2° Forum della Ricerca Sperimentale e Tecnologica

ARIEL primary mirror map at $0\vec{g}$

P. Picchi[a,b], A. Tozzi [b], A. Brucalassi[b], E. Pace[a], A. Scippa[c], E. Pascale[d], A. Bocchieri[d] , F. D'Anca[e], R. Lilli[c], D. Gottini[c], E. Guerriero[e], G. Falcini[b], P. Chioetto[f,g,h], P. Zuppella[g,h]

Presenter: Paolo Picchi (UniFi)

[a]Dipartimento di Fisica ed Astronomia-Università degli Studi di Firenze, Largo E. Fermi 2, 50125 Firenze, Italy , [b]INAF-Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy, [c]Dipartimento di Ingegneria Industriale-Università degli Studi di Firenze, Via S. Marta 3, 50139 Firenze (FI), Italy., [d]Dipartimento di Fisica, La Sapienza Università di Roma, Piazzale Aldo Moro 2, 00185 Roma, Italy, [e]INAF-Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, 90134 Palermo, Italy,, [f]Centro di Ateneo di Studi e Attività Spaziali "Giuseppe Colombo"- CISAS, Via Venezia 15, 35131 Padova, Italy, [g]INAF-Osservatorio Astronomico di Padova, Vicolo dell'Osservatorio 5, 35122 Padova, Italy, [h]CNR-Istituto di Fotonica e Nanotecnologie di Padova, Via Trasea 7, 35131 Padova, Italy,

INTRODUCTION

ARIEL it is an ESA Medium Size mission devoted to the study of exoplanets atmospheres. Its key technological aspect is the fact that all the telescope mirrors are entirely made of aluminum. Due to the high degree of innovation and risk of the implementation (see [1] and [2]), the Design Authority remained with the team headed by INAF, which continues the Research & Development activity on some critical parts of the telescope, mainly the Primary Mirror M1 with its mechanical support, and the M2-M4 mirrors. Some de-risking activities have been implemented to tackle the technological challenges of the mission.

Tab. 1: ARIEL M1 SM specifications.

Mirror	Mirror type	Clear aperture shape	Clear aperture dimensions at 50 K (mm)	SFE at 293 K (nm)
M1 SM	Concave spherical mirror	Elliptical	1100 x 746.8	1400

One open problem consists in understanding how gravity deforms the mirrors surface and so be able to validate the polishing process of the manufacturer. To investigate this aspect, interferometric measurements have been planned on the ARIEL primary mirror Structural Model (SM) (see Table 1 and Fig. 1) for two reasons:

1. To verify the SFE measured by the mirror manufacturer.
2. To experimentally derive the gravity deformation, to be able to measure the true SFE of M1 and to have the first correlation with the Finite Element Analysis (FEA) models.

The results of the points above will permit to optimize the manufacturer polishing activity and to implement the first correlations with the numerical models, which will be important for the prediction of the telescope performances.

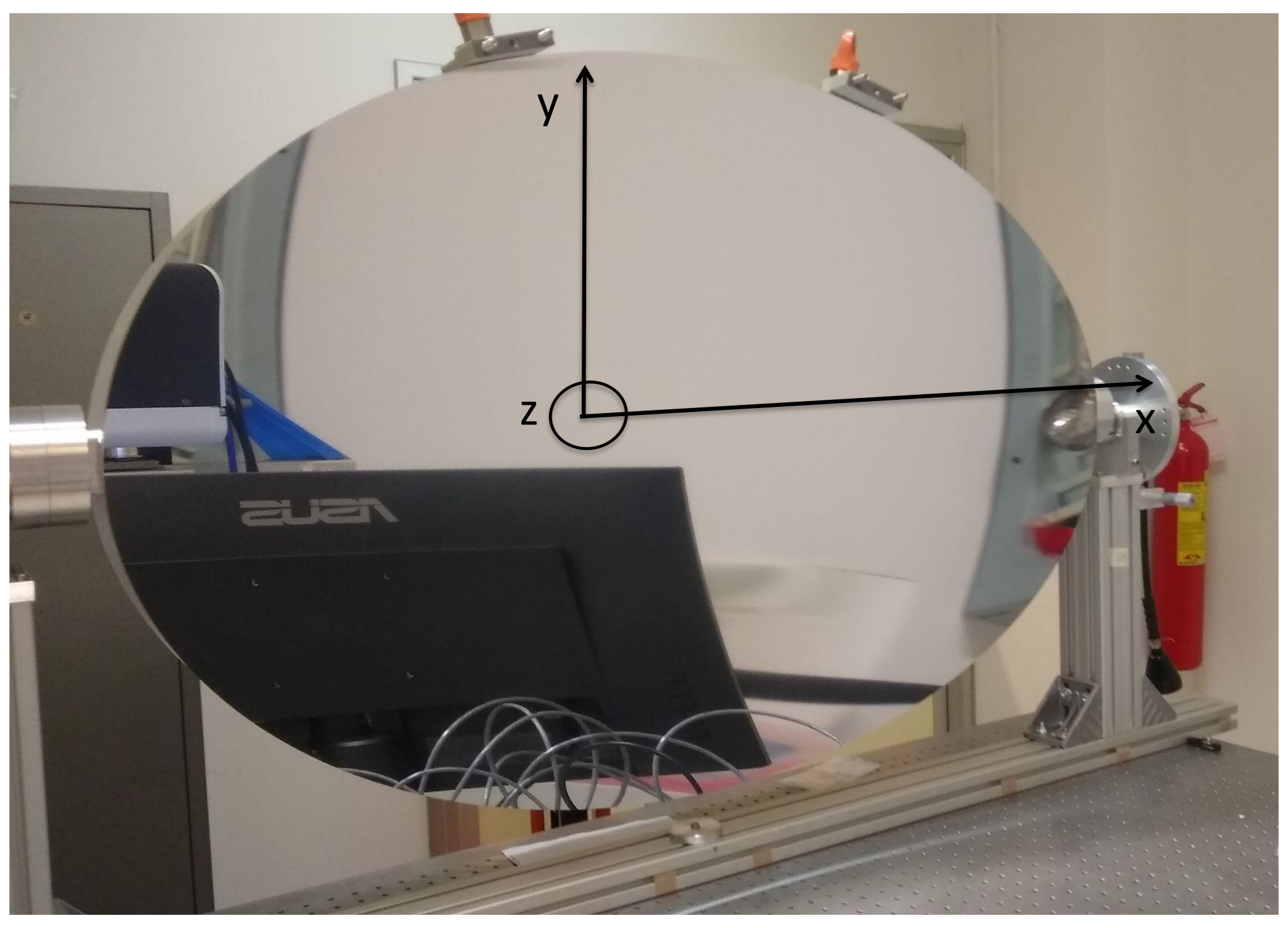

Figure 1. M1 SM mirror in the Arcetri laboratory mounted on the fork support.

M1 MAP at 0g

The measurements were done with the Apre interferometer, model S100, mounted in a confocal configuration with M1, using a metrological sphere at the entrance of the instrument. Between the M1 SM and the interferometer, a flat folding mirror was mounted to redirect the beam at 90 degrees toward the interferometer.

To measure the gravity deformation on M1, a so-called "fork" support was designed and manufactured in Firenze, with the collaboration between the UniFi mechanical engineering department and the INAF Arcetri Observatory. Since M1 is vertically mounted on the optical bench, (see Fig. 1), to isolate the gravity contribution, it is important to measure its deformations in two different orientations, one parallel and one anti-parallel to the gravity vector. To achieve this, one map shall be acquired with M1 in the nominal position, and another with M1 rotated by 180° around the z axis, which is parallel to the optical bench (see Fig. 1). The fork support allows this applying two separate rotations of 90° each in two separate axes: x and y (see Fig. 1). Once the two maps at $\pm$g are derived, it is possible to derive the true (gravity-free) shape of M1 applying the arithmetic mean of the maps, as shown in Eqn. 1:

$$\phi_{M1_{\pm g}} = \sum_i \left(a_i \pm a_{ig}\right) \cdot Z_i(R,\theta)$$

Equation 1: Interferometric map of M1 in terms of Zernike polynomnials. a_i are the M1 aberrations coefficients, while a_{ig} the aberrations coefficients due to gravity.

Where: $\phi_{M1_{\pm g}}$ are the measured maps at the two orientations, a_i and a_{ig} are, respectively, the M1 and gravity aberrations coefficients, and Z_i represents the Zernike polynomials. Fig. 2 shows the first 15 Zernike polynomials of the measured M1 maps at 0g. The black and blue dots represent a fork configuration in which the repeatability of the support was not acceptable and so it was improved, as shown by the successive sequences. The two horizontal blue lines show the $\pm$5 nm band.

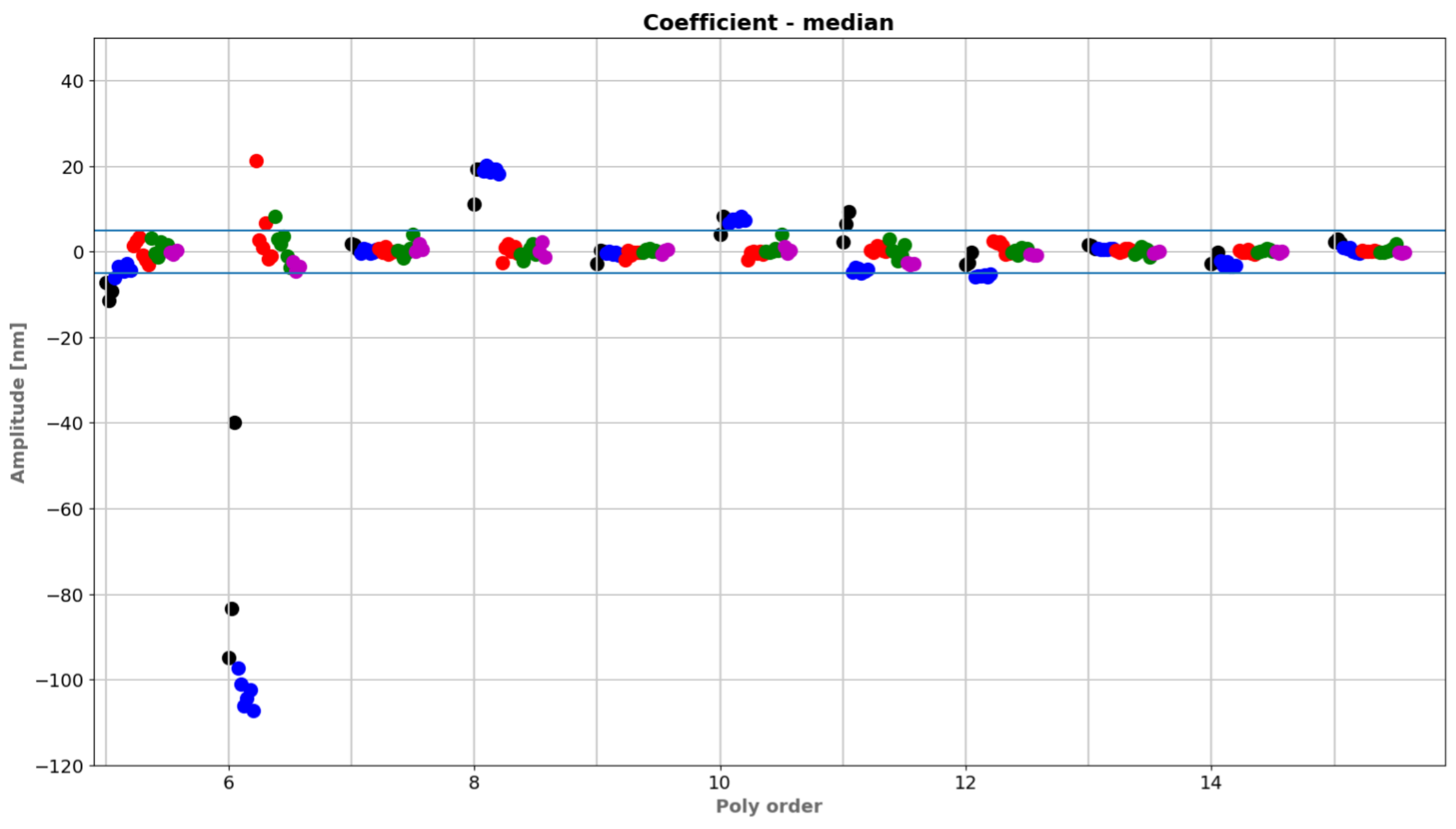

Figure 2. First 15 Zernike terms of M1 at 0g. Each dot is a map at 0g. The fork support produced very good repeatability after the last modifications on the support (represented by all the data points except for the black and blue ones, which show the performances before the support update). The two horizontal lines represent the $\pm$5 nm band.

FEA model

The fork system developed in Arcetri shows very good repeatability, of few nm per Zernike polynomial, as shown in Fig. 2. Using this support during the polishing campaign of the flight model will permit to manufacture M1 such that it will acquire the desired shape once it will be in an environment free of gravity. At this point, since we can precisely measure the M1 surface, we correlated the data with the validated FEA models of M1 on the fork. Fig. 3 shows the measured map and gravity deformations on M1 (top row) and the FEA gravity map (bottom row). The RMS values differ by <5% and the maps show a very good agreement.

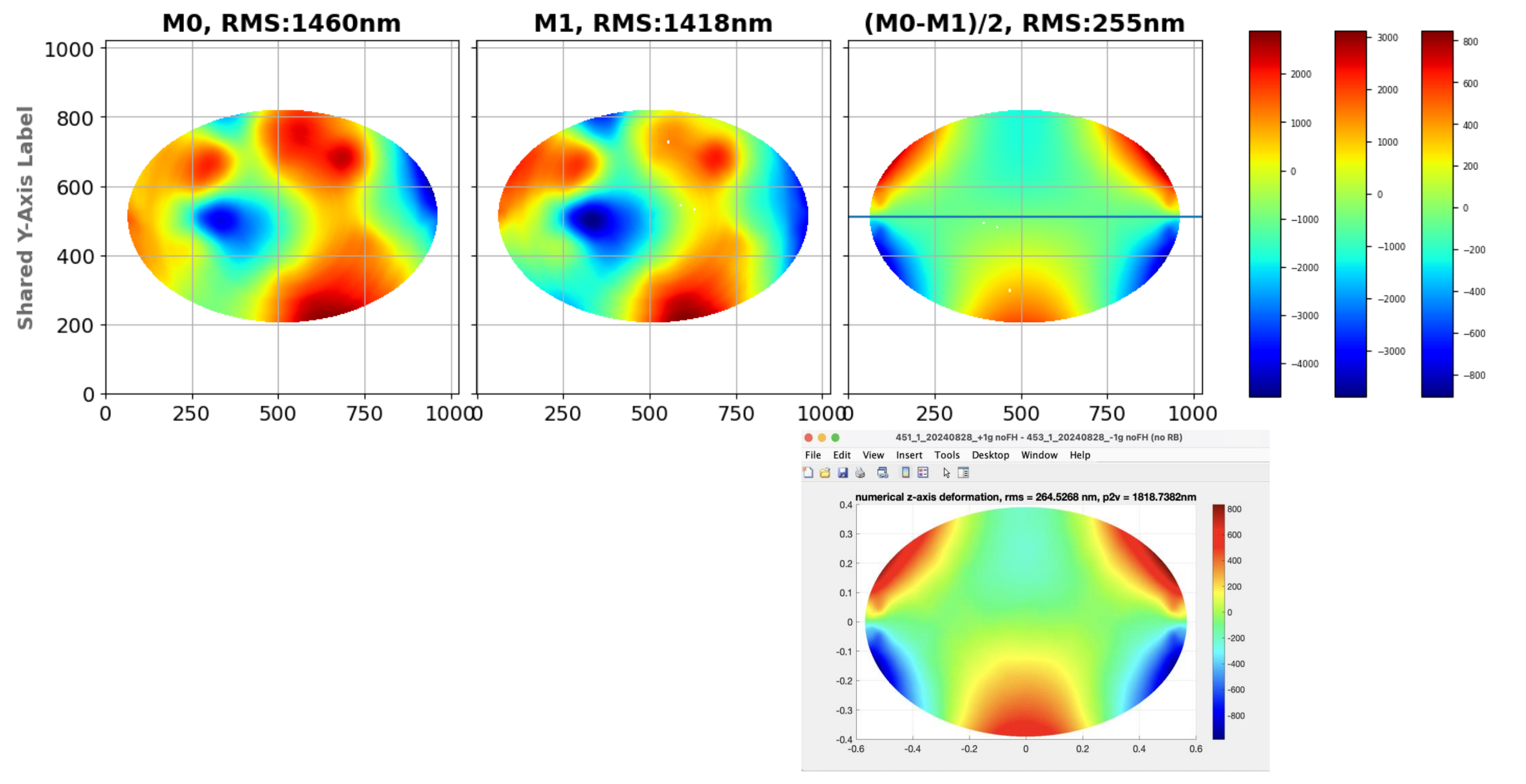

Figure 3: Measured gravity deformations of M1 on the fork support and below the map produced by the FEA model.

The residual between the data and the model has been evaluated, and the RMS is very good, of 15 nm, demonstrating that the model well correlates with the data.

Figure 4: Residual between the M1 measured gravity deformation and the model. The RMS is about 15 nm. Differences are due to a not proper modeling of the fork.

REFERENCES

1. Picchi, P. et al., Aluminum based large telescopes: the ARIEL mission case", Proc. SPIE 13092; doi: 10.1117/12.3018855".
2. Tozzi, A. et al., "Toward ARIEL's primary mirror", Proc. SPIE 12180; doi: 10.1117/12.2628906"

Paolo Picchi: paolo.picchi1@unifi.it;
paolo.picchi@inaf.it