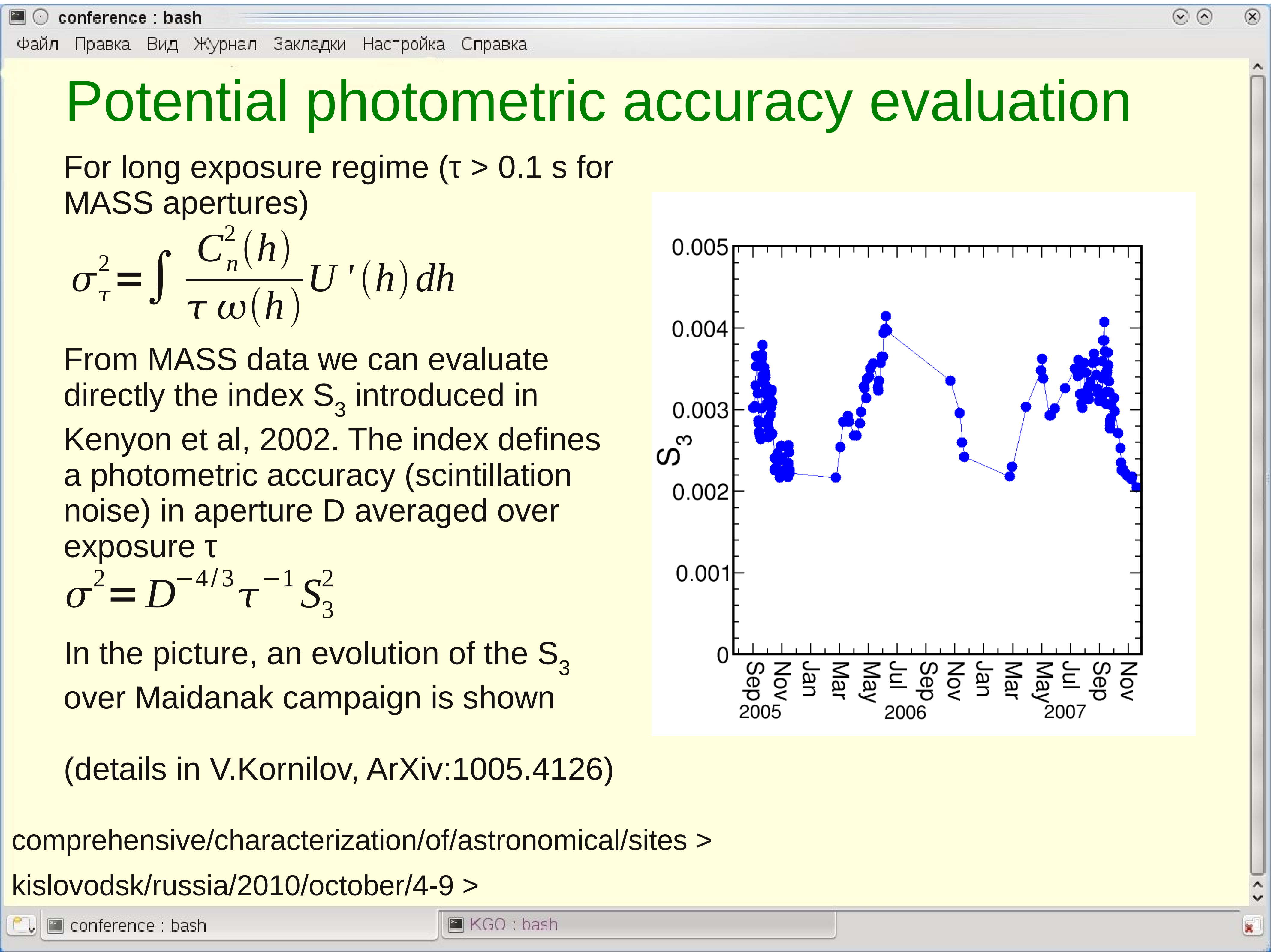

Potential photometric accuracy evaluation

For long exposure regime (τ > 0.1 s for MASS apertures)

$$\sigma_\tau^2 = \int \frac{C_n^2(h)}{\tau\,\omega(h)}\,U'(h)\,dh$$

From MASS data we can evaluate directly the index S_3 introduced in Kenyon et al, 2002. The index defines a photometric accuracy (scintillation noise) in aperture D averaged over exposure τ

$$\sigma^2 = D^{-4/3}\,\tau^{-1}\,S_3^2$$

In the picture, an evolution of the S_3 over Maidanak campaign is shown

(details in V.Kornilov, ArXiv:1005.4126)

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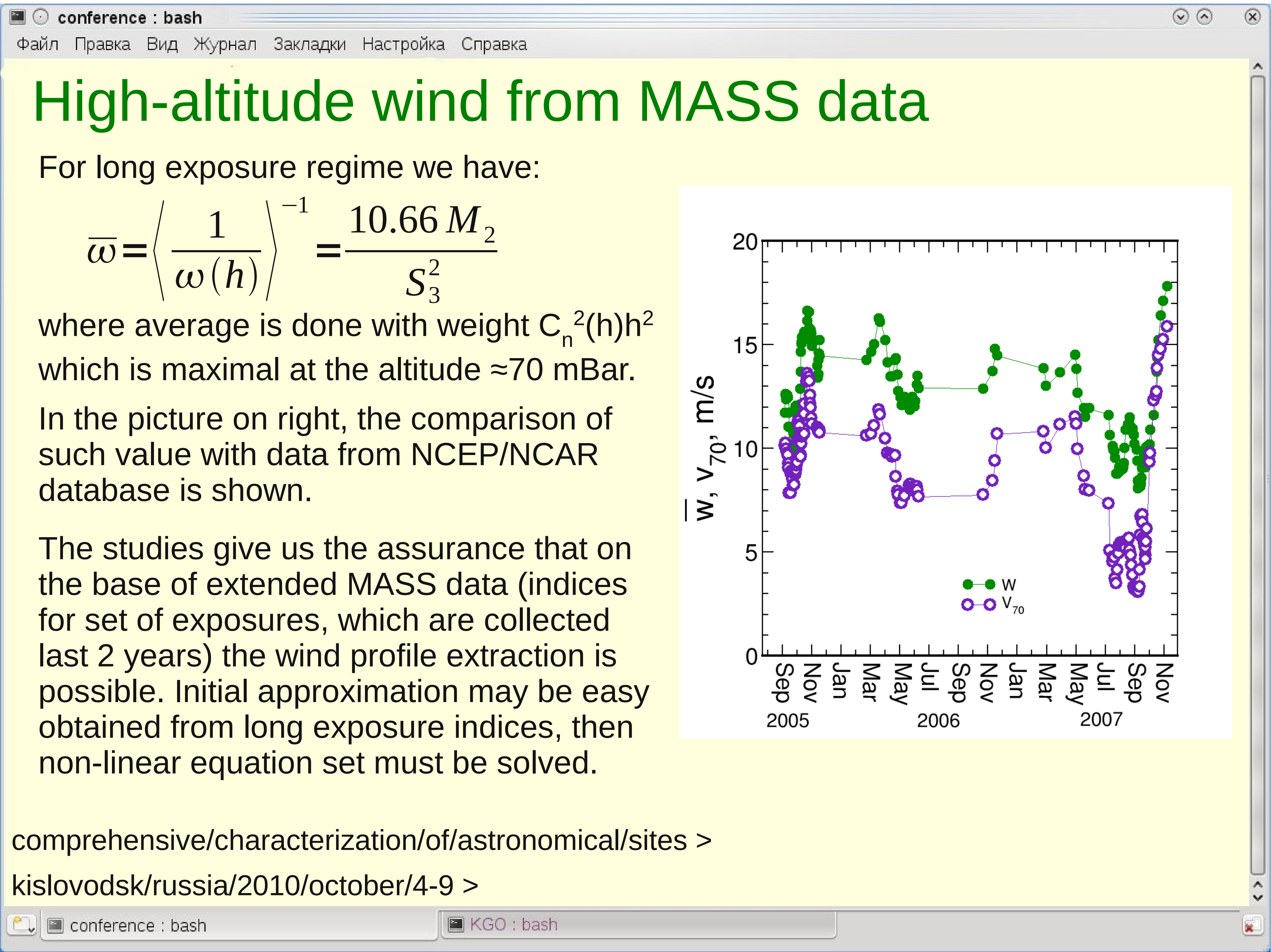

High-altitude wind from MASS data

For long exposure regime we have:

$$\overline{\omega} = \left\langle \frac{1}{\omega(h)} \right\rangle^{-1} = \frac{10.66\,M_2}{S_3^2}$$

where average is done with weight $C_n^2(h)h^2$ which is maximal at the altitude ≈70 mBar.

In the picture on right, the comparison of such value with data from NCEP/NCAR database is shown.

The studies give us the assurance that on the base of extended MASS data (indices for set of exposures, which are collected last 2 years) the wind profile extraction is possible. Initial approximation may be easy obtained from long exposure indices, then non-linear equation set must be solved.

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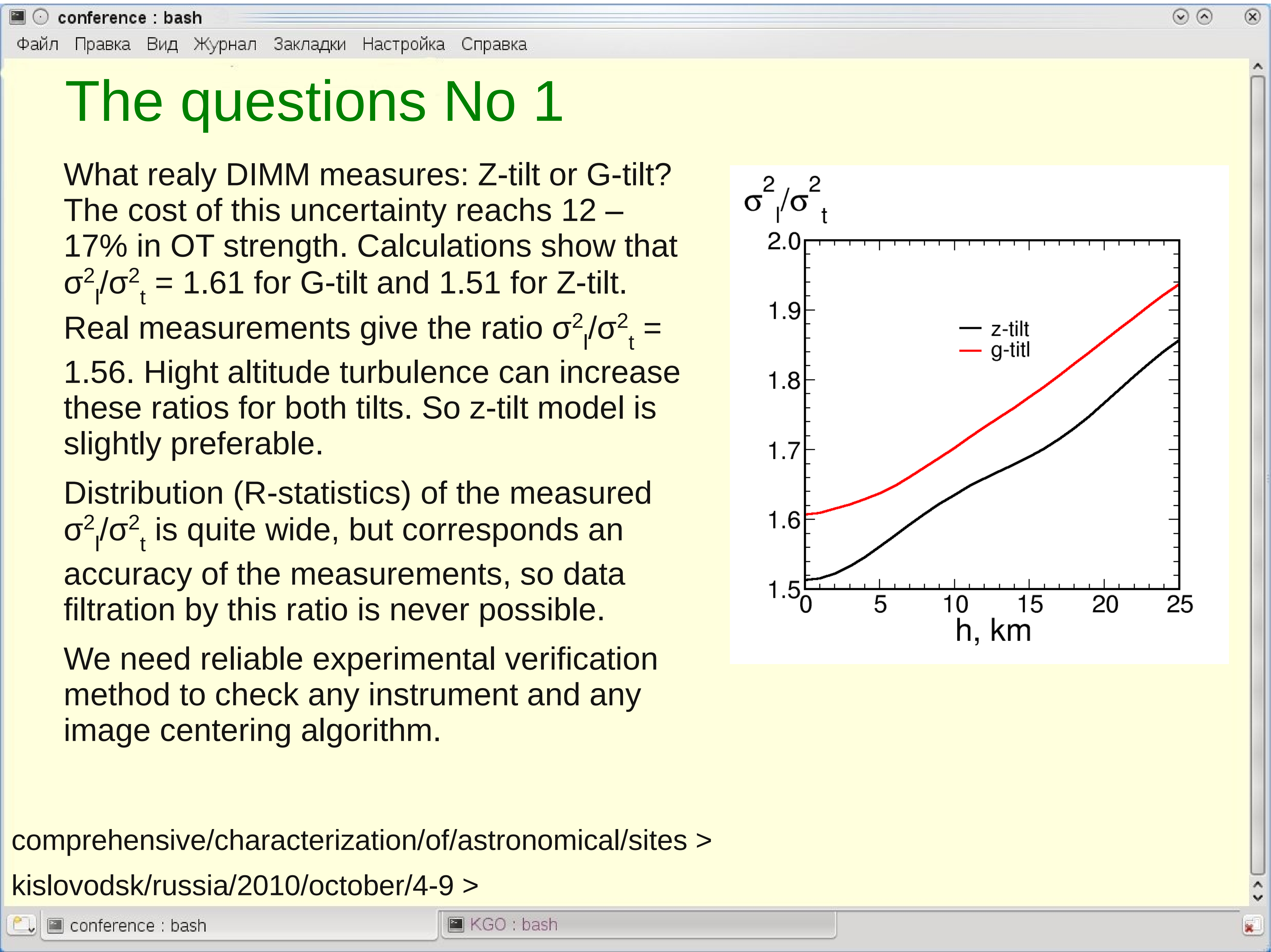

The questions No 1

What realy DIMM measures: Z-tilt or G-tilt? The cost of this uncertainty reachs 12 – 17% in OT strength. Calculations show that σ^2_l/σ^2_t = 1.61 for G-tilt and 1.51 for Z-tilt. Real measurements give the ratio σ^2_l/σ^2_t = 1.56. Hight altitude turbulence can increase these ratios for both tilts. So z-tilt model is slightly preferable.

Distribution (R-statistics) of the measured σ^2_l/σ^2_t is quite wide, but corresponds an accuracy of the measurements, so data filtration by this ratio is never possible.

We need reliable experimental verification method to check any instrument and any image centering algorithm.

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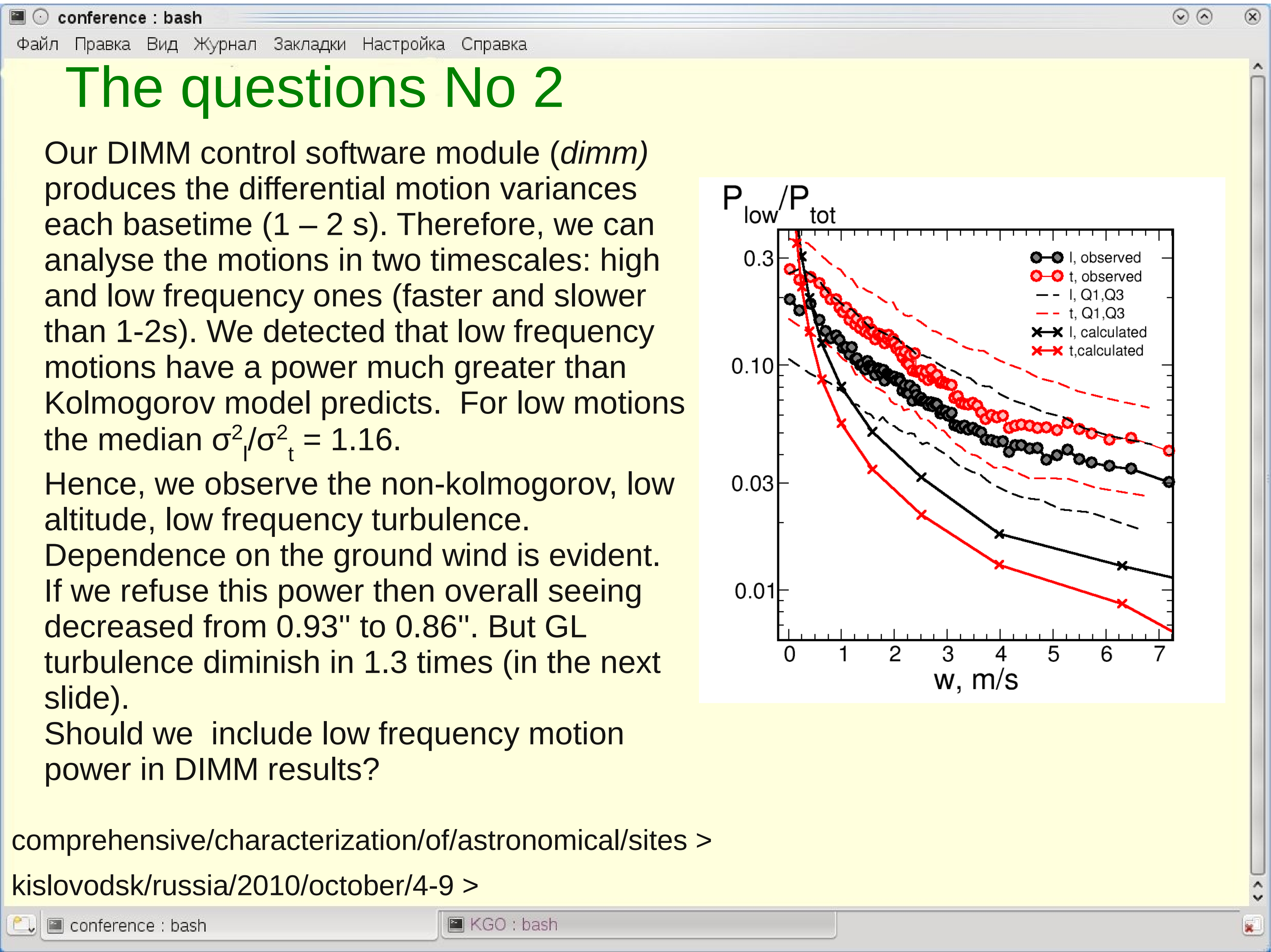

The questions No 2

Our DIMM control software module (*dimm)* produces the differential motion variances each basetime (1 – 2 s). Therefore, we can analyse the motions in two timescales: high and low frequency ones (faster and slower than 1-2s). We detected that low frequency motions have a power much greater than Kolmogorov model predicts. For low motions the median $\sigma^2_l/\sigma^2_t = 1.16$.

Hence, we observe the non-kolmogorov, low altitude, low frequency turbulence.
Dependence on the ground wind is evident.
If we refuse this power then overall seeing decreased from 0.93'' to 0.86''. But GL turbulence diminish in 1.3 times (in the next slide).
Should we include low frequency motion power in DIMM results?

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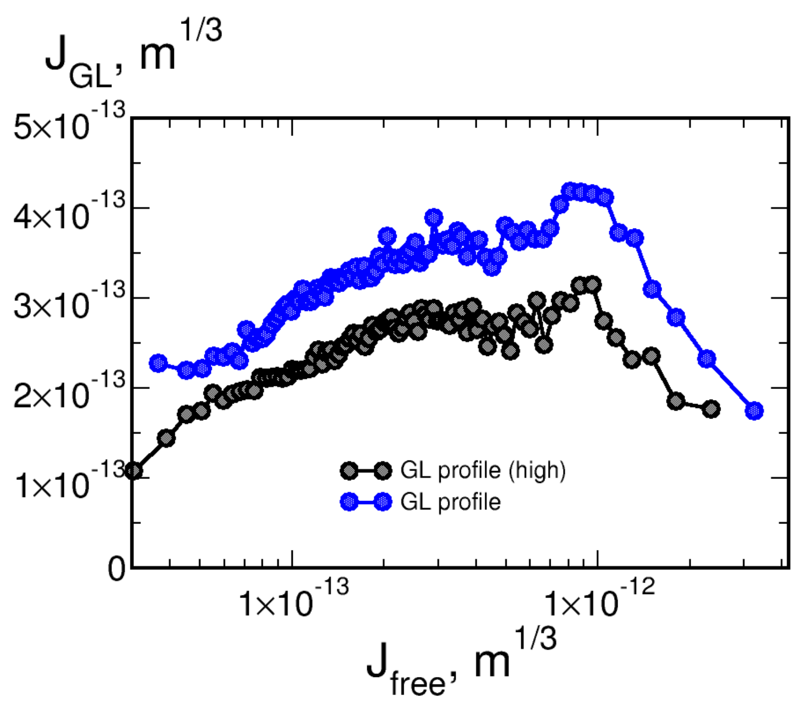
The questions No 3

In the last version *atmos-2.96.9* the strong scintillation correction was excluded. Only exact conversion of Rytov variances to scintillation indices was implemented. It is not enough – see picture on right.

The impact of strong scintillation is shown as sharp drop after 10^{-12} $m^{1/3}$ free atmosphere OT intensity. More important this effect in the range $10^{-13}\ldots10^{-12}$ $m^{1/3}$, where it is unevident.

Unfortunately, there is no clear theoretical description of the effect for real astronomical condition.



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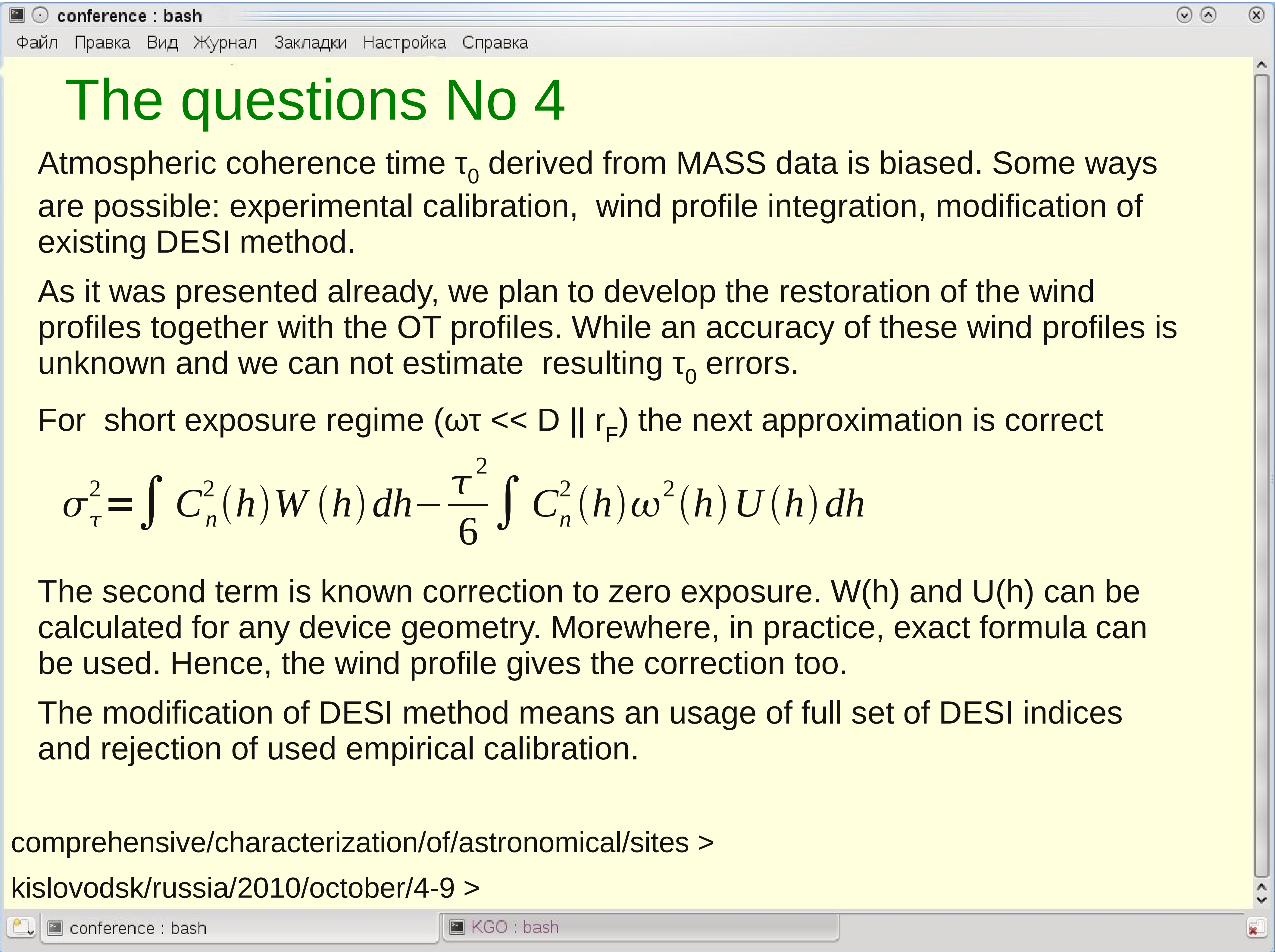

The questions No 4

Atmospheric coherence time τ_0 derived from MASS data is biased. Some ways are possible: experimental calibration, wind profile integration, modification of existing DESI method.

As it was presented already, we plan to develop the restoration of the wind profiles together with the OT profiles. While an accuracy of these wind profiles is unknown and we can not estimate resulting τ_0 errors.

For short exposure regime ($\omega\tau << D \,||\, r_F$) the next approximation is correct

$$\sigma_\tau^2 = \int C_n^2(h) W(h)\, dh - \frac{\tau^2}{6} \int C_n^2(h) \omega^2(h) U(h)\, dh$$

The second term is known correction to zero exposure. W(h) and U(h) can be calculated for any device geometry. Morewhere, in practice, exact formula can be used. Hence, the wind profile gives the correction too.

The modification of DESI method means an usage of full set of DESI indices and rejection of used empirical calibration.

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