European Community's Framework Programme 6

EUROPEAN EXTREMELY LARGE TELESCOPE DESIGN STUDY

ELT MASS-DIMM Calibration

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Issue 1.2 – DRAFT

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CHANGE RECORD

Issue	Date	Section / Paragraph affected	Reason / Initiation / Remarks
1.0 - DRAFT	03-10-07	All	First issue, Draft for review
1.1 - DRAFT	5-12-07	Figures	Draft for review. MASS filter applied.
1.2 - DRAFT	24-03-08	Figures	Draft for review: DIMMs filters applied ($fwhm_l/fwhm_t$ ratio between 0.8 and 1.2).

Contents

Abbreviations

DS	Design Study
DIMM	Differential Image Motion Monitor
EC	European Commission
ELT	Extremely Large Telescope
ESO	European Southern Observatory
FP6	Framework Programme 6
IAC	Instituto de Astrofísica de Canarias
ING	Isaac Newton Group
JKT	Jacobus Kapteyn Telescope
MASS	Multi-Aperture Scintillation Sensor
ORM	Observatorio Roque de los Muchachos
TBC	To Be Confirmed
TBD	To Be Defined
UNI	University of Nice
WP	Work package

1 Scope of Document

In the framework of the European Extremely Large Telescope (ELT) Design Study (DS), the partners participating in the Work Package (WP) 12200, "Site Characterisation: Instrumentation, Measurement and Modelling" have the responsibility of designing, building and operating standard site testing equipment, and performing long term measurement campaigns.

The aim of the present document is to report the results of the four nights cross-calibration performed at the ORM (La Palma, Spain) in order to calibrate the MASS-DIMM system with a stable existing DIMM (hereafter IAC-DIMM) AD01.

2 Applicable and reference documents

2.1 Applicable documents

The following documents of the exact issue are applicable to the present proposal. In the event of conflict between the documents referenced herein and the content of the present document, the content of the present document shall be taken as superseding requirement.

Ref.	Document title	Document number	Issue
AD01	Measuring Astronomical Seeing: The DA/IAC DIMM	1995, PASP 107,265	
AD02			
AD03			
AD04			
AD05			
AD06			
AD07			

2.2 Reference documents

Ref.	Document
RD01	Sarazin, M., Roddier, F. "" (1990) A&A 227, 294
RD02	Vernin, J. & Muñoz-Tuñón, C. "Measuring Astronomical Seeing : The DA/IAC DIMM" (1995), PASP 107, 265-272

3 Observations summary

The observations were performed during the nights from 10th to 13th September at the ORM, La Palma. Both MASS and DIMM devices were operating simultaneously, as well as the IAC-DIMM. The MASS-DIMM system consists of:

- ✓ Celestron C11 (Ø11').
- ✓ ASTELCO mount.
- ✓ PixelFly PCO CCD.
- ✓ MASS-DIMM device.

The main features of both DIMM systems are shown in the following table:

Table 1. *Main characteristics of the two systems: MASS-DIMM and IAC-DIMM.*

SYSTEM	MASS-DIMM	IAC-DIMM
Telescope	Celestron C11 (11')	Celestron C8 (8')
CCD	PCO PixelFly	ST-237 (SBIG)
Pixel size (μm)	9.9	7.4
Pixel scale ("pix^{-1})	0.81±0.1	0.80±0.1
d (cm): distance between apertures at telescope entrance	20	14
D (cm): diameter of the apertures at telescope entrance	9	6
f_{eff} (m): system effective focal length	2.52	1.908
t_{exp} (ms): exposure time	10	10
Δt (min): time sampling	1	1
h (m): height above ground level	~1.5	~0.5
Distance between instruments (m)	0 (origin)	~4
Airmass correction	$\varepsilon=\varepsilon_{obs}/X^{3/5}$	$\varepsilon=\varepsilon_{obs}/X^{3/5}$

The two telescopes were located near the JKT building close to each other, within a distance of approximately 4 meters and, given the differences in their tripods, there exists also a difference between MASS-DIMM and IAC-DIMM heights. **Fig. 1** and **Fig. 2** illustrate the systems location and layout. Note that the location shown in **Fig. 2** is not where the calibration took place (unfortunately pictures were not taken during the calibration), but the picture shows a very similar relative positions of both instruments.

As can be seeing in **Table 1**, the pixel scales of both instruments (which were measured empirically through the observation of a double star with known angular separation) are almost the same, so similar performances were expected of both systems. Differences in the measurements might arise from the fact that IAC-DIMM was assembled employing a temporary tripod, by far less robust than MASS-DIMM's and so, more sensitive to wind gusts.

It has to be also taken into account that the sensitivity of DIMM part of the MASS-DIMM and IAC-DIMM is not the same in such a way that it was not always possible to observe the same star either due saturation (MASS-DIMM) or for too low number of counts (IAC-DIMM). The observation was made trying to select targets with suitable brightness and as near to the zenith as possible.

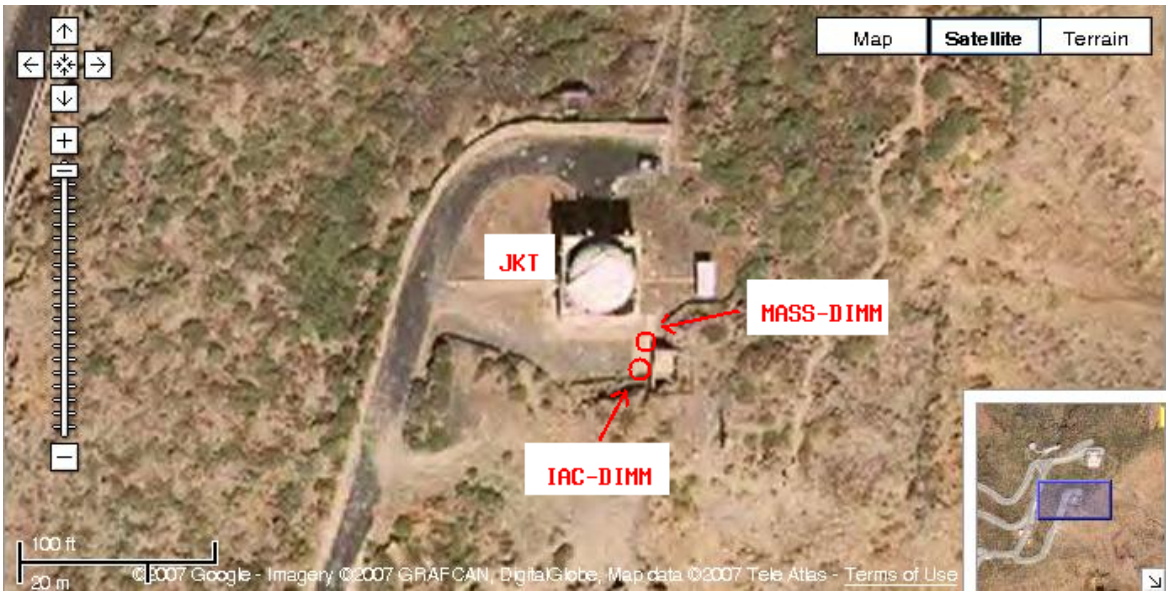

Figure 1. *Satellite picture of the calibration location inside the ORM. The places where MASS-DIMM and IAC-DIMM were located (close to the JKT building) are indicated by the arrows and the labels.*

Figure 2. *Picture showing the situation of the two systems: IAC-DIMM and MASS-DIMM. The place that can be seeing is not the one where the observations were carried out, but the relative distances between the systems is very similar. Note the differences in height due to tripods.*

4 Calibration results

After the acquisition of data, they were analyzed and compared. Seeing (from DIMMs devices) and free seeing (from MASS device part) time series are plotted in **Fig. 3**. Data shown in **Fig. 4** have been smoothed by a moving mean of 5 data, so every 5 min; note that the time sampling of both DIMM instruments is the same (see **Table 1**).

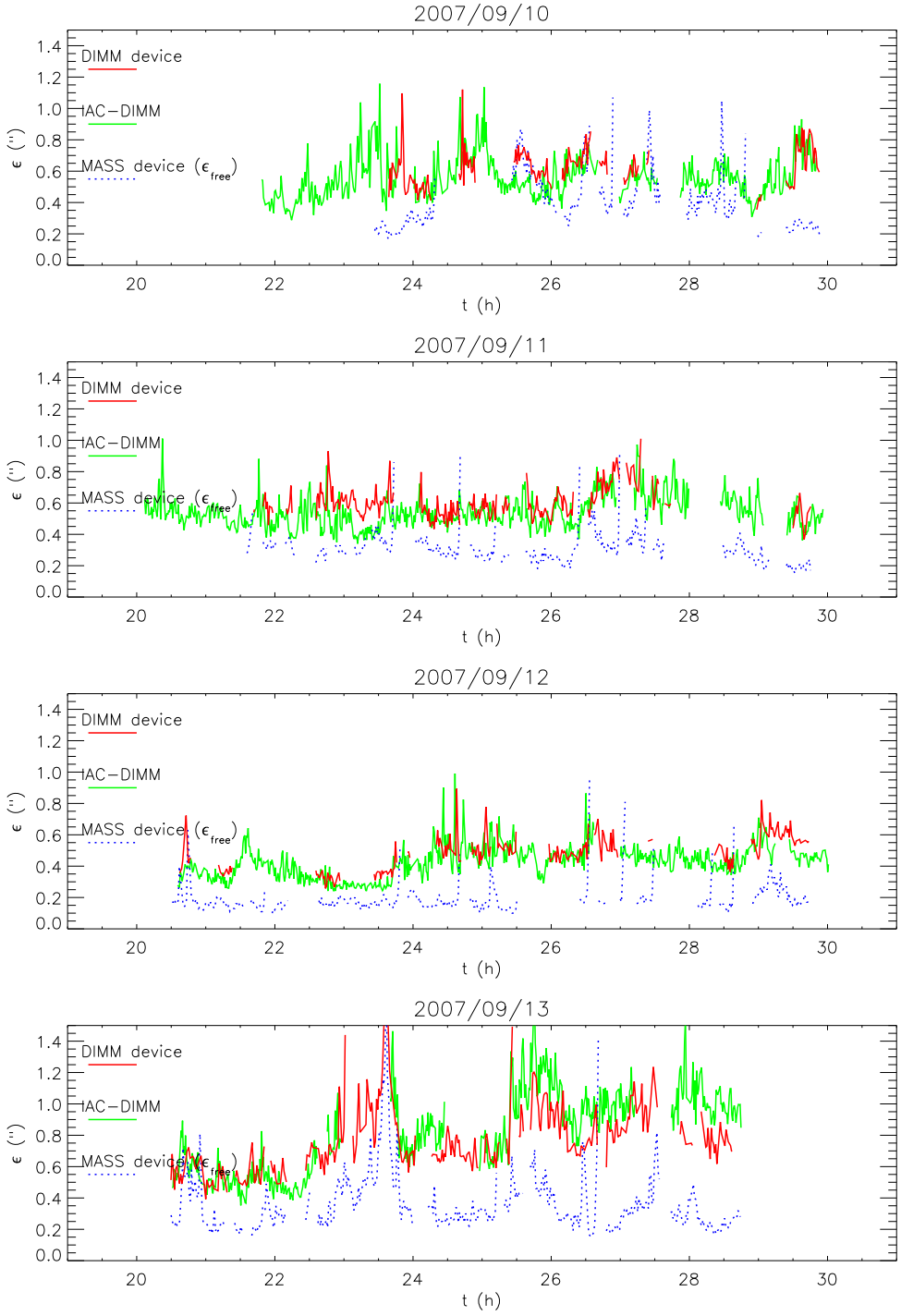

Figure 3. *Seeing values obtained by DIMMs devices and the free seeing provided by MASS device.*

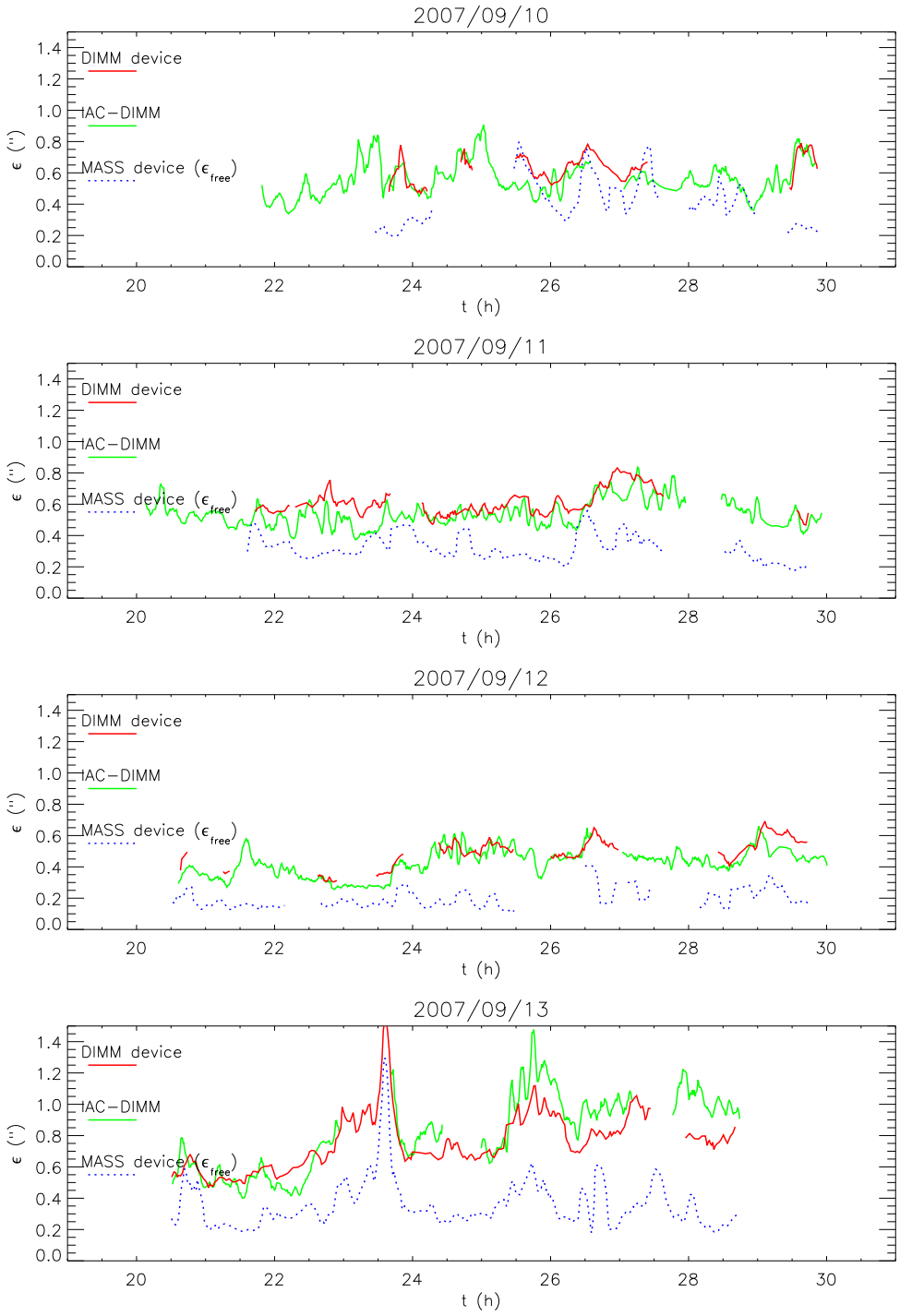

Figure 4. *Seeing values obtained by DIMMs devices and the free seeing provided by MASS device. All three data sets were average every 5 min.*

IAC-DIMM measurements and those taken by DIMM device of MASS-DIMM have been compared in the plots shown in **Fig. 5** for every night of the calibration campaign. Given that data were not acquired at exactly the same time, a range of $\Delta t = \pm 30s$ has been defined in order to decide whether a pair of measurements can be considered simultaneous or not. If so, they are included in the plots. **Fig. 6** shows the resulting plot of the entire run, as well as a histogram of the time offsets between both instruments recorded UT corresponding to the plotted data.

Fig. 3 and **Fig. 4** show data after performing the filtering:

- MASS filtering in order to reject data when the object is not well pointed (applying the filter provided by Marc Sarazin that removes the vignetted data and corrects for MASS overshooting).
- Only IAC-DIMM and DIMM device (MASS-DIMM) data with a ratio $fwhm_l/fwhm_t$ between 0.8 and 1.2 are included in the plot.

The relative differences between data coming from IAC-DIMM and DIMM device (MASS-DIMM) were computed as follows:

$$\delta\varepsilon = 100\frac{\varepsilon_{DIMM-device} - \varepsilon_{IAC-DIMM}}{\left(\varepsilon_{DIMM-device} + \varepsilon_{IAC-DIMM}\right)/2}(\%)$$

A few statistical values of the relative differences between both devices:

- $\delta\varepsilon$ median = +4.4%
- $\delta\varepsilon$ mean = +4.5%
- $\delta\varepsilon$ standard deviation = 22.4%
- 95% of data considered as simultaneous; i.e. with $\Delta t<30s$, have relative differences less than 45%

The histogram of the observed relative differences is shown in **Fig. 7**. Additionally, assuming a normal distribution of $\delta\varepsilon$, a Gaussian fit:

$$f(\delta\varepsilon) = A_0 \exp\left(\frac{\delta\varepsilon - A_1}{A_2}\right)$$

has been performed to data yielding the values of mean and standard deviation shown above.

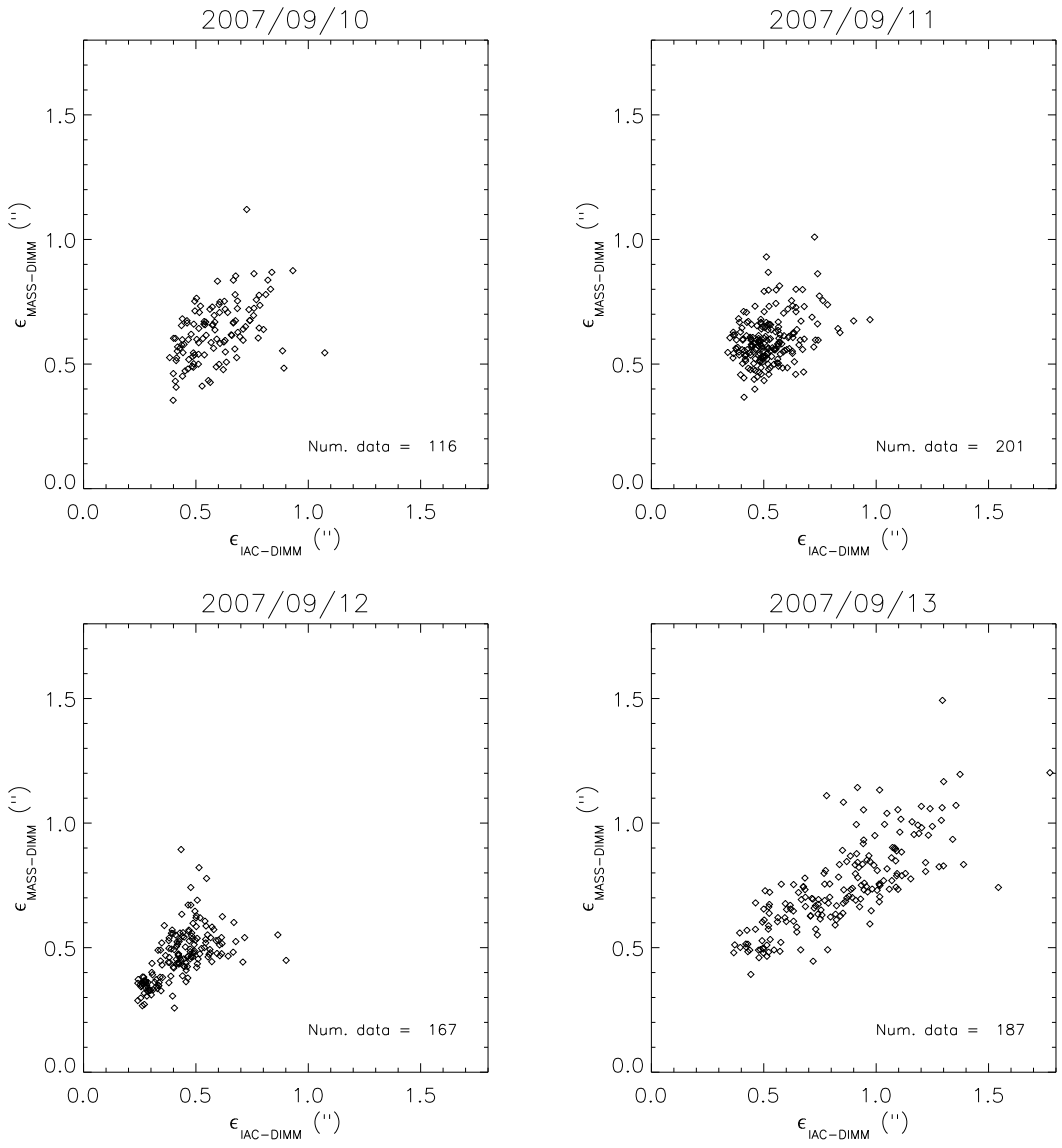

Figure 5. *Comparison between MASS-DIMM (DIMM part) and IAC-DIMM seeing measurements for every night.*

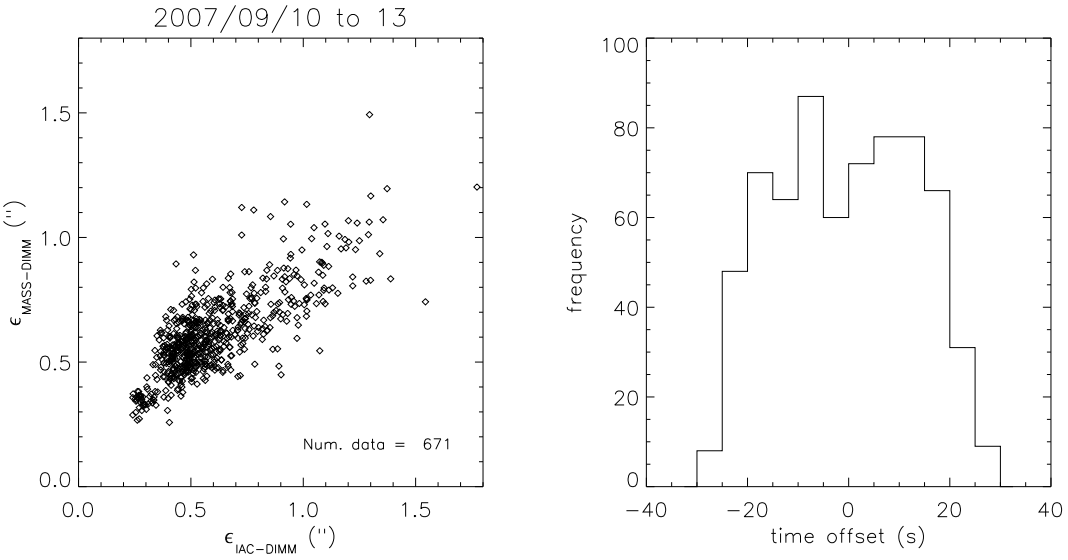

Figure 6. *Left: Comparison between MASS-DIMM (DIMM part) and IAC-DIMM seeing measurements for the whole run. Right: Histogram of the time offset between IAC-DIMM and MASS-DIMM measurements (IAC-DIMM recorded UT minus the one stored by MASS-DIMM).*

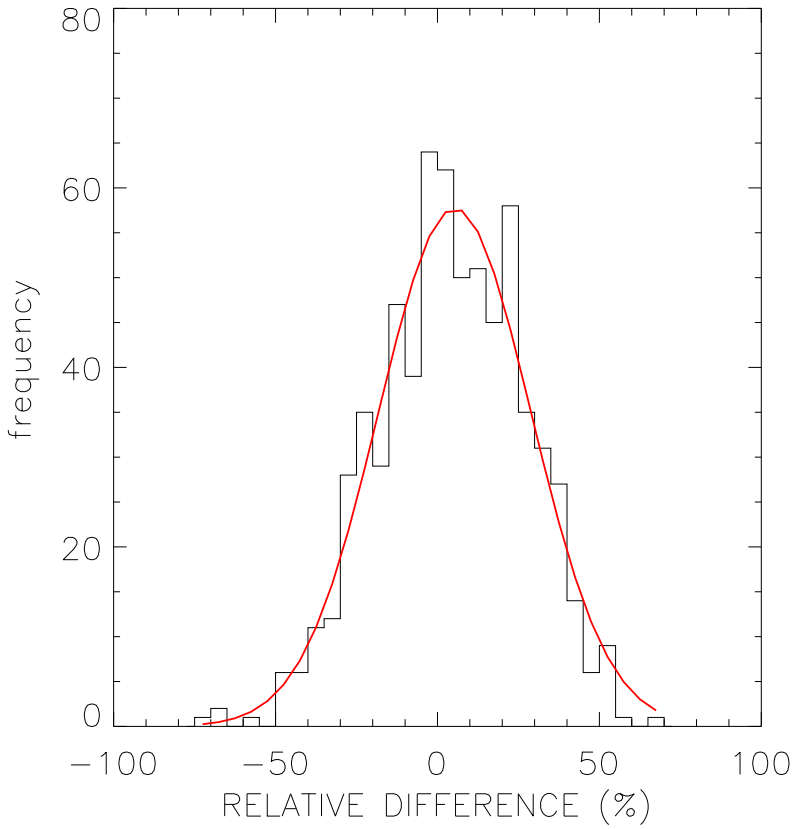

Figure 7. *Histogram of the relative differences $\delta\varepsilon$ between the seeing values measured by IAC-DIMM and DIMM part of the MASS-DIMM (in percentage). A Gaussian fit is also shown in red.*

The main results can be summed up as follows:

1. There exists a very good agreement between MASS-DIMM and IAC-DIMM measurements. The time evolution of seeing values retrieved by both exhibit highly correlated variations, showing the same main features.
2. The free seeing provided by MASS device of MASS-DIMM is lower than that observed by DIMM part, as expected.
3. Seeing values coming from DIMM devices were compared. The histogram of their relative differences fits well with a normal distribution with mean value 4.5% and standard deviation 22.4%. For a seeing value of 1.5", this means that the mean difference between instrument measurements is expected to be 0.07" ± 0.34", being DIMM part of the MASS-DIMM device expected measurement higher than that of IAC-DIMM.
4. The few discrepancies observed sometimes between both instruments during the run could be attributed to the different instrument tripods robustness (being IAC-DIMM's more sensitive to wind gusts than MASS-DIMM's) and particular wind speed and direction regimes that can have some effect on measurements. In that regard, whether conditions are available in the ING's web site:

   http://catserver.ing.iac.es/weather/archive/index.php

5 Conclusions

The overall conclusion of the calibration run is that the DIMM part of the MASS-DIMM was successfully calibrated employing IAC-DIMM.