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High-precision Photogrammetric Surface Figure Measurements under Cryogenic Environment† ⋆

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Abstract Limited by the working temperature of the test equipment, most of high-precision surface figure measurement techniques cannot be put into application under a cryogenic environment. This paper reports the first attempt to measure the surface figure of a high-precision terahertz reflector panel under low temperatures based on photogrammetry. The measurement employs a high-resolution industrial camera sitting on the automatic testing platform which enables photos been taken in an automatic fashion inside a climate chamber. A repeatable accuracy of 2.1 μm (rms) is achieved under the cryogenic environment. Furthermore, the surface figure measured by a three-coordinate measuring machine under the room temperature is used to calibrate the thickness differences of the targets. By this technique, the surface figure of an aluminum prototype panel of the 5 meter Dome A Terahertz Telescope (DATE5) is measured from room temperature down to -55°C to obtain the rule of variation of surface deformation of the panel under low temperatures.

Key words THz telescopes—techniques: surface figure measurements—photogrammetry—panels—cryogenic environment

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1. INTRODUCTION

The terahertz waveband intermediate between the radio and infrared wavebands is the important measure of astronomical observations, especially suitable for studying the dark energy, large-scale structure, 1st-generation star formation, galactic formation and evolution, the star and planetary system formation and early-period evolution, the atmospheric physics and chemistry of extrasolar planetary system, the cosmic origin of life, and other important scientific problems in modern astronomy. At present, the built and building ground-based terahertz observational instruments in the world include the Atacama Large Millimeter/submillimeter Array(ALMA)[1] and Submillimeter Array (SMA)[2], etc. Besides, the planning terahertz telescopes include also the Cornell Caltech Atacama Telescope (CCAT)[3] and China's Antarctic Dome A terahertz telescope (DATE5)[4], etc.

With the increasing observing frequency and increasingly high performance of the telescopes, the requirement on the surface accuracy of telescope reflectors becomes higher and higher. According to the Ruze formula, in order to guarantee the antenna gain of a telescope, the rms error of reflector surface should be less than 1/20 observing wavelength, taking the observing frequency of 1 THz as example, it requires the rms error of reflector surface be less than 15 μm. And in order to realize the precision measurement of this kind of reflector surface, the measuring error of the measurement system should be in the order of magnitude of micrometer.

On the other hand, in order to pursue a good observing condition, the terahertz telescope is generally installed at an extremely cold high-altitude site, such as the Antarctic Dome A, where the average temperature in the winter season is -60°C, the mean atmospheric water vapour content is only 0.14 mm[5], it is considered to be one of the best sites for the ground-based terahertz astronomical observations. For the telescope operated in such kind extreme environment, besides the normal surface figure measurement, additional cryogenic simulation experiment is necessary, in order to verify the operation performance and surface figure variation under the cryogenic environment. For example, the initial fabrication error of the subreflector of the American South Pole Telescope (SPT) was 11 μm, however under the Antarctic low-temperature environment, the surface error increased to be 50 μm, even later it was returned to the room temperature, but the surface accuracy could never recover the initial level[6], this phenomenon is believed to be caused by the residual stress after the fabrication of the subreflector. This demonstrates that in order to guarantee the good performance of the telescope under cryogenic environment, to make in advance the low-temperature surface measurement on the reflector panel in an environmental test chamber is necessary.

Now the reflector surface measurement techniques with an accuracy in the order of magnitude of micrometer include the contact measurement method, such as the 3-coordinate measuring machine, and the non-contact measurement method, such as the laser speckle interferometer[7], microwave holographic measurement[8], and photogrammetric method[9−13],