Madrid, November 17^{th}, 2014

Dear Editor,

Authors would like to transmit you our acknowledgements for your response and reviewers comments on our manuscript. We have reworked the manuscript according to the comments. We hope that this revised version fulfills reviewer's expectations and accordingly, it is considered as a publication in GID.

According to referees #1 and #2 the following changes have been made.

1. The style of the manuscript has been changed trying to fit referees' comments.
2. The lists have been suppressed and the text has been adapted for a more fluid reading. Some redundant information has been removed and summarized (table 4, table 7, table 11 and table 12)
3. The scientific objectives have been clarified as well as the compliance with expectations. Also the comparison of the instrument performance and datasheet has been improved.
4. It has been included some required details on the design, specifically on the flipping mechanism.
5. An author (A. B. Fernández) has been included.

The document attached has the text to be replaced in the different sections and subsections of the previous version of the manuscript.

The authors

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The previous Abstract should be substituted by the following (changes highlighted):

MOURA instrument is a three axes magnetometer and gradiometer equipped with an inclinometer designed and developed for Mars MetNet Precursor mission.

The former scientific goal of the instrument is to measure the local magnetic field in the surroundings of the lander i.e. to characterize the magnetic environment generated by the remanent magnetization of the crust and the superimposed daily variations of the field produced either by the solar wind incidence or by the thermomagnetic variations. Therefore, the qualification model (MOURA QM) will be tested in the frame of magnetic surveys on terrestrial analogs of Mars, with the aim to achieve some experience prior to the arrival to Mars.

In this work, it is presented a practical first approach for the calibration of the instrument in the laboratory; a finer correction after the comparison of MOURA data with those of a reference magnetometer located in San Pablo de los Montes (SPT) Intermagnet observatory; and a comparative recording of a geomagnetic storm as a demonstration of the compliance of the instrument capabilities with the scientific objectives.

The section 1 "Introduction" should be substituted by the following:

MOURA is a three axes magnetometer and gradiometer instrument, to be included in the Spanish payload for the Finnish-Russian-Spanish Mars MetNet Precursor Mission (MMPM), rescheduled for 2018. The mission concept of MMPM is to deploy the first lander of a net of meteorological stations based on the penetrator concept over the surface of Mars. One of the targeted measurements of MOURA instrument will be to measure the change in remanent magnetization of Mars lithospheric minerals. We will search for temperature transitions for the compositional analysis of the crust (Sanz et al., 2011; Fernandez et al., 2013) aiming to explain its local magnetic anomalies, with intensities several orders of magnitude higher than the Earth ones. The second scientific objective is to measure the variations of the field related to the solar wind effects.

Due to the limited development time (2 years), mass and energy constrains of the mission (150 g and < 0.5 W for the three Spanish payloads), and the martian environment envelope (temperatures ranging from -90 to 20°C in operation and from -120 to 125 °C storage, and a total irradiation dose up to 15 kradSi^{-1}), MOURA development has singular characteristics, which have an impact in its performances. MOURA followed a double design: one compact sensor with macroscopic front-end electronics including many COTS and PEMS components upscreened for the mission, and a second with a mixed applied specific integrated circuit (ASIC) based front-end (Sordo-Ibanez et al., 2013). This work focuses on the former one.

MOURA instrument is located on top of the inflatable structure of the lander (Fig. 1) to provide a certain distance from the penetrator, avoiding any extra mass for a deployment system. Therefore, apart from the two magnetometers (for close gradiometry) and the compensating temperature sensors, it has a tilt angle detector to determine the relative position respect to the horizontal.

Because of the above mentioned mission constraints, both the sensing and the electronics suppose a trade-off between performances under that expected environment, power and mass budget. In addition, the magnetic signal of the electronic components was also carefully measured, in order to improve the magnetic cleanliness of the compact instrument (of a total mass of 72 g). As a result, the part list for the electronics was restricted according to their magnetic signal. Under the mentioned demanding criteria, the selected sensing element was the tri-axial HMC1043 magnetic sensor by Honeywell (Honeywell Magnetic Sensors, 2014). The HMC1043 sensors belong to a family of sensors based on Anisotropic Magnetoresistance (AMR) effect (Freitas et al., 2007) which has been exhaustively up-screened (temperature, thermal shock, life cycle, and radiation) by INTA (Sanz et al., 2012) and successfully used in previous space missions (Michelena et al., 2010; Michelena, 2009, DTUsat, 2014). Although the selection of HMC1043 for the two magnetic sensing elements presents advantages in terms of weight and power consumption, the AMR technology based sensors present several drawbacks like their resolution (lower compared with other sensing technologies, like the fluxgates), or an important dependence of their response (gain and offset) with temperature (Ripka et al. 2013, and Díaz-Michelena et al., 2014). This point is particularly challenging because MOURA is expected to be allocated outside the lander (Fig. 1) and thus, exposed to Mars surface thermal fluctuations. As one of the main objectives of MOURA is to measure the thermal variation of Martian magnetic minerals magnetization, this thermal characterization of the instrument becomes critical due to the necessities of the project, after the successful qualification (mechanical shock, vibration, thermal and vacuum), the qualification model (QM) of the magnetometer was slightly modified, and therefore should be strictly denominated engineering qualification model (EQM). This EQM is still fully representative (electric and functional) of the flight model (FM) but not mechanically representative. This fact will have implications in the calibration with temperature of the instrument.

In the present work we focus on the first calibrations performed to MOURA EQM (MOURA from now on) as is (Fig. 2), which involves: magnetic, tilt angle detector, including gravity measurements characterization, and thermal behavior. The purpose of this calibration is to demonstrate the capability of MOURA instrument to fulfill the above mentioned scientific objectives on Mars by means of measurements on Earth. For this reason, the field range has been increased to ±65.000 nT (extendable to ±130.000 nT, see Table 1).

On Earth the contrast in magnetic field intensity in on ground prospections is generally due to the magnetic carriers of the surface rocks (up to tens of meters). Despite the limited data of ground surveys on Earth, a reasonable goal in terms of detectivity for MOURA instrument is to be able to detect a variation of 1 % vol. concentration of phyrrotite by the corresponding magnetic contrast (20 nT) apart from the daily variations corresponding to either the temperature swings and the solar wind incidence.

Finally to demonstrate experimentally the capability of the sensor, and for a fine recalibration we show a comparison of the corrected data registered by MOURA versus the nearest official magnetic daily variation data provided by San Pablo de los Montes Geomagnetic Observatory (IAGA code: SPT) (Geomagnetic observatories, 2014).

The subsection 2.1 “Brief description of MOURA and tested parameters” should be substituted by the following:

MOURA is a vector magnetometer and gradiometer to measure the magnetic environment on the surface of Mars. It is based on AMR technology. The main characteristics of the instrument are summarized in Table 1.

The front end is based on a flipping mode of the AMR, the SET/RESET flip recommended by the manufacturer (Honeywell Magnetic Sensors, 2014) in order to avoid cross axis effects, increase repeatability by decreasing the thermal disorder of magnetic domains, and reduce hysteresis. Therefore, the measurement will consist in the subtraction of the two mirror states (after the SET and RESET pulses): Set-Reset mode (Set pulse - V_{Set} acquisition - Reset pulse – V_{Reset} acquisition – calculation of $V_{S/R}$ =(V_{Set} – V_{Reset})/2…) with open loop conditioning of the AMR Wheatstone bridges, though either operations in Set / Reset (Set / Reset pulse - $V_{Set/Reset}$ – Set / Reset pulse - $V_{Set/Reset}$ …) or just one pulse based modes

(Set/Reset pulse - $V_{Set/Reset}$ - $V_{Set/Reset}$ …) are foreseen. In order to guarantee the correct flipping of the domains in the AMR, and therefore, its repeatability, the pulses of SET and RESET are generated by the discharge of several capacitors charged to 12 V. The shape of the pulses is therefore that of the capacitors discharge.
The noise is expected to be in the order of 1 nT. The offset coils are used for the calibration of the sensor gain and to double the dynamic range (to ± 130.000 nT max.) when the response of any axis is saturated. Due to mass and power constraints, the instrument is designed to operate in open loop (no feedback) and the thermal compensation is performed by calibration in contrast to other developments (Brown, et al., 2012 and Ripka, et al. 2013, Díaz Michelena M. et al. 2014). The consequent cross axis effects will be assumed.
The instrument has several temperature sensors based on platinum resistors (PT-1000 previously calibrated) for the compensation of the thermal drifts of the different elements. Of particular importance are the temperature sensors located on top of the two magnetometers (TMP1 and TMP2), which will be used for the compensation of the magnetic signals with temperature.

The instrument also comprises a tilt angle detector (a three axes accelerometer ADXL327 by Analog Devices) for the correction of the inclination and northing. The accelerometer is selected amongst other devices because of its lower magnetic signature (magnetic moment lower than 1 μAm^2 when exposed to moderate fields (100 pT) contributing less than 0.5 nT in the position of the sensor).
The instrument has a physical envelope of 150 x 30 x 15 mm^3 and 72 g.
For the present characterization we focus on the signals described in Table 2 (denoted as channels).

The subsection 2.2 "Employed equipment" should be substituted by the following:

All the calibration has been performed in the Space Magnetism Laboratory at INTA headquarters with the exception of the magnetic daily variations, which were registered in San Pablo de los Montes Observatory, Toledo, Spain.

Controlled magnetic fields are generated by a set of three pairs of high mechanical precision Helmholtz coils (HC), model Ferronato BH300-A. Each pair of coils (denoted as HC_X, HC_Y and HC_Z) is calibrated by means of Bartington FG100 fluxgate (certified by Bartington, against the calibration references, in accordance with ISO10012: Mag- 01 magnetometer, Mag Probe B, solenoid with current source and DC scaling solenoid, see Table 3). The coils constants are: HC_X = 524.38 pT A^{-1}, HC_Y = 542.15 pT A^{-1}, and HC_Z = 525.6 pT A^{-1}. The electric currents to generate the magnetic fields are supplied by a Keithley 6220 precision current source.

Non-orthogonalities in the HC are lower than 4''; according to the documentation provided by the manufacturer (Honeywell Magnetic Sensors, 2014), orthogonality between *X*-*Y* axes is better than 3.6'' and it is checked experimentally that between the *Z* axis and the XY plane the non-orthogonality is below 0.5°.

For monitoring magnetic field pulses a fluxgate magnetometer FG-500 is used (see Table 3).

A thermal chamber (Binder MK53) is employed to set and control the temperature during the characterization tests. This chamber allows to apply temperatures from -70 to 180 °C, and to circulate dry N_2 gas inside of the chamber in order to control the humidity of the atmosphere. The N_2 flow is kept between 1 and 5 Lmin^{-1}. The measurement of the atmospheric humidity inside the chamber is performed by a Vaisala HMI31 humidity and temperature indicator, and always kept under 18%. This is done to prevent water condensation in the low temperature range. It is not observed any influence of humidity on our sensors' performance.

For the characterization tests, the temperature register is performed by the included thermal chamber temperature sensors, those included in MOURA and two additional temperature sensors. These additional temperature sensors are two PT- 1000 resistances calibrated by means of a SIKA TP 38165E, and connected to a data acquisition system (Agilent 3497A Automatic DAS, computer commanded).

For the calibration of the inclinometer it is used a sine bar and gauge blocks with 5 values between 1.5 and 141 mm to generate the desired tilt angles around *X* and *Y* axes (α and β angles). The rotations are obtained with one of the cylindrical plugs leaning on the gauge blocks and the other on the surface plate. The accuracy of the method is better than 10 min of arc.

The introduction to subsection 3.1 “Room temperature characterization” should be substituted by the following:

In this section it is described the room temperature characterization of the offsets, gains and output field generated by the offset coils.

In subsection 3.1.2 “Non-orthogonalities and Euler angles determination - gain characterization”, the text from 395 (included) to the end of this point should be replaced by the following:

MOURA was fixed in the centre and aligned with the set of HC, taking as a reference the geometrical shape of its box: for this measurement, a high-precision container was made ad hoc in order to fit rigidly the magnetometer, and a set of laser theodolites was used to align HC and the sides of the container. Doing so, we could set MOURA and the set of HC in co-axial position, with a calculated misalignment below 0.1'.

The whole set was placed into the magnetic shielded chamber.

The calibration tests are performed in thermal equilibrium (thermal variations < 0.2°Cmin^{-1}). MOURA non orthogonalities between i’ and j’ axes (MOURA reference system) are determined by comparison of orthogonalities between MOURA and HC system (i and j axes in HC reference system): ΩMOURAi’j’, and ΩHCij. The comparison is performed by successive application of rotating magnetic fields in the different planes of the HC reference system (XY, ZX, YZ – Table 5) and the corresponding linear fit with MOURA readings of field (Fig. 4):

$$\Omega_{HC_{ij}} = \delta + P \cdot \Omega_{MOURA_{i'j'}} \quad (4)$$

δ is de misalignment between *ij* and *i'j' HC and* MOURA axes respectively. *P* is the slope of the linear fitting between Ω_{HCij} and $\Omega_{MOURAi'j'}$.

Room temperature GAINx, GAINy, GAINz calculation is performed by comparison of the MOURA registered magnetic signals and reference positive and negative signals of intensity (Pi+ and Pi-) using:

$$B_{MOURA}(T)_i^+ - B_{MOURA}(T)_i^- = cos\theta_i \cdot (P_i^+ - P_i^-) \cdot GAIN_i \cdot (T_G) \quad (5)$$

Note that X1 and Y1 have opposite sense directions than X2 and Y2, respectively for engineering purposes.

The results from the fittings are presented in Table 6.

Once the linear fitting and then the misalignment angles between planes were obtained, it was possible to approximate the misalignment of each axis by direct composition. Under this approximation the gains for each axis were obtained by direct calculus employing Eq. (5) and statistical corrections of the measured magnetic moduli. The results are shown in Table 4.

With this correction, relative errors in the measurement of the field with the different axes are below 0.3% except for the case of the Y1 sensor, which has an error of up to 0.9%.

The title of subsection 3.1.3 should be changed by "Characterization of output fields of the offset coils".

The subsection 3.1.3 "Characterization of output fields of the offset coils" should be substituted by the following:

The characterization of the offset coils constant (field vs. current) needs to be performed since the field vs. current provided by the manufacturer is subject to an error and these coils are used for the calibration of the sensors prior to the use. Also these coils are used to extend the dynamic range of the magnetometer when it is saturated in the automated mode.

This characterization is performed in the same conditions as the gain characterization (using the same HC system in the zero field chamber).

Decreasing and increasing field ramps are applied in 126 steps (between -45 655 and 45 665 nT). At room temperature the field generated by the different offset coils is between 0.8293 and 0.8767 ± 0.0003 times that generated by the external field. More details will be given in Sect. 3.2.3, where the temperature calibration data are shown.

In subsection 3.1.4 reference to table 8 should be changed to Table 7 (Page 398, line 13) and reference to table 9 should be changed to Table 8 (Page 398, line 21)

The subsection 3.2.1 "Offset characterization with temperature" should be substituted by the following:

The variation of the offset with temperature was formerly estimated with the daily fluctuation of the temperature outside the building (10-30 °C). It was observed that the variation of the offset with temperature was very similar to that of the gain. This test was performed inside a shielding chamber with a field stability that is better than 1.5 nT. Therefore the offset observed is only attributed to the variations of temperature inside the chamber, which are registered and are in good correlation with the offset values monitored. Consequently for the extended range of temperature, both variations with temperature will be considered equivalent, i.e. AOFFSET = AGAIN.

This assumption will be corrected with the long term records at San Pablo de los Montes Observatory with the local temperature data.

In subsection 3.2.2 "Gain characterization with temperature - V_{REG} compensation", the text from 404 (included) to the end of this point should be replaced by the following:

The test is carried out at six temperature values in the range of temperatures in which field measurements were performed, using as first reference the thermal chamber temperature controller: -60, -30, 0, 15, 45, and 60 °C. The registered humidity inside the chamber is < 18% for the test (as explained in Sect. 2.2). The square magnetic pulses along the six semi-axis were applied by means of a Keithley precission source (10 mA current) supplied to the three pairs of HC simultaneously at thermal equilibrium < 0.1 °C min^{-1} (Table 9). The amplitude of each magnetic pulse was taken as the mean absolute value of each pulse applied along the same axis (positive and negative pulse). The registered magnetic field amplitudes were normalized to that obtained at room temperature: TMP1 = 25.9 ± 0.2°C and TMP2 = 25.6 ± 0.2°C. Two additional temperature sensors (calibrated PT-1000, denoted as TT and TL) were placed on the top (TT)

and on a side (TL) of MOURA in order to guarantee thermal equilibrium. Since the level of magnetic noise generated by the hardware of the thermal chamber (mainly rotor and pumps) makes it impossible to obtain suitable accurate data, the thermal chamber was switched-off when the pulses were applied (Fig. 7).
These variations of temperature affect the voltage sourcing of the magnetoresistive bridges. VREG has a variation with temperature of 0.1 %. The variation is recorded and will also be taken into account for the response correction.
The thermal chamber control is switched off to measure. The obtained values of amplitude for each axis were normalized by those obtained at TMP1 = 25.9°C and TMP2 = 25.6 °C. These normalized amplitudes were linearly fitted with the corresponding temperature (T - 25.9°C for Sensor 1 data and T - 25.6 °C for Sensor 2 data) (see Fig. 8).
ΔGAIN values, derived from these fits, are presented in Table 4. For example:
$\Delta GAIN_{X1} \cdot (T - T_G) = (-0.00370 \pm 5 \cdot 10^{-5})\ °C^{-1} \cdot [TMP1(°C) - 25.9°C]$.
The coefficients for the thermal drift correction of the magnetic data for each axis are summarized in Table 4.

The title of subsection 3.2.3 should be changed by "Offset coils characterization with temperature".

The subsection 3.2.3 "Offset coils characterization with temperature" should be substituted by the following:

In this section it is calibrated the thermal variation of the offset coils constant (nT nT^{-1} or nT mA^{-1}). For simplicity only sensor 1 parameters are displayed.

This characterization is performed by means of a relative measurement of the constant variation with temperature and then referred to the temperature of reference in a similar way of the gain characterization with temperature.

In this case, two ramps (Ramp I: decreasing from 45 665 to -45 665nT, and Ramp II: increasing from -45 665 to 45 665nT) of 126 steps (4.56 mA) have been applied with the offset coils.

Previously it has been checked that the current passing through the offset coils do not increase the temperature of the magnetoresistors and thus, it does not alter the response.

In order to obtain the values of the offset coil constant variation with temperature (($nTnT^{-1}$)/°C), the above mentioned magnetic field ramps were applied at the 5 different temperatures in the same thermal chamber as the previous test.

In this case, MOURA temperature sensors were also employed to register the temperature variation during the test. The ramps were applied in thermal equilibrium (< 0.1 °C min^{-1}) with the control of the chamber switched off. The control of the humidity (< 18 %.) was performed with N_2.

An example of the obtained data is presented in Fig. 9. As it can be noted the offset value is higher than the obtained in the magnetic shielded chamber due to the lack of a magnetic clean environment.

The obtained coils constants for sensor 1 from the linear fits for each ramp at different temperatures, and averaging data corresponding to Ramp I and Ramp II, are presented in Table 10 and represented in as a function of TMP1.

The obtained Gains for each temperature were linearly fitted versus the registered temperature byTMP1 sensor (Fig. 10).

The thermal variations of the offset coils constants are presented in Table 11. For example: $\Delta Constant_{X1}$ (nT nT^{-1}) · (TMP1 - T_{ref})(°C) = (-0.088034 ± 7 x 10^{-6}) $°C^{-1}$ ·(TMP1 - 25.9)(°C).

The title of section 4 should be changed by "Data comparison of MOURA and SPT reference

magnetometers".

The section 4 "Data comparison of MOURA and SPT reference magnetometers" should be replaced by the following:

In this section it is described the calibration of the offset with temperature by means of comparison with another magnetometer (reference) at a temperature different from the that of the laboratory, and a final measurement of a space weather event as a demonstration of MOURA capabilities in terms of resolution. These measurements have been performed at the Geophysics Observatory of San Pablo-Toledo (SPT) facilities, (39.547 ºN, 4.349 ºW) in Spain, during late January and February months of 2013 (offset drift with temperature) and during June, July and August months of 2013 (geomagnetic storm). The comparison needs to be performed in situ for the large crustal magnetic anomalies variability in the peninsula and other factors like magnetic contamination (Martínez Catalán, 2012).
SPT belongs to INTERMAGET (www.intermagnet.org), a global network of observatories, since 1997 and to the International Association of Geomagnetism and Aeronomy (IAGA) (available at www.iugg.org/IAGA). SPT has a fluxgate magnetometer FGE-Danish Meteorological Institute and a fluxgate vector magnetometer Geomag M390. Also it is equipped with Overhauser effect magnetometers GSM90 for calibration purposes. The instrumentation set up is completed by a dIdD Gemsystem equipment. Two declinometers-inclinometers Zeiss 010B with a fluxgate Bartington probe are used for absolute weekly observations. This suit of magnetometers offers raw data, which are further corrected by the observatory (contamination removal: instrumentation faults or man-made interferences, and daily basis filtering). In the present comparison partially treated and compensated available data will be used for the comparison. Final data are provided in the order of one year after the measurements.

For the test campaigns some auxiliary instrumentation was moved to SPT: MOURA instrument (with axes orientation defined in Fig. 11), a voltage source with two output channels, a laptop, a modem 3G USB and a 82357B USB/GPIB interface by Agilent Technologies.

Due to the distance between Toledo (test station) and Madrid (INTA headquarters), a Modem 3G USB was used for a remote control of the computer enabling enabled all basic operations of MOURA. The final complete setup with the elements described in the instrumentation point is showed on Fig. 12.

A first campaign between 21/02/2013 and 25/02/2013 (dd/mm/yyyy) was used to refine the laboratory calibration.

During the acquisition, a percentage of erroneous data were detected (Table 12). They are attributed to transfer data errors during set and reset pulses or packing data errors. Retrieval software is able to detect and suppress automatically the errors.
The first campaign takes place during quiet days. Fig 13 shows the variation of the different components of the magnetic field measured by MOURA sensors (sensor1 and sensor2) versus SPT in February 21-24 2013. It can be seen the typical terrestrial magnetic field daily variation, with a higher amplitude of the X component pointing to the North of the Earth during sunny hours, directly related with the exposure to the solar radiation during the day hours. MOURA data fit quite well with the reference data showing a daily variation of ±35 nT with highest values at around 12:00 to 14:00 on X magnetic field component. It can be seen a not negligible offset deviation of MOURA data. It is related to the variation of the offset with the temperature. Notice that offset calibration performed in the laboratory takes place at 18 ºC and the average temperature at SPT in the time of the campaign is 5 ºC. This fact is used to correct the previous estimation performed in section 3.2.1 according to the next expression:

$$\frac{\Delta Offset}{\Delta T}\left(\frac{ppm}{°C}\right)=\frac{\frac{Offset \pm \Delta(MOURA-SPT)-1}{Offset}}{T_{Offset}-T_{SPT}}\cdot 10^6$$

The resulting values are included in Table 4. As well as in the drift of gain with temperature the dispersion of the offset drift with temperature is very wide, which makes it necessary to up screen the sensors to be used and filter the most suitable for the purpose.

After this last correction of the offset drift with temperature, and the corresponding modification of the retrieval software, a new campaign is performed with the double objective to validate the calibration and to demonstrate the suitability of the sensor to measure the space weather events. In this case it has been selected a period with some solar activity: the period of three months from June to August 2013. Fig. 14 shows the data corresponding to the geomagnetic storm occurred in June 28th and 29th. Such event is characterized by a decrease of horizontal magnetic field component H, that is $H=(X^2+Y^2)^{1/2}$, of about 100-200 nT respect to the initial level of H accompanied by irregular fluctuations of varying frequencies (periods from seconds to hours) and intensities (from nT to tens of nT). Therefore, Fig. 14 represents the horizontal component of MOURA sensors (sensor1 and sensor2) as well as SPT reference data. The results confirm that MOURA reproduce quite well the magnetic field variations measured by SPT official magnetometer.

In general the parameters characterized are in agreement with the manufacturer datasheet. The non orthogonalities between the in plane components (X and Y) is negligible compared to our resolution, and the measured deviation between the Z axis and the XY plane is lower than 1º as specified.

Sensitivities match very well the values of the datasheet, and offsets are lower than maximum swing specified because the sensors have been screened to choose those with the lowest offsets at room temperature. Regarding the gain drifts with temperature the parameters measured are in accordance with the manufacturer data but it exists a wide dispersion of values like in the gain drift of sensors 1 and 2. The observed offset drift with temperature is higher than the values specified by the manufacturer for Set and reset operation. Also it has to be highlighted the anomalous offset drift of the Z component of sensor 2. Though the dispersion is attributed to manufacturing processes and it is considered normal, this is an important factor, which needs to be taken into account in the selection of the components for future missions.

The title of section 5 “Conclusions” should be changed by “Conclusions and Future work”

The section 5. “Conclusions and Future work” should be replaced by:
A practical calibration of MOURA magnetometer and gradiometer has been performed to demonstrate its capability to fulfil the pursued scientific objectives on Mars: to measure the magnetic anomalies of the landing site and to observe the daily variation of the field and its perturbations with the solar activity.
The calibration comprises the characterization of the offsets, gains, non-orthogonalities and Euler angles, as well as offset and gain drifts with temperature in a range from 0 to 60 ◦C, and the tilt angle detector characterization. The retrieval software includes the equations to derive the magnetic field referred to the martian surface temperature compensated.
The offset drift with temperature has been characterized by means of measurements performed at a reference observatory, San Pablo de los Montes, Toledo.
Finally it has been performed a successfully comparison of MOURA measurements with the reference magnetometer during a geomagnetic storm. The results are considered very useful: it is feasible to obtain scientific information on the magnetic environment with a 72 g compact magnetometer of < 0.5 W . The

extended use of such instruments (net of landers / rover) could help the characterization of the unknown martian magnetic scenario highly improving the understanding of the remanence of the crust and possibly on the ancient magnetizing field.
In forthcoming works we will also report on our real and long-term prospections with MOURA in comparison with a scalar absolute magnetometer (Geometrics 858), and the data interpretation, to describe the potential of this miniaturized compact magnetometers for rovers and balloons.

TABLES
Previous Table 4, 7, 11 and 12 should be removed.
In the following we list tables from 4 to the end:

Table 4 – Gains and offset values as well as their temperature drifts

SENSOR 1 axis	**GAIN @ T_G=TMP1= 25.9 ±0.2°C**	**ΔGAIN (°C^{-1}) (referred to T_G)**	**OFFSET (nT) @ TMP1=18.13±0.03°C**	**ΔOFFSET (°C^{-1}) (referred to TMP1)**
X	0.910 ± 0.003	($-0.00370 \pm 5\cdot10^{-5}$)	764 ± 5	($-0.0037 \pm 5\cdot10^{-5}$)
Y	0.902 ± 0.002	($-0.00382 \pm 7\cdot10^{-5}$)	-1130 ± 16	($-0.00450 \pm 7\cdot10^{-5}$)
Z	0.832 ± 0.003	($-0.00384 \pm 4\cdot10^{-5}$)	1582 ± 8	($-0.00352 \pm 4\cdot10^{-5}$)
SENSOR 2 axis	**GAIN @ T_G=TMP2= 25.6 ±0.2°C**	**ΔGAIN (°C^{-1}) (referred to T_G)**	**OFFSET (nT) @ TMP2=19.21±0.03°C**	**ΔOFFSET (°C^{-1}) (referred to TMP2)**
X	0.815 ± 0.003	($-0.00591 \pm 5\cdot10^{-5}$)	1107 ±3	($-0.00200 \pm 5\cdot10^{-5}$)
Y	0.807 ± 0.001	($-0.00621 \pm 9\cdot10^{-5}$)	-538 ±5	($-0.00794 \pm 9\cdot10^{-5}$)
Z	0.783 ± 0.002	($-0.00616 \pm 6\cdot10^{-5}$)	1427±	($-0.0379 \pm 4\cdot10^{-4}$)

Table 5 - Applied electrical currents in the different planes

Plane	**Electrical current (ω=1^{o} step^{-1})**	**Sequence of steps**
XY	$I_x(t)$ = 60mA · cos(ω· step) $I_y(t)$ = 60mA · sin(ω· step)	From 1 to 360
ZX	$I_z(t)$ = 60mA · cos(ω· step) $I_x(t)$ = 60mA · sin(ω· step)	From 361 to 721
YZ	$I_y(t)$ = 60mA · cos(ω· step) Iz(t) = 60mA · sin(ω· step)	From 722 to 1082

Table 6 - Parameters δ and P of equation 4.

MOURA / HC planes	**δ (°)**	**P**
X1Y1 / XY	0.64± 0.05	-0.997 ± 0.001
X1Z1 / XZ	7.3 ± 0.2	-0.986 ± 0.004
Y1Z1 / YZ	-0.42 ± 0.2	1.005 ± 0.004
MOURA / HC planes	**δ (°)**	**P**
X2Y2 / XY	1.76 ± 0.05	-0.997 ± 0.001
X2Z2 / XZ	-5.3 ± 0.1	0.973 ± 0.002
Y2Z2 / YZ	1.12 ± 0.1	-1.006 ± 0.003

Table 7 - Tilt angles around + X (α tilt angle) and experimental values (converted into g) for the first 5 steps

α (º)	**Δα (º)**	**ACC_X (g)**	**ACC_Y (g)**	**ACC_Z (g)**	**ACC (g)**
4.9719	< ± 0.16	0.2299	0.7839	-0.4297	0.92302
11.5369	< ± 0.16	0.3043	0.7182	-0.4747	0.9131
19.4711	< ± 0.16	0.3953	0.6261	-0.5170	0.9031
30.0000	< ± 0.16	0.5080	0.4920	-0.5483	0.8948
41.8103	< ± 0.16	0.6411	0.3583	-0.6114	0.9556

Table 8 - Relative error between experimental and theoretical values of α for different α

α (º)	**ACC_X (g)**	**ACC_Y (g)**	**ACC_Z (g)**	**ACC (g)**
5	2.7%	-1.5%	0.0%	-0.9%
12	3.5%	-3.5%	-0.5%	-2.0%
19	4.6%	-6.8%	-1.2%	-3.1%
30	4.8%	-12.3%	-2.8%	-3.9%
42	7.8%	-15.0%	5.4%	2.6%

Table 9 - Temperature registers and their temporal variation

Measurement	TT(^oC)	TL(^oC)	TMP1 (^oC)	TMP2 (^oC)
1	59.4 ± 0.1	58.9 ± 0.2	50.4 ± 0.1	50.04 ± 0.04
2	32.6 ± 0.2	32.2 ± 0.1	25.9 ± 0.1	25.6 ± 0.1
3	5.4 ± 0.2	4.1 ± 0.1	-0.3 ± 0.2	-0.6 ± 0.2
4	16.6 ± 0.1	17.3 ± 0.1	11.8 ± 0.2	11.55 ± 0.2
5	44.8 ± 0.1	45.4 ± 0.1	38.4 ± 0.1	38.2 ± 0.1
6	58.4 ± 0.2	58.8 ± 0.2	50.6 ± 0.1	50.51 ± 0.01

Table 10 - Inner coils constants at the different temperatures

TMP1 (^oC ± 0.05)	Constant (nT/nT) ± 0.0003		
	X1	Y1	Z1
16.41	0.8879	0.9116	0.8617
49.55	0.7743	0.8022	0.7644
26.92	0.8518	0.8767	0.8293
0.69	0.9406	0.9656	0.9086
11.42	0.9045	0.9290	0.8760
37.53	0.8160	0.8414	0.7961
50.37	0.7722	0.7988	0.7564

Table 11 - Sensor 1 inner coils characterization with temperature

ΔConstant Axis	Value ((nT/nT)/ $^oC^{-1}$)
$\Delta Constant_{X1}$	$-0.088034 \pm 7\cdot10^{-6}$
$\Delta Constant_{Y1}$	$-0.086506 \pm 1\cdot10^{-5}$
$\Delta Constant_{Z1}$	$-0.078218 \pm 4\cdot10^{-5}$

Table 12 – Percentage of transmission errors during five consecutive days (21 – 25 / 02 / 2013).

	Errors percentage (%)	
Axis	Sensor 1	Sensor 2
X	0.20	0.0
Y	0.00	4.2
Z	0.35	4.2

FIGURE CAPTIONS

Previous figure 11 is removed. The following figures should be added:

Fig. 11. Relative axes of MOURA: X1, Y1, Z1 and X2, Y2, Z2 and SPT observatory: X_{SPT}, Y_{SPT} and Z_{SPT}.

Fig. 12. Set up of the measurements.

Fig.13. Comparison between measurements from SPT and MOURA, X axis (bottom), Y axis (middle) and Z axis (top).

Fig.14. Horizontal component of the geomagnetic field measured with MOURA magnetometer and SPT reference magnetometers in June 28 – 29 2013.

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Diaz Michelena M., Cobos P., Aroca C.: lock-in amplifiers for AMR sensors, Sensors and Actuators A (Physical), In press, 2014.

Martínez Catalán J.R.: The Central Iberian arc, an orocline centered in the Iberian Massif and some implications for the Variscan belt, Int J Earth Sci (Geol Rundsch), 101, 1299-1314, 2012.

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The next references:

Michelena, M. D.: Small Magnetic Sensors for Space Application, Sensors, 4, 2271–2288, 2009.

Michelena, M. D., Arruego, I., Oter, J. M., and Guerrero, H.: COTS-Based Wireless Magnetic Sensor for Small Satellites, IEEE T. Aerospace Elect. Syst., 46, 542–557, 2010.

Should be modified to:

D. Michelena, M.: Small Magnetic Sensors for Space Application, Sensors, 4, 2271–2288, 2009.

D. Michelena, M., Arruego, I., Oter, J. M., and Guerrero, H.: COTS-Based Wireless Magnetic Sensor for Small Satellites, IEEE T. Aerospace Elect. Syst., 46, 542–557, 2010.