Towards the Eurasian Submillimeter Telescope (ESMT): Telescope Concept Outline and First Results

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Abstract. The Euroasian Sub-Millimeter Telescope (ESMT) project is devoted to the development of three sub-millimetric observatories in the Northern emisphere. The ambitious goals of ESMT include observations in the sub-millimeter range, down to 200-300 microns; this implies a significant technological improvement over existing observatories, in order to reach and to keep the necessary surface accuracy. The antenna of ALMA developed for the European contribution of the interferometer has been selected as the baseline system for the development of ESMT. A short overview of the ongoing efforts towards ESMT are presented.

Keywords: telescopes; submillimetre: general

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1 Introduction

The Euroasian Sub-Millimeter Telescope (ESMT) (Khaikin et al. 2020) is a project dedicated to the design and constrution of three sub-millimeter observatories, to be located in the Northern emisphere. Its scientific objectives constist in providing wide-field imaging of continuum and spectral objects, formation of molecular clouds, formation of protoplanetary disks, CMB science, studies of hot gas in intracluster medium, chemical evolution of the Universe, sub-mm follow up of gravitational wave sources, imaging of the shadows of black-holes in the framework of the EHT collaboration. Thanks to its excellent pointing and surface accuracy performances, the Atacama Large Millimeter Array (ALMA) (Wootten & Thompson 2009; Event Horizon Telescope Collaboration & et al. 2019; Doeleman et al. 2009) represents a good starting point to develop the design of such a demanding observatory. The main development directions can be summarized as follows: increase of the main dish size, improvement of the main dish surface accuracy, improvement of the pointing / tracking performances. Such developments can be combined in different ways, depending on the science drivers, but for what concerns ESMT, it is necessary to provide a combination of at least two of them, namely a significantly larger dish (diameter 21m) and a superior surface accuracy. Furthermore, the development of the design must take into consideration the specific requirements of ESMT instruments (see for instance Duan et al. (2020b,a)) and the expected environmental conditions. Among the several factors that contributed to the success of ALMA, we mention here some of the most relevant. The first is related to the material used for the construction. The antenna of ALMA is made up of five main structures: the base, the yoke, the receiver cabin, the main reflector and the sub-reflector. Three of them (cabin, backup and sub-reflector structures) have been totally designed in CFRP material to reduce the total weight and, at the same time, to increase the stiffness and reduce the thermal deformations, which can be otherwise particularly severe during daytime observations. Another relevant aspect that contributed to the performances is related to the main dish. The 120 reflecting panels, making up the parabola, are installed on the bus surface through 600 micrometrical adjusters, five for each panel. Each adjuster is designed in such a way to passively compensate for the different thermal behavior of the panel and the structure. The stability of the surface shape is then guaranteed by a specific combination of an accurately engineered back-up structure, by compensanting adjusters and by high accuracy panels. The third important element contributing to the performances is the metrology (thermal and dynamic). The Thermal Metrology system, which includes 100 thermal sensors and a thermal matrix, provides every 5 seconds a correction command to the main axes, to compensate for thermally induced distortions of the mount. The Dynamic Metrology includes two inclinometers installed inside the arms, and it provides through a correlation formula the instantaneous axis correction, to stabilize the antenna pointing and tracking during operations in windy conditions. We underline here that the design development of ALMA was focused by taking into account specific environmental conditions. In particular, the surface accuracy ($< 21\mu$m) and pointing & tracking performances (0.28 arcsec and 0.04 arcsec, respectively) are met within a temperature range of -20°C to +40°C, at the environmental conditions encountered on the ALMA site.

2 Towards ESMT: Design Approach

The main differences between ESMT and ALMA do not concern the surface accuracy and the larger dish only. According to the current project baseline, the antennas of ESMT will not work in a real-time interferometric mode, possibly leading to a relaxation of some structural and performance requirements. Furthermore, the layout of the instruments under study may require significant modifications to the bus structure and to the receiver cabin. Despite such differences, ALMA can be used a baseline model to study possible developments and to identify critical areas.

2.1 Optical Design

A preliminary approach consists in keeping the shape of the primary dish, while extending its aperture diameter to the value required by ESMT, allowing for only small modifications to the sub-reflector geometry to achieve optical quality. The off-axis aberrations have been calculated following Lamb (1999) (no tapering). Under such assumptions the loss of aperture efficiency is <10% for an extension up to 15-m dish diameter, at the field edge (0.18 deg). If the aperture diameter is increased up to 20m, the loss of aperture efficiency is such, that the field must be lowered by about 30% in order to have the same losses expected for the 15m antenna (at the wavelenth of 300 μm). Therefore, ESMT requires a largerly different optical design with respect to that of ALMA. A possible development direction consists in using a configuration with a primary mirror having a focal length of 8000 mm, keeping the same magnification of ALMA and adjusting the conic constant and position of the secondary dish to achieve optical quality. Under such assumptions, the drop of aperture efficiency can be limited to < 7% at the edge of the field. An alternative approach consists in using a larger magnification, leading to a configuration with a longer extraction for a given primary mirror focal length. This approach allows the installation of a tertiary mirror along the optical path, and thus to install a Nasmyth platform, easing the installation of the instruments.

2.2 Structural Configuration

The structural performances of the back-up structure, in terms of gravity and thermal deformations, largely drive the overall performances of the main dish. Usually, small-size antennas feature a closed back-up structures, while medium or large-size radio telescopes feature an open truss as a back-up structure. The threshold at which, performance-wise, an open truss BUS becomes better than a plated BUS lies at about 20-25 m primary mirror diameter. The trade-off also depends on the material in which the BUS is made: it is easier and cheaper to manufacture a large plated steel structure, which does not have all the issues and costs linked to molds and adhesives connections, than a CFRP one. So, one can conclude that the threshold is about 20 m for CFRP BUSes and 25 m for steel ones. Being thermal stability of the essence for THz observation, a CFRP BUS is a must. Therefore ESMT, with its 21 m primary mirror diameter, lies in the field where an open truss is to be preferred. ALMA design is to be replicated for what regards the technology of the panels and their adjustment tools, both for the primary mirror and the secondary mirror, the CFRP to steel mechanical interface, the thermal metrology, and the main axes drives. With the above-mentioned observations in mind, a preliminary concept of a mixed CFRP-steel BUS for the ESMT has been studied by means of Finite Element Analysis. The structural concept features 96 active segments, controlled by 129 actuators. Each segment is then composed by 4 to 6 tiles of maximum 500x500 mm size, supported by a CFRP/aluminium frame. This allows to greatly reduce the number of needed actuators, and to greatly simplify the manufacturing of the panels while reaching higher surface accuracy. The upper part of the BUS is composed by CFRP struts, with steel joints, while the lower part of the BUS is composed by steel beams. The concept of the BUS weights about 45 t, taking into consideration all contributing masses (see Table 1). Modal analysis and gravity analysis have been performed to have a preliminary assessment of this BUS concept. Modal analysis shows that the first frequency is about 8.4 Hz, which can be considered already a good starting point for the development of the design. The next step will be to extract gravity deformations results of the parabola at different elevation angles, so to obtain a preliminary assessment of the antenna surface accuracy and pointing error.

Table 1. Mass table for the open truss concept

ESMT BUS concept mass table			
Item	Material	Quantity	Mass [kg]
Segments	CFRP/Aluminium	96	7000
Actuators	Steel	129	2000
BUS Joints	Steel	–	5000
Secondary	CFRP/Aluminium	1	500
CFRP BUS	CFRP	1	10000
Steel BUS	Steel	1	9000
Quadripod & M2 BUS	CFRP	1	1000
Elevation Wheel	Steel	1	7000
EL Bearing Support	Steel	2	1800
Total Mass			45000

2.3 Surface Accuracy

The evaluation of the performances of the open truss structure has been performed by means of the tool *SurfCalc*, developed in EIE and checked against the real performances of ALMA. The description of the optics geometry in terms of the eight parameters deriving from Granet (1998) is a mandatory step for assessing the contribution to surface accuracy and pointing error provided by main dish deformation, sub-reflector translation and rotation. The surface accuracy error and the pointing error due to rigid motion here above can be assessed according to Levy (1996). The preliminary results of the surface error set the requirements on the actuators for the active control of the primary dish surface. The deformations induced by the gravity are of the order of 300 microns; including some margin to achieve the initial alignment plus further margin to cope with thermal deformation, the preliminary evaluation of the actuator range is of the order of ±3 mm, close to the range of the manual adjusters used for ALMA.

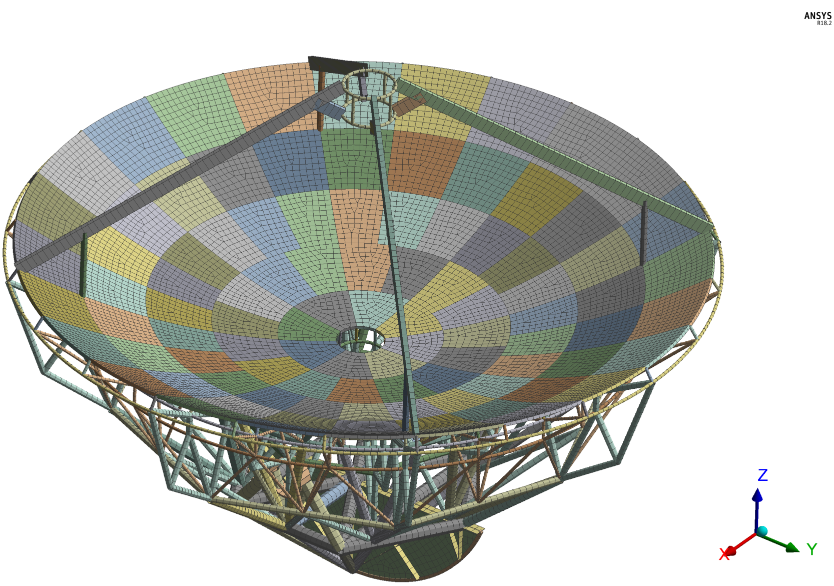

Fig. 1. 3D model of the ESMT open truss structure

3 Conclusions

ALMA represents a good starting point for the development of ESMT. The larger size, the required surface accuracy, and the necessary long term stability against temperature gradients are among the main design drivers. A new optical layout has been developed to minimize off-axis losses. On this basis, a new design for the back-up structure was developed and checked, setting preliminary requirements for the actuators of the active surface control system.

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