Results of astroclimate parameters measurements at the Caucasus highland observatory of Sternberg institute of Moscow University (KGO SAI) in 2007 – 2008.

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Astroclimate site monitor (ASM) of SAI

at Mt. Shatzhatmaz

Photo of N.Shatsky and A.Belinsky, July 2008

Aims of study of optical turbulence and other 2.5m telescope site parameters

Primary goal is the collection of the statistically reliable data on seeng and altitude atmospheric optical turbulence distribution at the Sternberg institute 2.5m telescope installation site.

Additional goals – accumulation of information on clear nights frequency and measurement of the weather parameters at the site.

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Wavefront propagation through turbulent atmosphere

Refraction index fluctuations (optical turbulence) cause phase distortions of the lightwaves.

While propagating, phase distortions convert to amplitude distortions.

In the space scales 1cm to 10m (optical telescope sizes), these fluctuations obey Kolmogorov law.

The turbulence intensity at a given altitude is fully described by the refractive index structure function coefficient $C_n^2(h)$

The main parameter characterizing the integral influence of the turbulent atmosphere is the Fried radius:

$$r_0 \sim \left[\int C_n^2(h) \cdot dh \right]^{-3/5}$$

and the derived parameter – image quality (seeing):

$$\beta = 0.98 \frac{\lambda}{r_0}$$

What we know from optical turbulence measurement

Seeing defines the efficiency of a telescope in a classical imaging mode at a given site

Fried radius – the basic unit for modeling of the adaptive optics systems (AO), meanwhile not the sole one

The layout and parameters of the optimal AO are determined by the knowledge of altitude turbulence distribution

Altitude optical turbulence distribution defines the precision of photometric and astrometric measurements

Statistical properties of these quantities help to develop the strategy of the telescope use

Realtime turbulence data acquisition is used for prompt operative planning of observations

General understanding of the phenomenon of the turbulent atmosphere behavior is crucial for well-directed site search for future large and giant optical telescopes

MASS – multi-aperture stellar scintillation sensor

Measured scintillation indices:

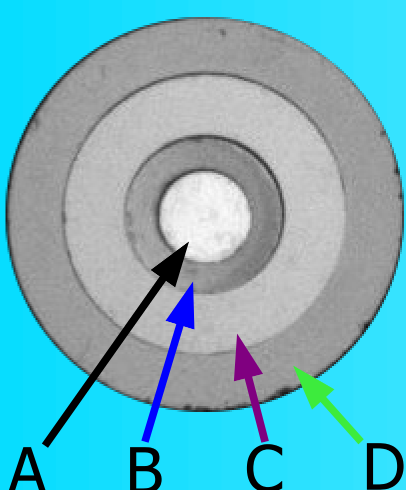
normal $$s^2 = \langle (\Delta \ln I)^2 \rangle$$

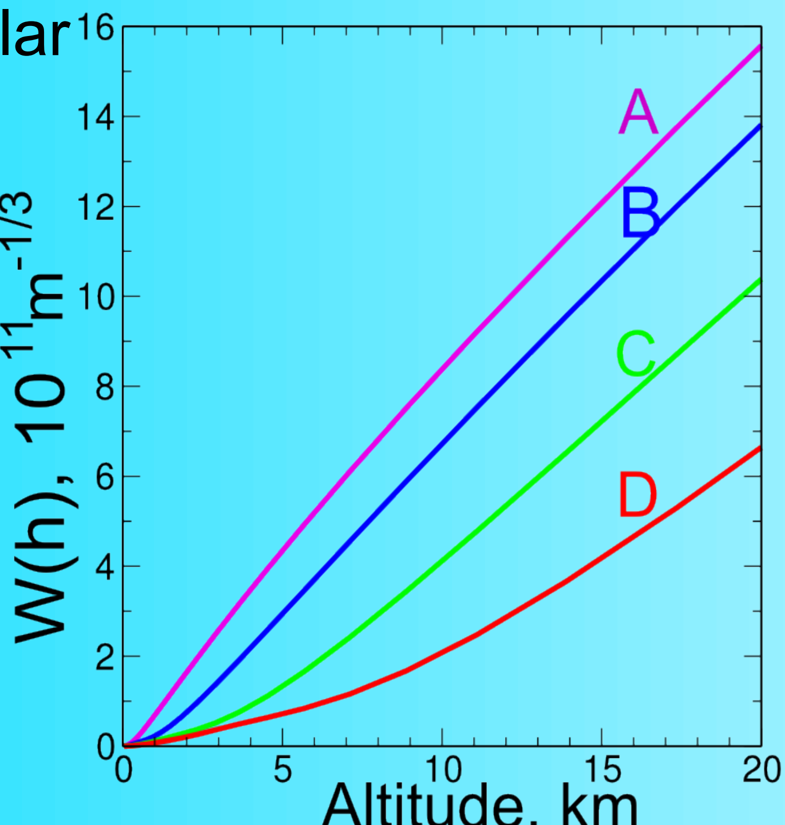
differential $$s_d^2 = \langle (\Delta \ln (\frac{I_1}{I_2}))^2 \rangle$$

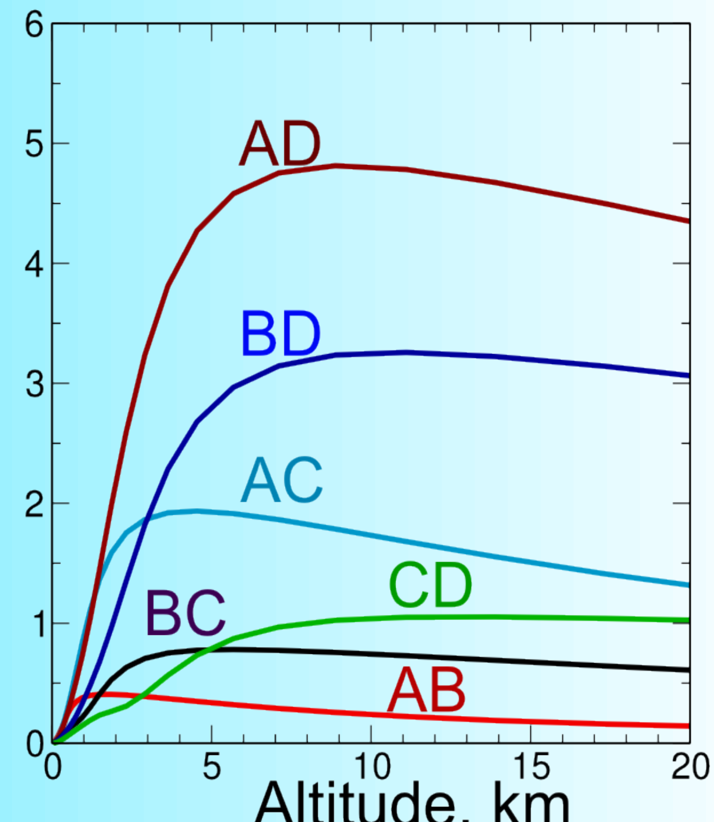
theoretical scintillation index $$s^2 = \int C_n^2(h) \cdot W(h)\, dh$$

where $W(h)$ is aperture geometry-computed weighting function

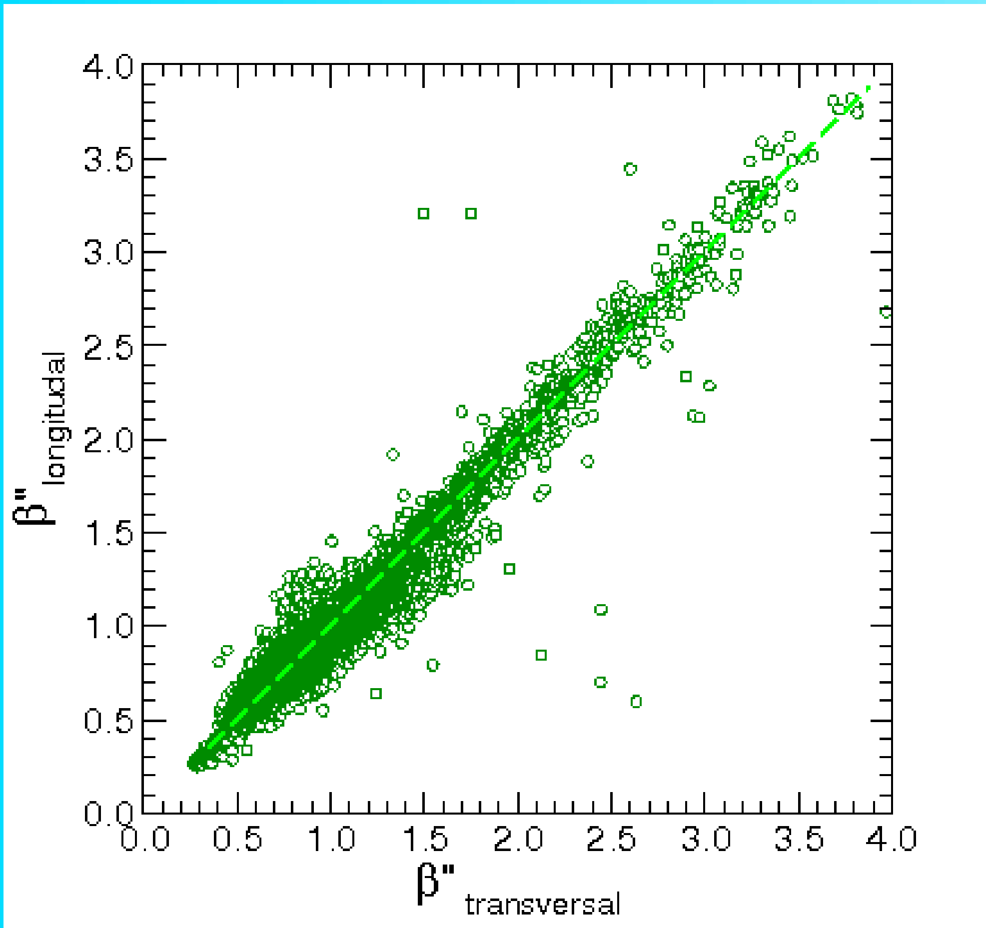
For the annular geometry:







DIMM – differential stellar image motion monitor



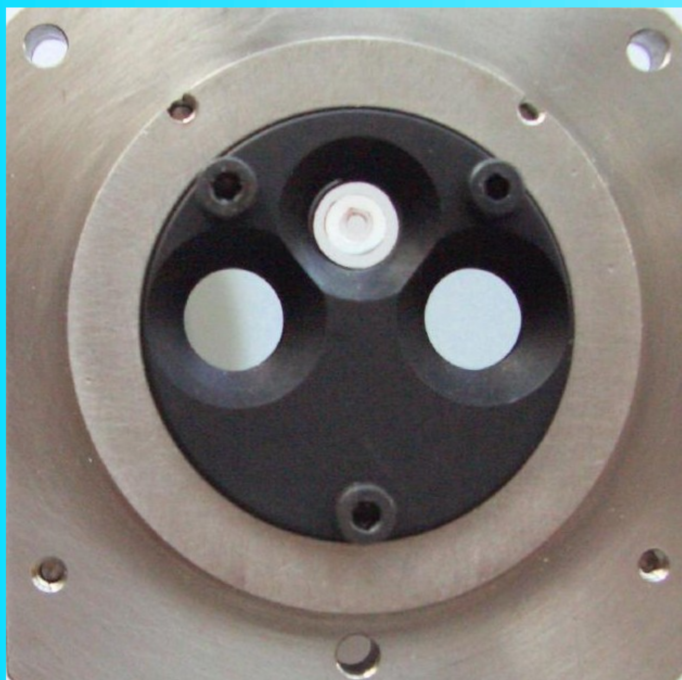
The basic relation which ties the measured differential image motion with the Fried radius (i.e. with image quality or seeing):

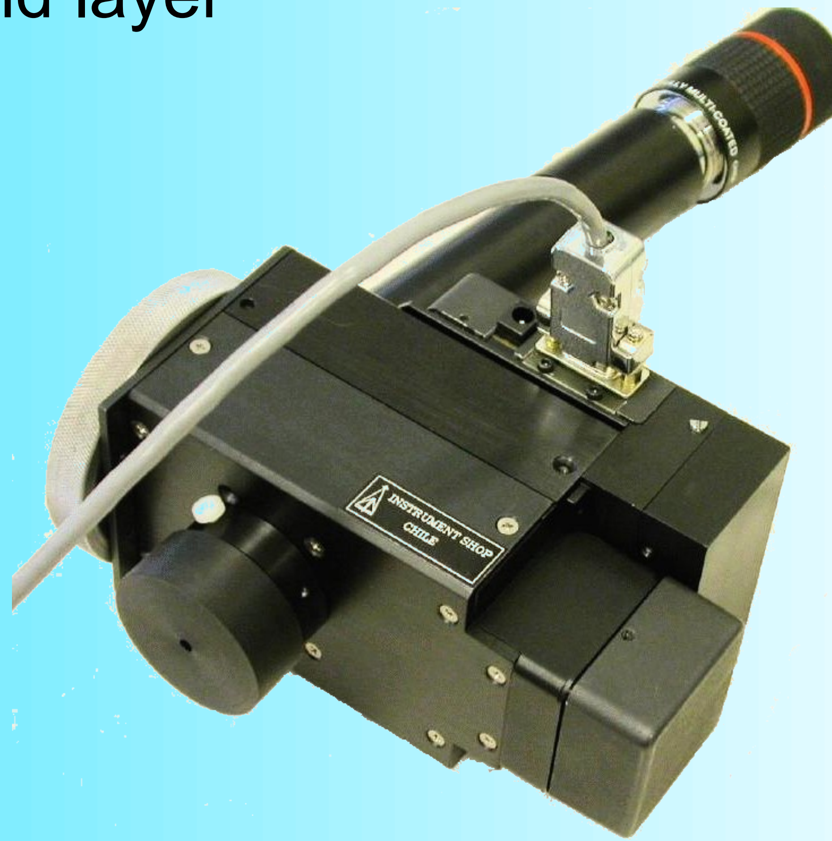
$$\sigma_{l,t}^{2} = K_{l,t} (\lambda / D)^{2} (D / r_{0})^{5/3}$$

Indices *l* and *t* relate to longitudinal and tangential wavefront distortions (random slopes).

Combined MASS/DIMM device

allows the turbulence study through all the atmosphere including the ground layer





- the single feeding telescope is utilised
- the same line-of-site is involved in both device operations
- the measurements are time-synchronised
- These circumstances allow the combination of the two methods results for restoration of the complete altitude turbulence profile.

The electricity supply problem

Digging a cable drain in July 2008

After a two-year fight for energy and continuous repairs of a wind-generator after each serious storm, the problem was solved by laying of a 800m cable from Pulkovo solar station to the site. ASM is still fed autonomously (due to halvanic security reasons) but batteries are routinely charged once a 7-15 days.

Feeding telescope problems

The RCX400 scope with MASS/DIMM device and a custom 3-pipe dew-cap. March 2008.

Four ways of Meade driving were assayed in 18 months of exploitation.

Three problems remained unresolved:

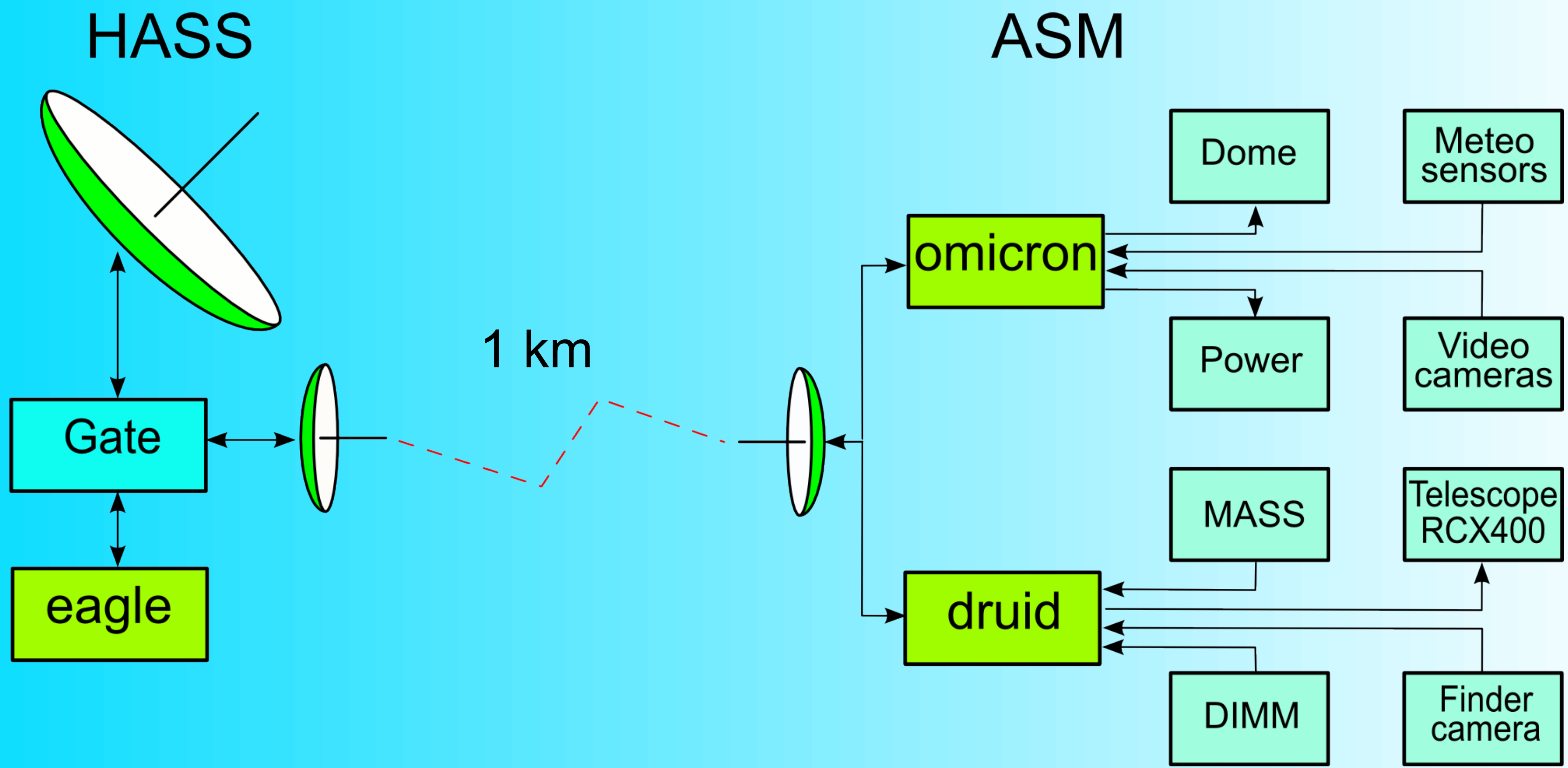
Focusing gradually violates collimation

CCD-Finder and OTA axes diverge with time (effect also depends on temperature)

Once a 2-3 weeks the scope orientation fails (due to its firmware features)

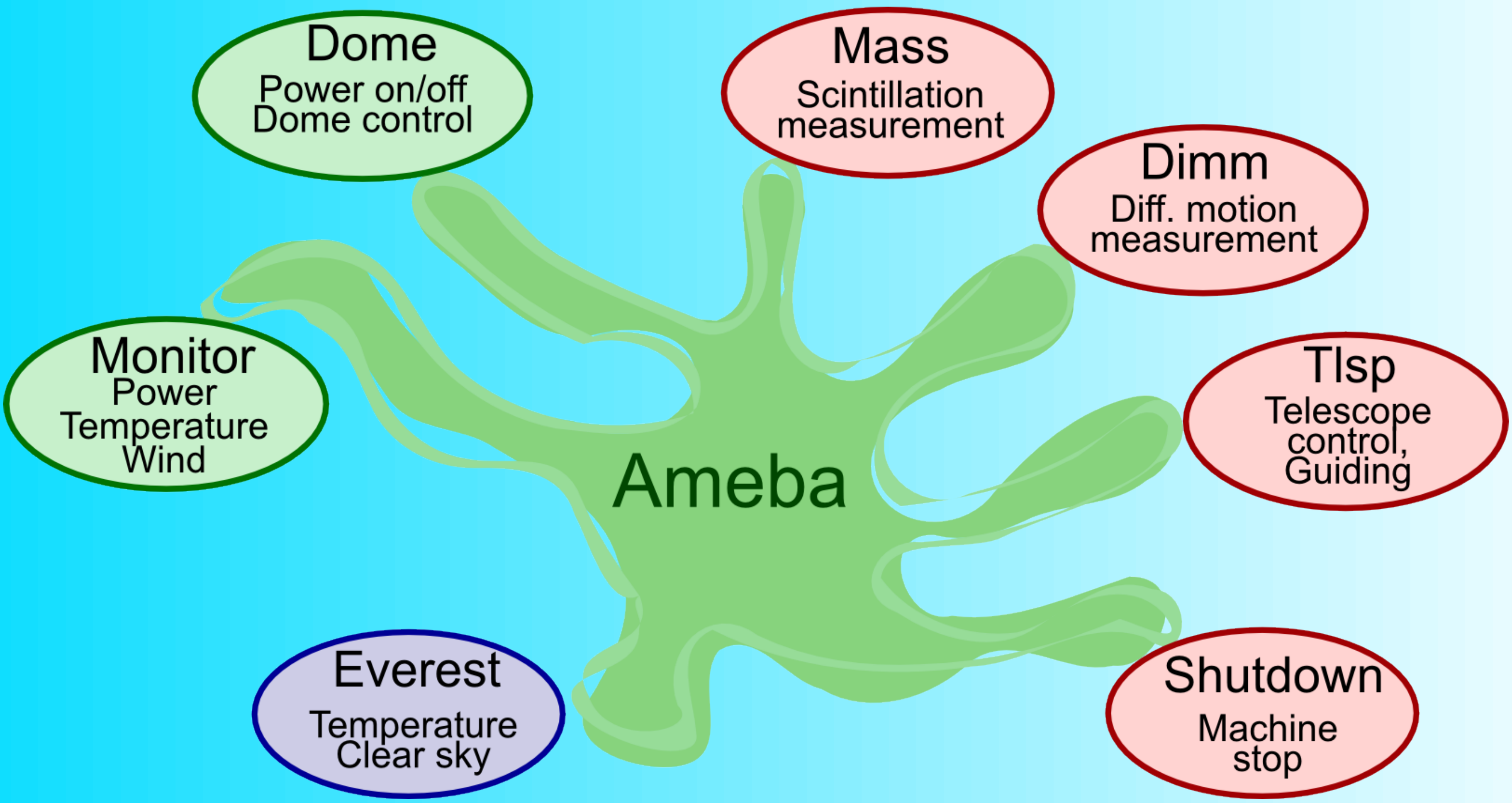
Nevertheless, 1926 pointing were already made successfully

Data flow structure



Computer eagle – system control, http-server, data storage
Computer omicron – link to KHSS, dome control, auxilliary web-cameras control, weather sensors, power control
Computer druid – telescope and MASS/DIMM control, data acquisition and primary processing

Software structure

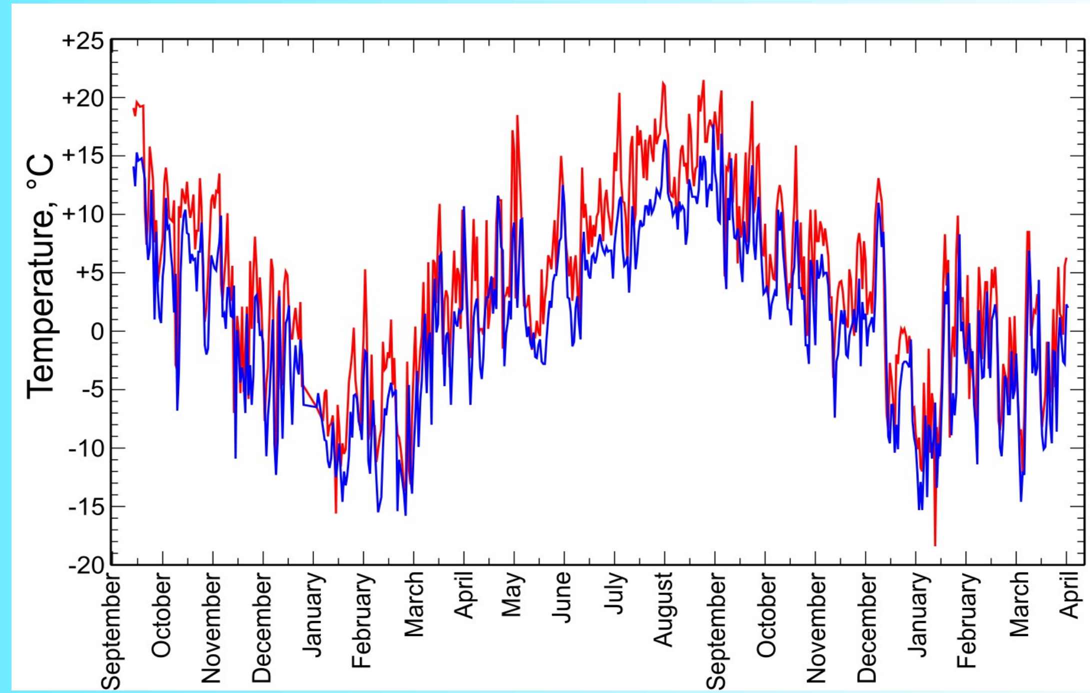


The brain of a robotic system (Ameba program) interfaces to 7 component programs running on 3 machines via socket connections. Each component program runs in a background and serves its dedicated functions. These programs fire up in a computer startup time or by a cron table.

Factors of automatic (scheduler) work

Night beginning and end moments calculation (Hsun<-12°)
Tracing the timeouts, skies clearness, wind speed and power supply
In case measurements allowed, startup of observation session
Open dome, working computer (druid) startup, connect to component programs, hardware initialization.
Select a program star by brightness, airmass, Moon distance, available measurement duration
Pointing to the star, centering, flux verification, guiding startup
Measurement up to 1.5h or until any observation conditions violation
Measurement of background (before and after a program star and at least once an hour)
In case flux drops below a threshold (clouds?) - point to another star. In case of 3 unsuccessful pointing (too much extinction?): end of observations session and make a 20-30min timeout.
Session is start up again when conditions allow so
Full shutdown at sunrise (Hsun>-12°)

Weather data



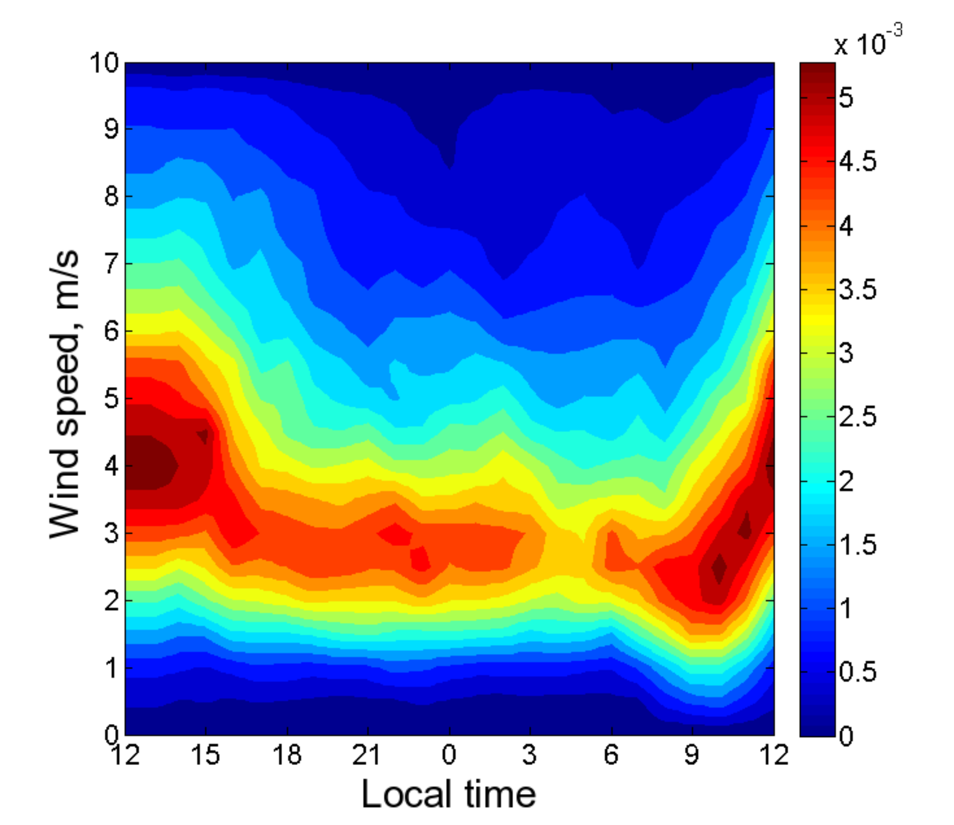
Temperature variation history from Sep-2007 to April-2009. Red are midday and blue are midnight temperatures.

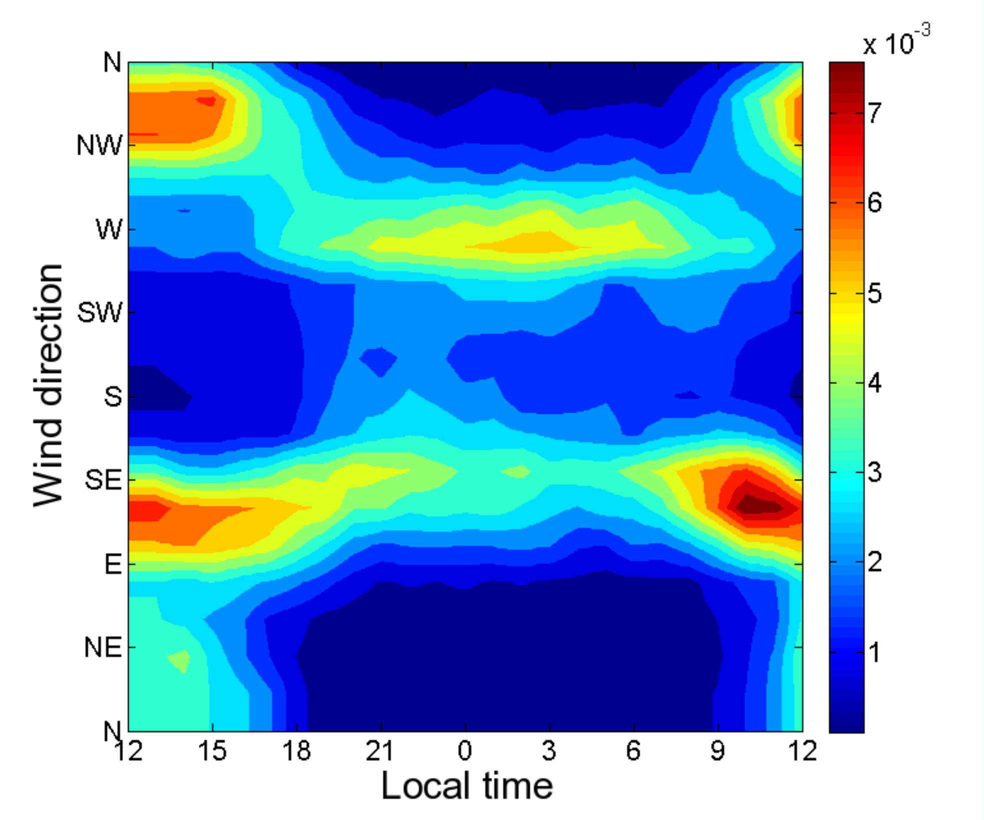
Wind speed in clear night statistics

25%	50%	75%	98%
<1.4	<2.3	<3.6	<9.0

Weather data

from September 2007 to March 2009

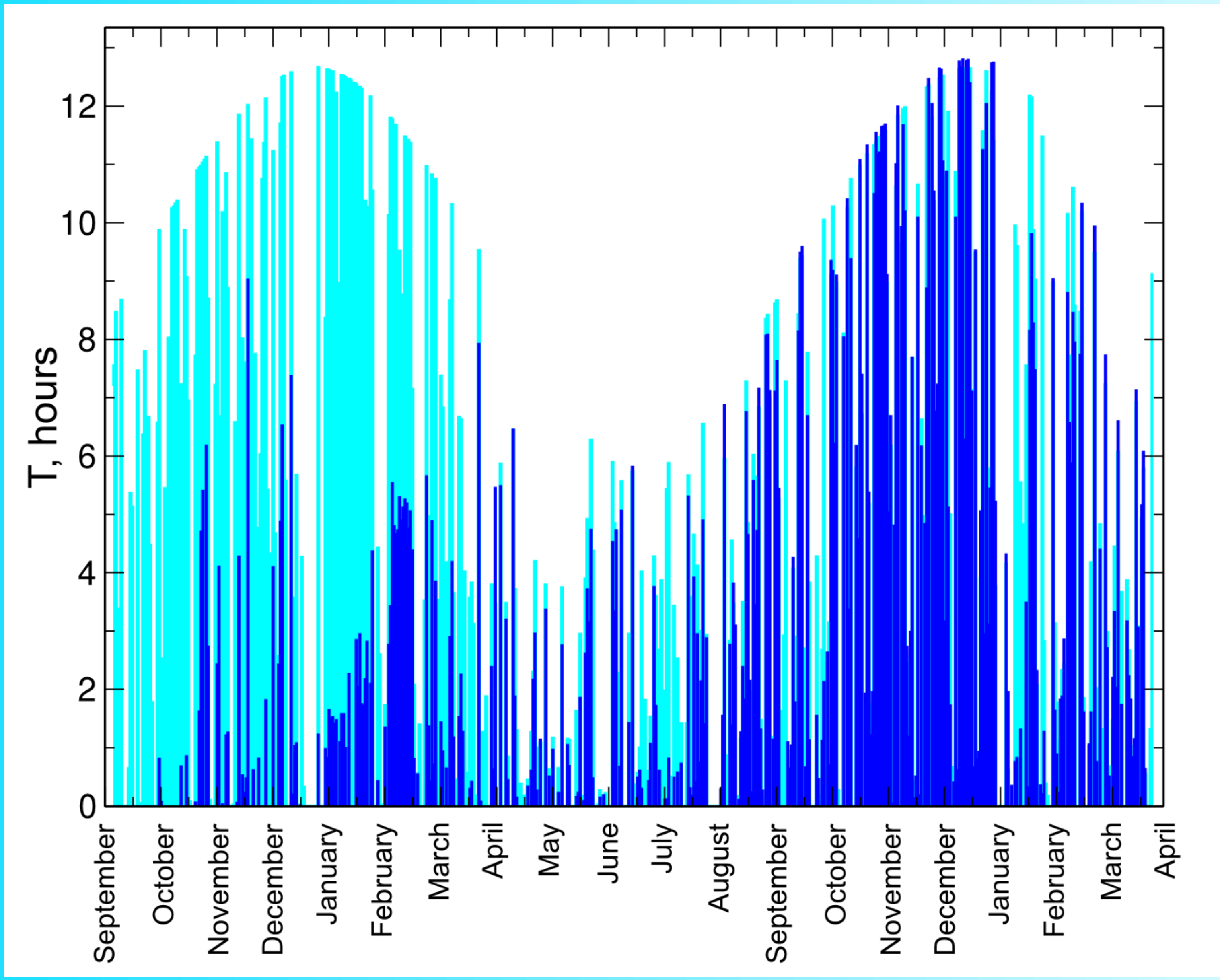




Left: 2D probability density distribution in localtime — windspeed space. Right: the same in localtime -winddirection space. It is clear that the windspeed is lower in night and this time is dominated by western winds. Another favoured wind direction (SE) is also prominent.

Clear night time and measurements coverage

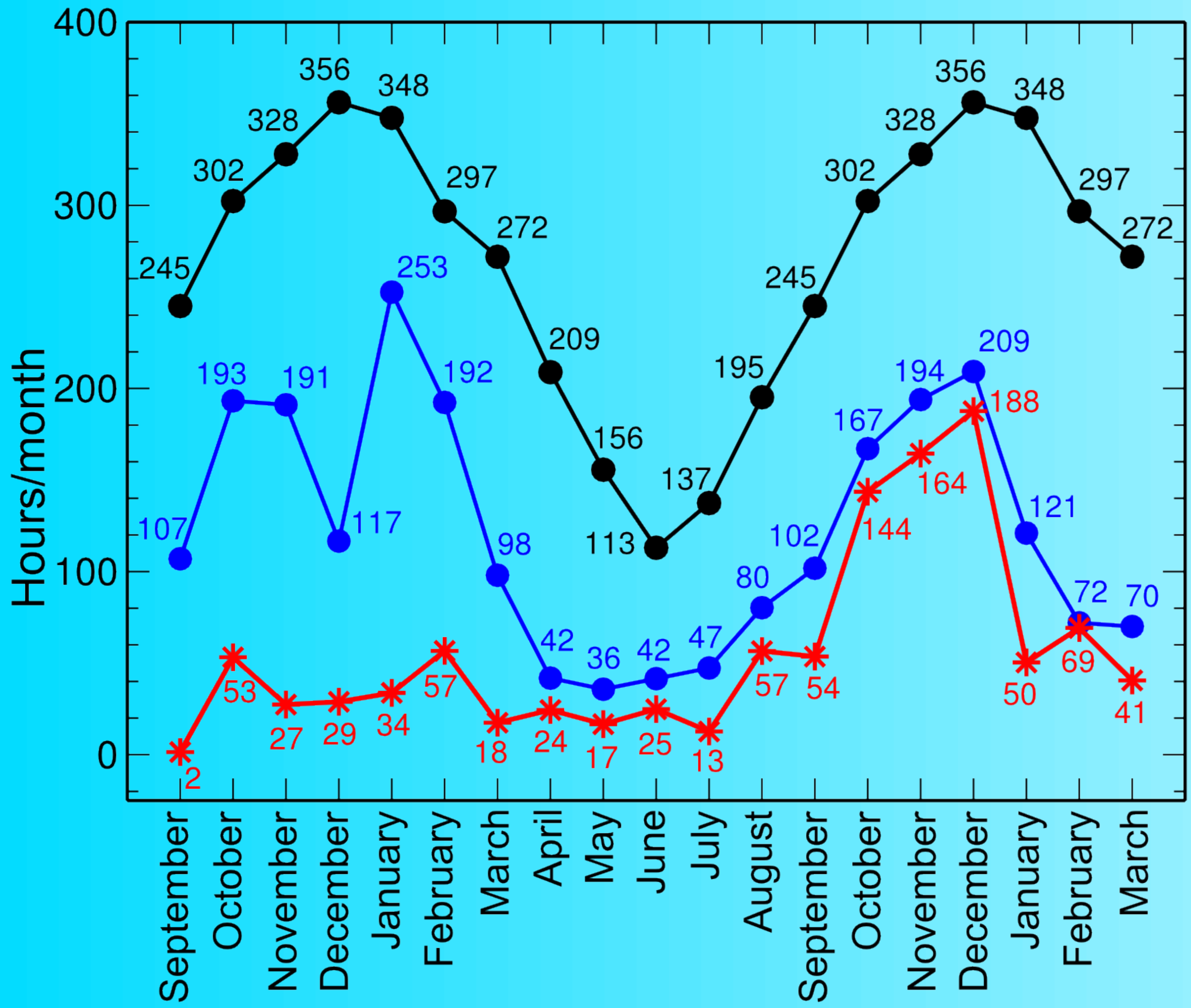
from 1 September 2007 to 1 April 2009



For each calendar night two bars are plotted: cyan bars — duration of clear night time, blue bars — measurement duration.

Clear night time & observation time statistics

from 1 September 2007 to 1 April 2009



Total night time duration 5105 hours

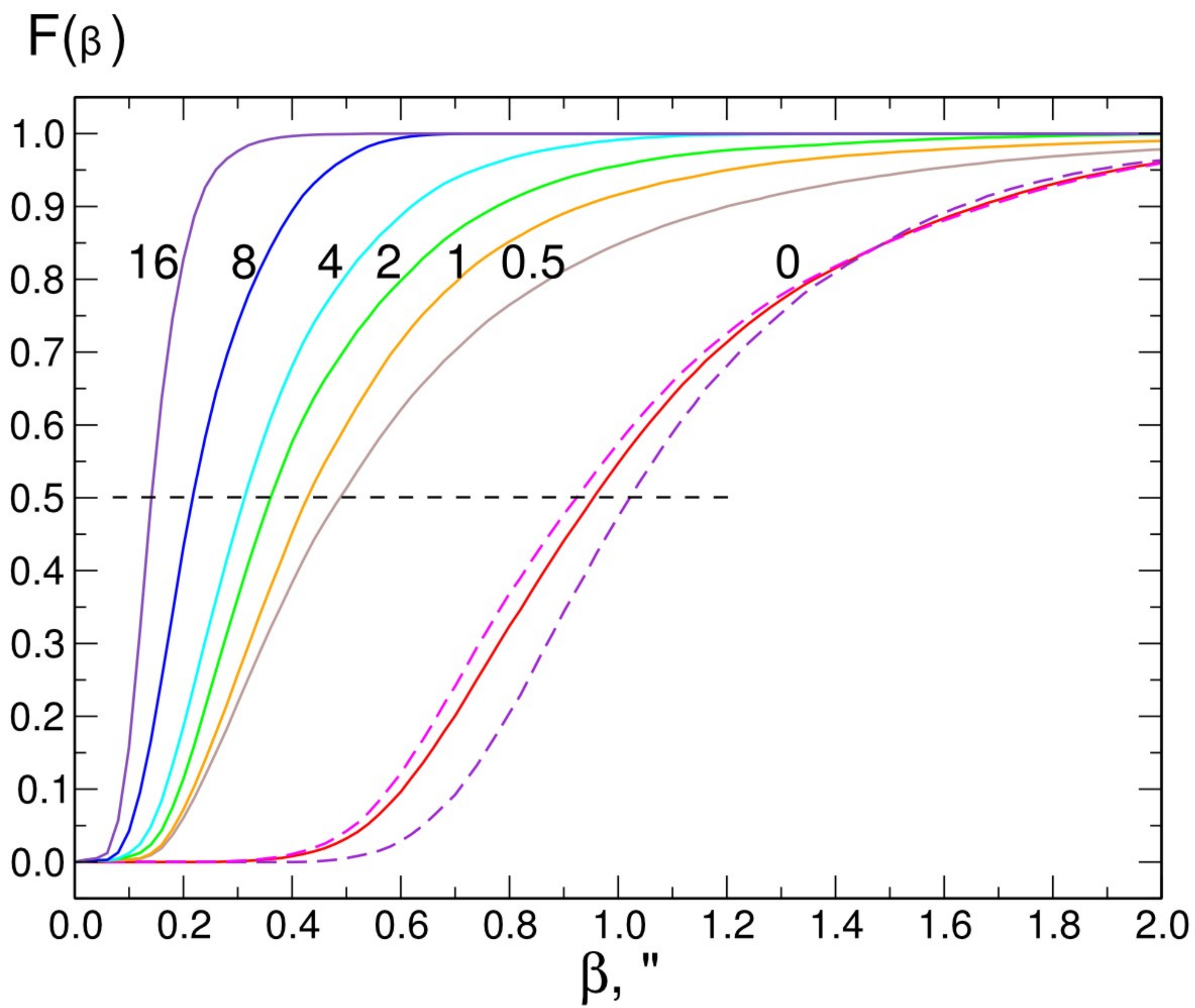
Total clear night time 2461 hours

Sum of observations duration 1326 hours

Total measurement (exposure) duration 1064 hours

Black curve – total monthly duration of astronomical night time. Blue — total monthly duration of clear night time. Red — monthly sum of measurements duration

Seeing statistics



Cumulative distributions of seeing for different parts of atmsphere: 0 — total thickness, 0.5 — a half-kilometer layer and above, 1 — layer 1km and above etc. These layers are those which intensity is restored from MASS scintillation measurements.

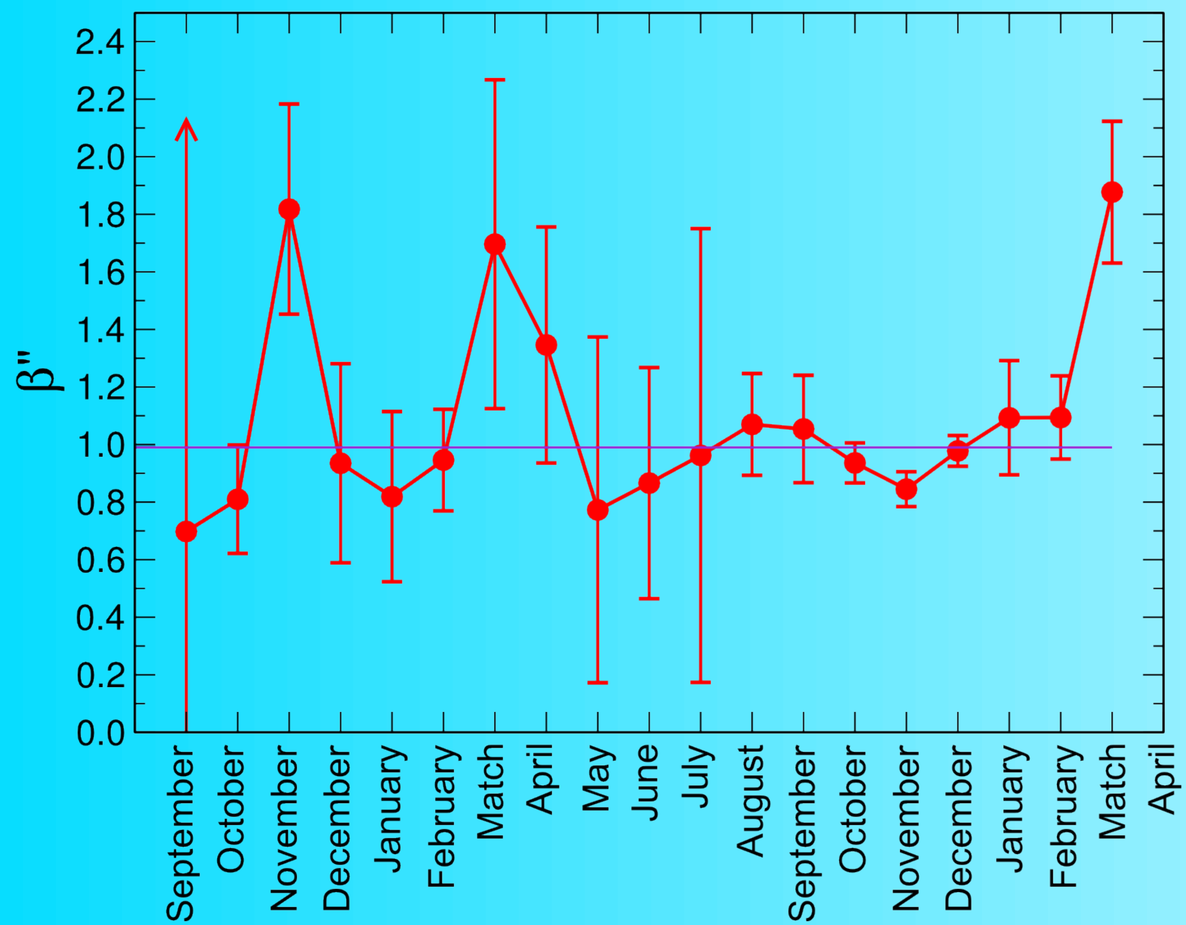
Magenta and violet dashed lines — total seeing in winter and summer, respectively

Image quality (seeing)

Distribution	25%	50%	75%
DIMM (total of data)	0.77	0.99	1.32
DIMM (summer months)	0.83	1.04	1.30
DIMM (winter months)	0.76	0.98	1.33
MASS (0.5 – 16 km)	0.35	0.54	0.90
MASS (1 – 16 km)	0.31	0.46	0.71
MASS (2 – 16 km)	0.26	0.38	0.59
MASS (4 – 16 km)	0.23	0.33	0.49
MASS (8 – 16 km)	0.17	0.23	0.33
MASS (16 km layer)	0.11	0.14	0.18

Backward history of seeing statistics: DIMM data up to 15/02/2008: median seeing is 0.96'', up to 01/12/2008: median seeing is 0.95''. Statistics worsens from December 2008 to March 2009

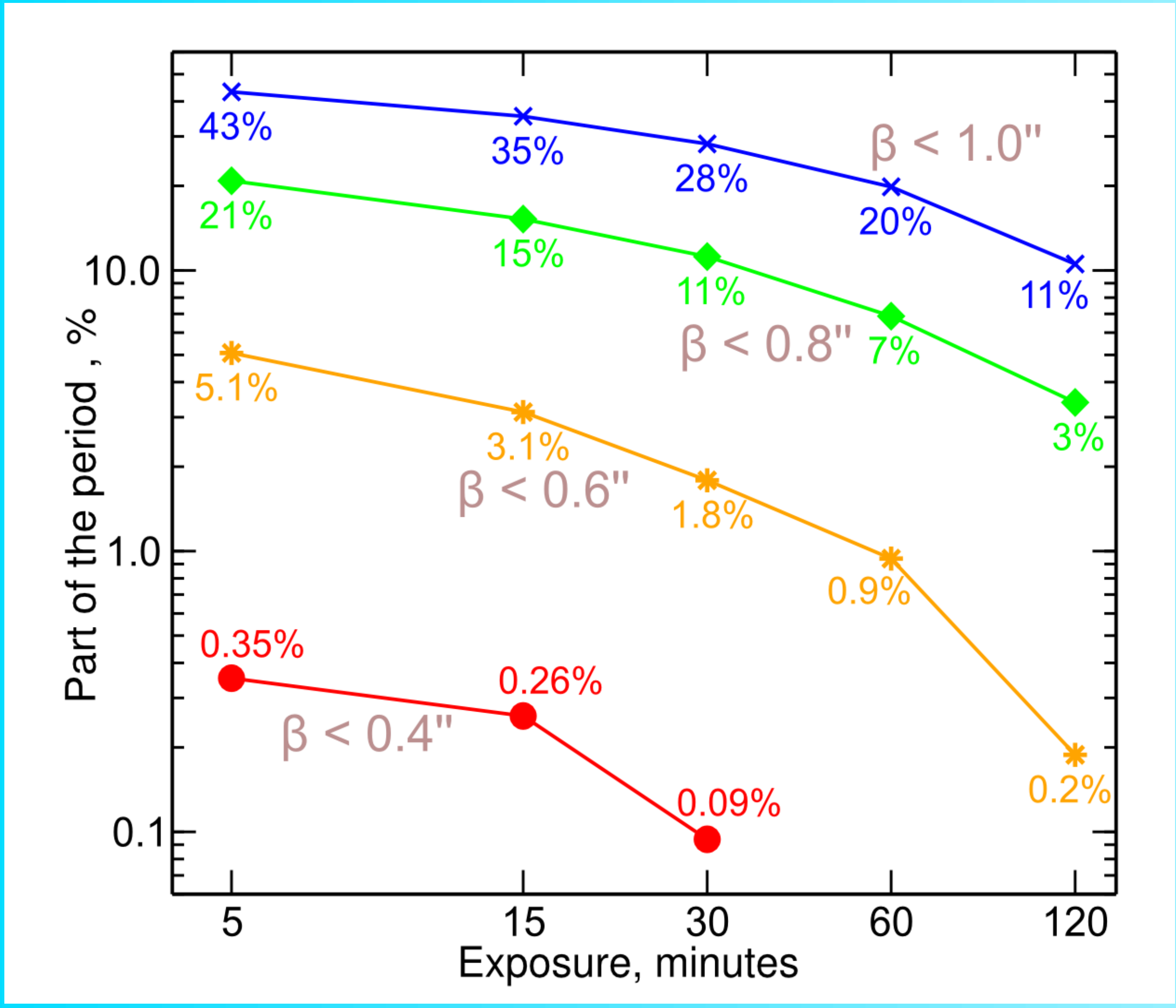
Monthly Seeing data



Variations of monthly median image quality. Vertical bars are inversely proportional to number of measurements.

Significance of variations indicates non-stationary nature of a phenomenon at time scales up to year and longer.

Seeing and long exposure quality

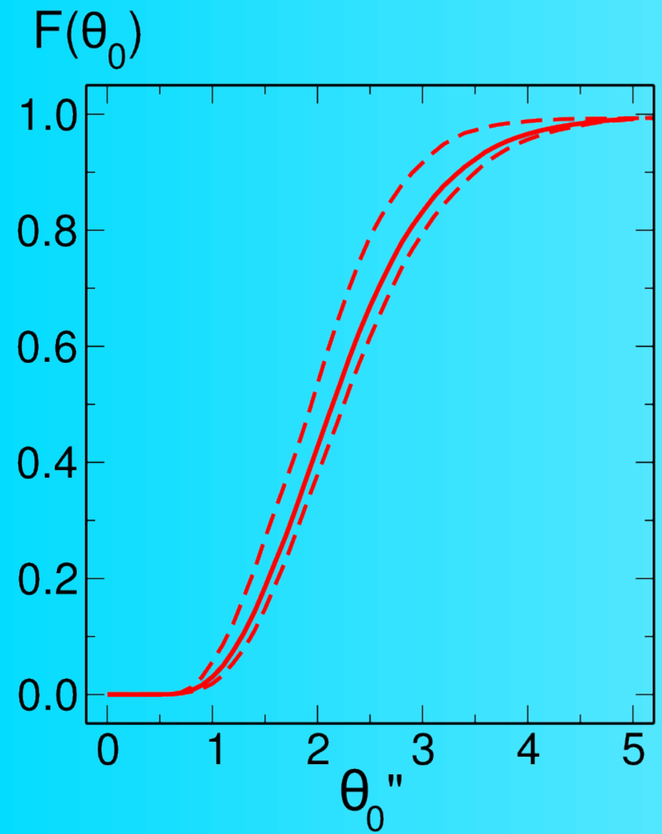


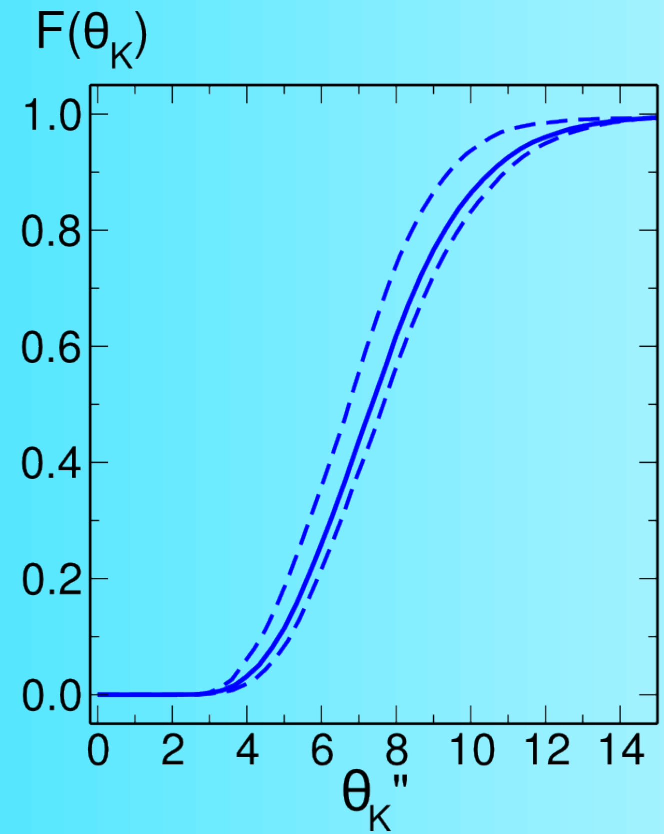
Contribution of time which allows to take an image of a given exposure time which is of not worse than a specified image quality (for a curve).

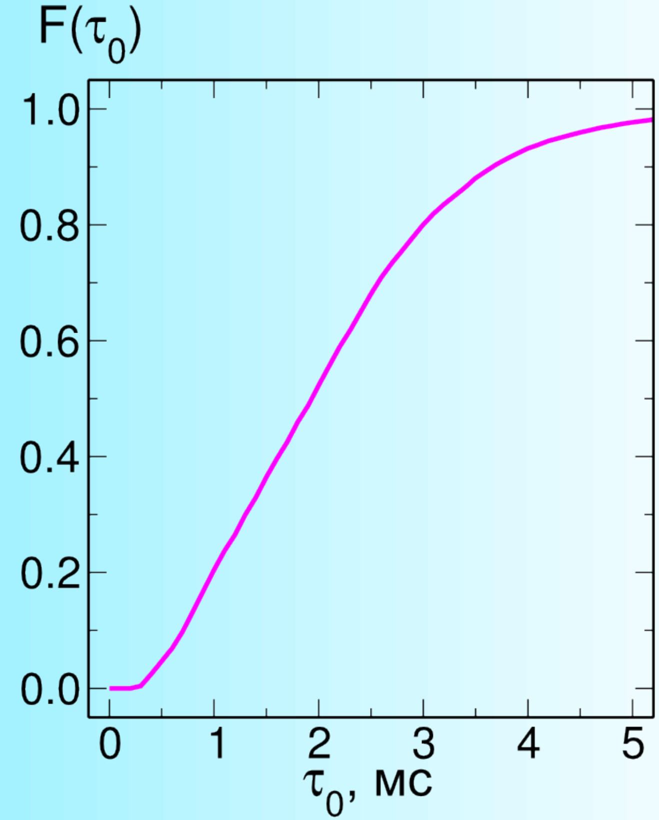
For the total span of observations one could acquire 11 quarter-hour-long frames of images with stars better than 0.4" in width.

Apart from angular resolution of imagery, seeing 0.6" adds one magnitude of detection threshold compared to o 1" images, and 0.4" adds two!

Supplementary characteristics of turbulent atmosphere





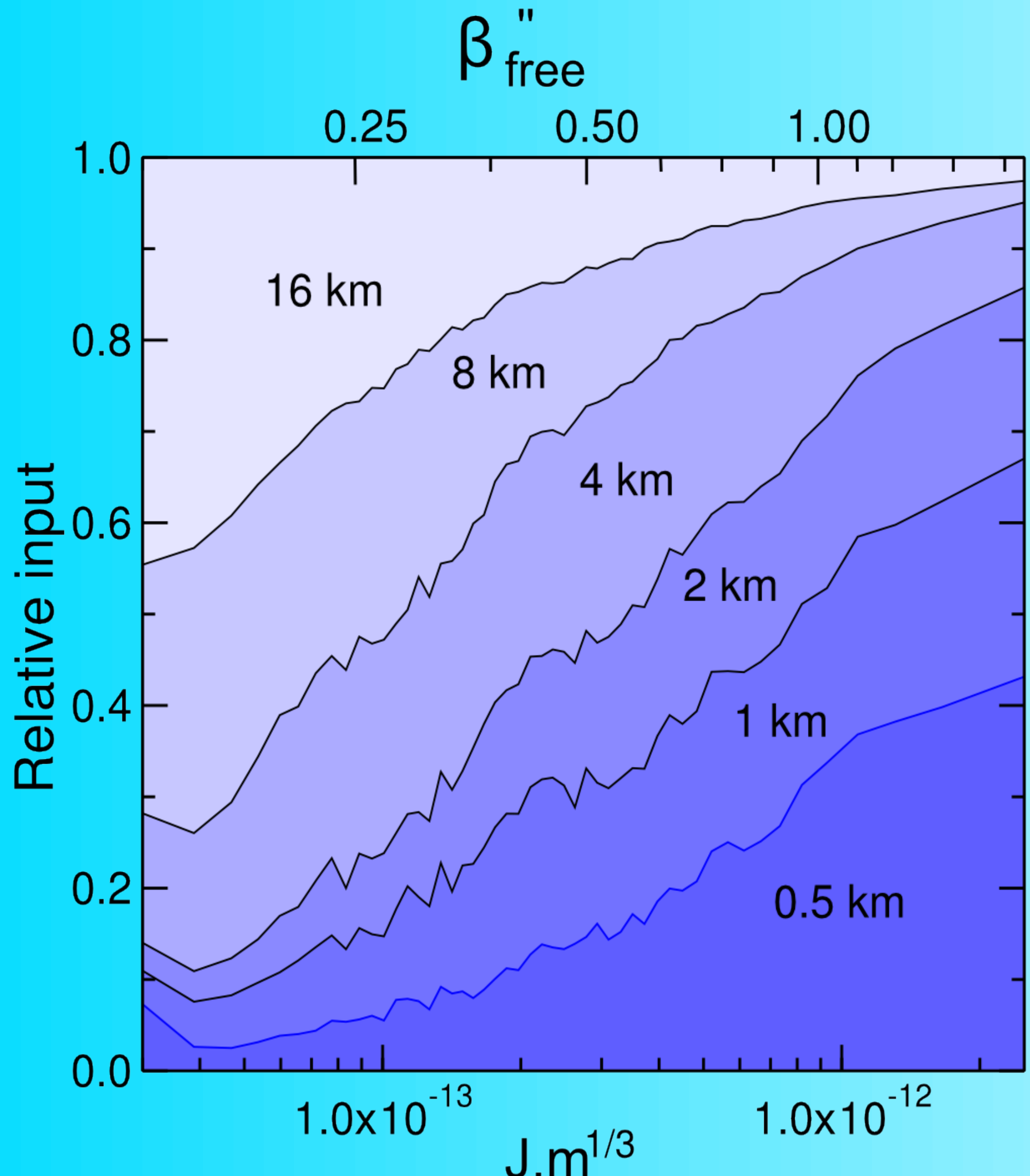


Isoplanatic angle determines the correlation of wavefront deviations in different directions. Median is 2.02''

Isokinetic patch – this angle is analogous to isoplanatic one, but correlations are restrictied to wavefront tip-tilts only. Median: 6.74''

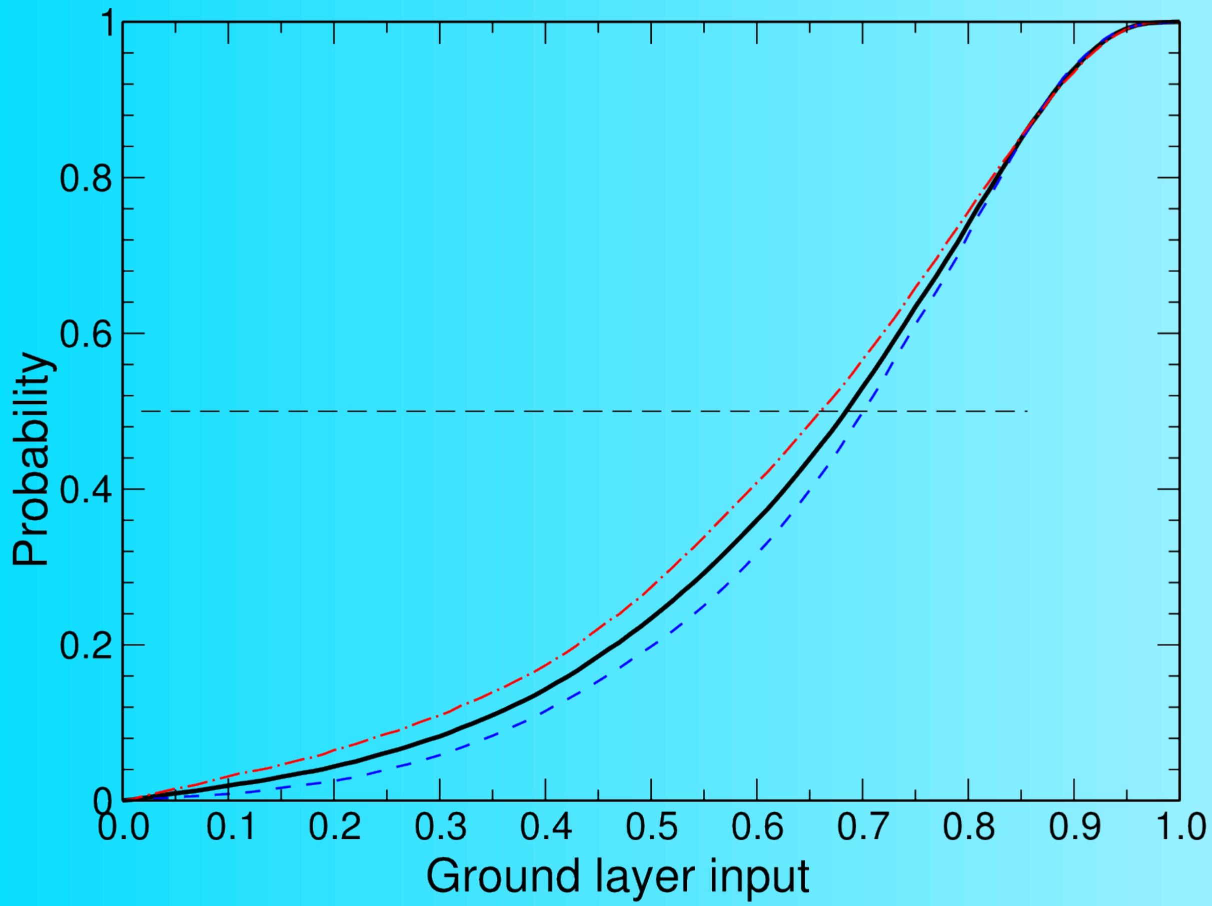
Atmospheric coherence time (time constant) — determines wavefront shape frozen time. Median is 1.93 ms

Free atmosphere structure



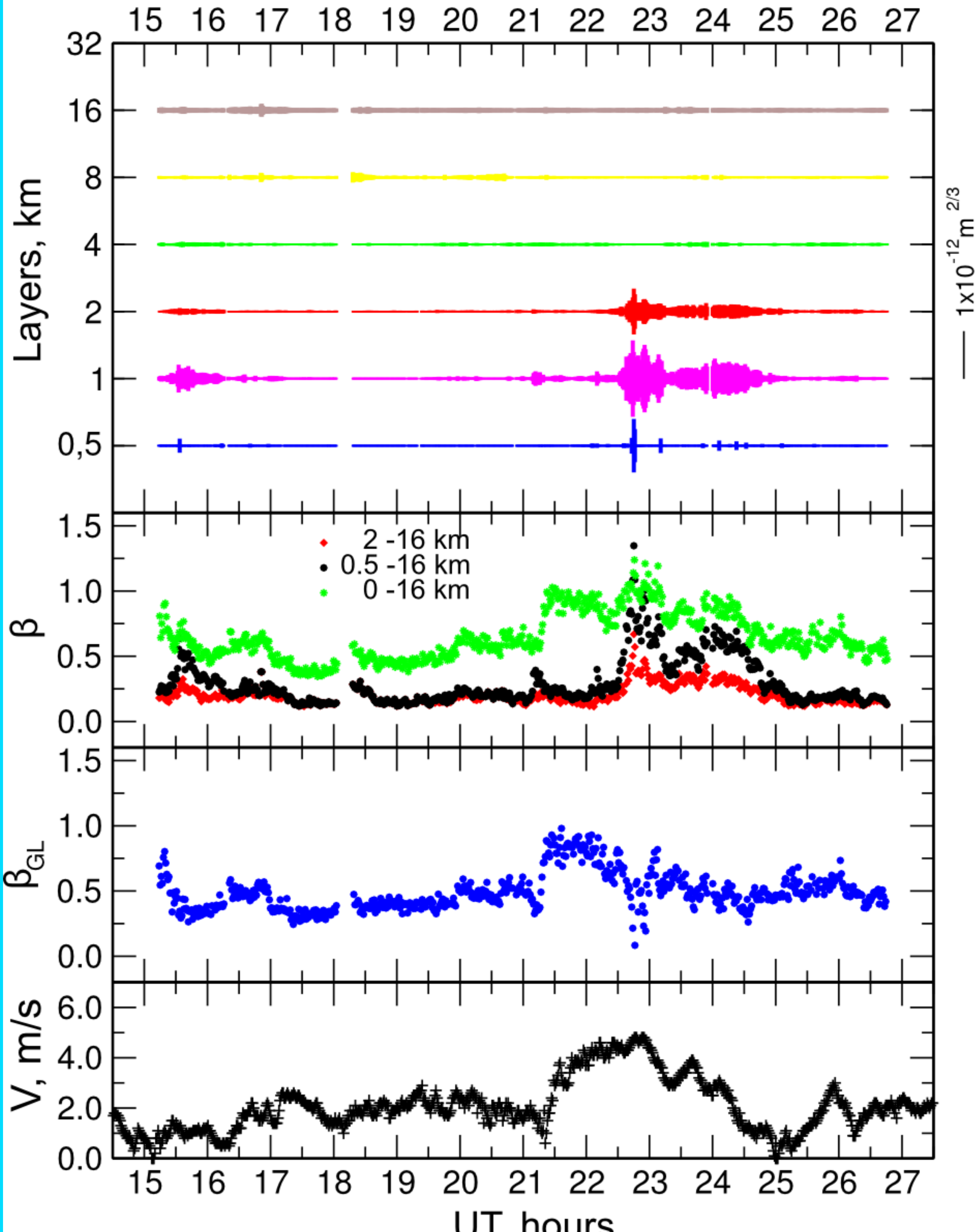
The dependence of relative contribution of different layers of atmosphere on the total seeing (or integral turbulence) in a free atmosphere (0.5km and above). Weak turbulence (good seeing) nights are dominated by uppermost (16km) layer; bad images are mostly due to boundary layer (0.5km).

Ground layer



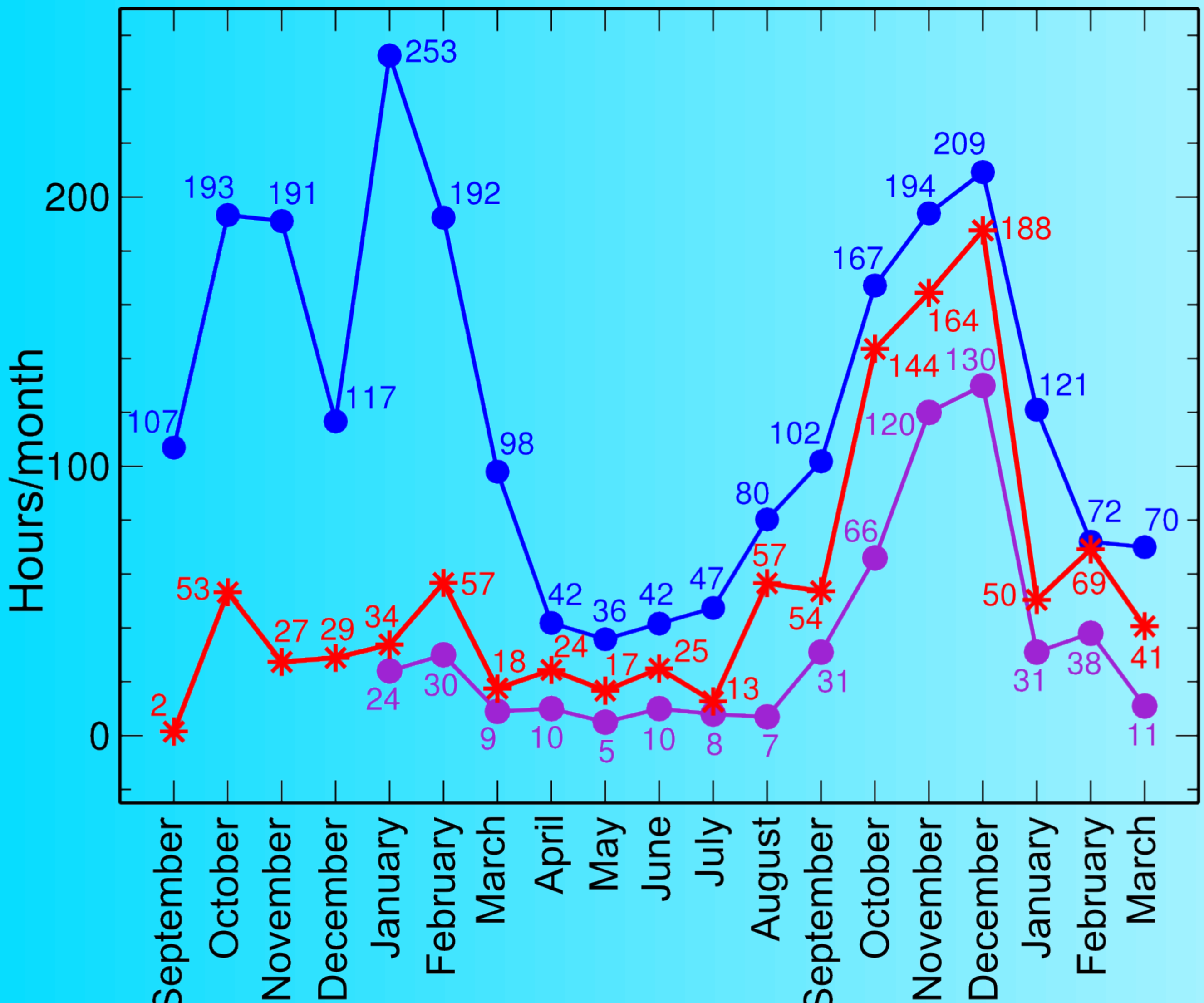
Cumulative probability of input of a ground layer (below 0.5km) into total seeing. Red and blue curves are for «bad» (worse than median) and «good» (better than median) images, respectively. Median contribution of a ground layer is 0.68"

Ground layer



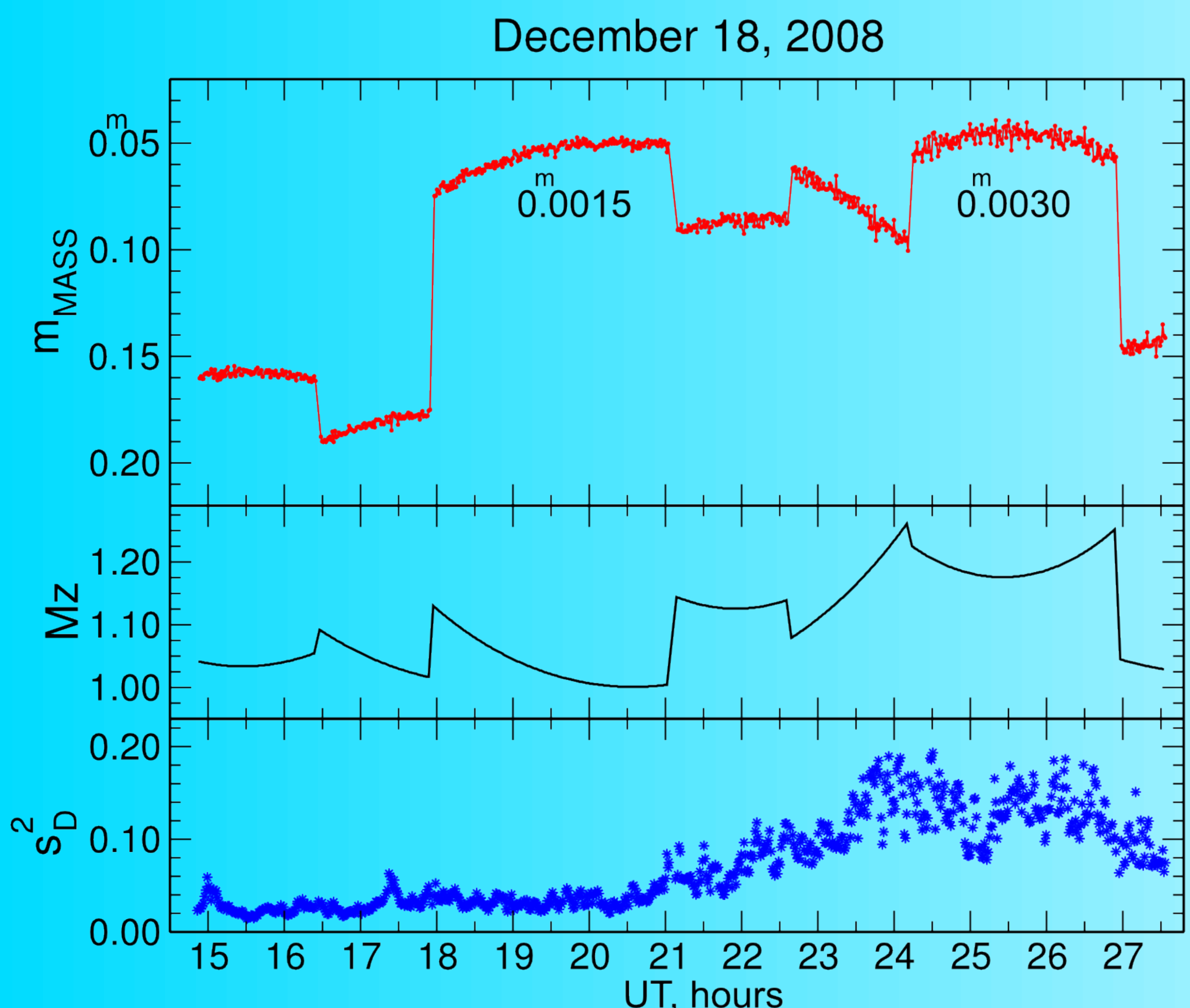
Example of evolution of turbulence in a ground layer during night (blue dot graph), which is derived from DIMM and MASS data. The growth of turbulence power is related to increase of a ground wind speed. Possibly related is a prominent event in a free atmosphere 1,5 hours later.

Photometric aspects of astroclimate



Blue curve — total available monthly clear night time (as shown before). Red curve — total measurement time in month, violet — photometric time monthly duration, which contribution for a period from January 2008 to March 2009 is 56%

Example of a good photometric night



Red dots are instrumental magnitudes in D-channel of MASS device with 1min accumulation. Blue dots — scintillation index in the same channel (aperture 10cm).

Derived extinction for the night is $0^m.18$ ($\lambda_{eff} \approx 4700$Å)

The spread of red dots is totally due to long-term scintillation. In telescopic measurement conditions (D >> Fried radius) it is quantified as:

$$\sigma_I = C \cdot M_z^{7/4} \cdot D^{-2/3} \cdot t^{-1/2}$$

Main conclusions after 18-month observations

The preliminary estimate of seeing at Mt. Shatzhatmaz is rectified to a median value 0.99".

Free atmosphere optical turbulence intensity is ascertained. Median seeing in free atmosphere is 0.54".

Main weather statistics are confirmed, low wind conditions is a specific site characteristics: median wind speed is 2.3 m/s

Astroclimate parameters of the site are comparable to those of Cerro Tololo and La Silla observatories, meanwhile the clear night fraction (and site elevation) are somewhat lower.

Reliable statistics will be obtained after two summer and one winter period observations (i.e. to fall 2010)

Main targets to nearest future

System maintenance and support. Most desirable is an electronics modernisation (replacement) for the telescope

Interesting parameter to add into the scope of monitoring is a water column on a line of site and more detailed study of clouds pattern.

Conversion of data reduction into real-time mode, more advanced access to data base on measurement results, integration of a more precise weather station (those planned for 2.5m telescope support) into the system.

To the time of 2.5m telescope commissioning (winter 2010), conversion of ASM into an instrument for the tactic observation scheduling and manipulation.

Layout of local Caucasian sites: KGO (Pulkovo solar), Terskol obs. and two potential sites: Kinzhal (2900 m) and Bermamyt (2600 m): next sites to study?