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DEVELOPMENT OF NEW STITCHING INTERFEROMETRY FOR THE SPICA TELESCOPE

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ABSTRACT

The telescope to be onboard SPICA (Space Infrared Telescope for Cosmology and Astrophysics) has an aperture diameter of 2.5 m and its imaging performance is to be diffraction-limited at a wavelength of 20 μm at the operating temperature of <8 K. Because manufacturing precise autocollimating flat mirrors (ACFs) with sizes comparable to the SPICA telescope is not technically feasible, we plan to use sub-aperture stitching interferometry through ACFs for optical testing of the telescope. We have verified the applicability of the sub-aperture stitching technique to the SPICA telescope by performing stitching experiments in a vacuum at a room temperature, using the 800-mm telescope and a 300-mm ACF. We have also developed a new method to reduce uncertainties possibly caused by cryogenic and gravitational deformations of ACFs.

Key words: instrumentation; infrared space telescope; cryogenic optical testing; SPICA; stitching interferometry

1. INTRODUCTION

SPICA (Space Infrared Telescope for Cosmology and Astrophysics) is the second Japan-led infrared astronomical satellite project, following AKARI. A telescope system of SPICA has been studied by the Europe-Japan telescope working group led by ESA with European industries (Castle et al., 2012). The telescope has an aperture diameter of 2.5 m and the mirror is made of silicon carbide (SiC) or its related material to achieve lightweight body (the telescope total weight is to be lighter than 620 kg). The imaging performance is to be diffraction-limited at a wavelength of 20 μm, which corresponds to the total wave-front error (WFE) of the telescope of 1.4 μm rms (2.2 λrms) at the operating temperature of <8 K. Here and hereafter, λ is the He-Ne laser wavelength of 633 nm. To meet the required imaging performance, we need precise optical measurements of the large-aperture telescope. Using an optical interferometer through autocollimation by reflecting flat mirrors (autocollimation flats; ACFs) is a popular technique to evaluate a telescope whose diameter size is smaller than 1 m. However, accurate ACFs with sizes comparable to the SPICA telescope are not technically feasible. For this reason, we plan to apply sub-aperture stitching interferometry to the optical testing of the SPICA telescope. It is notable that ACFs are likely to be deformed thermally and gravitationally, which causes errors in the sub-aperture stitching result, and that they are difficult to be measured directly in the test.

In this paper, we report the current results of our experimental study for sub-aperture stitching interferometry. We also propose a new method to mitigate the effects of ACF errors in the sub-aperture stitching result and show a preliminary result of measurement with this method.

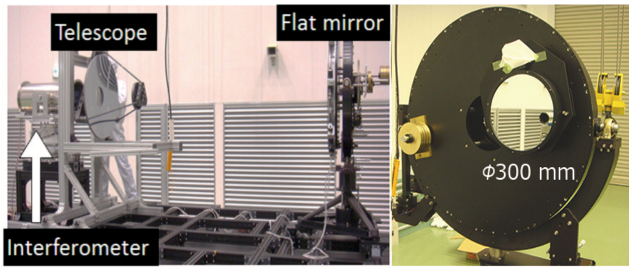

Figure 1. (Left) The configuration of the stitching measurement with the precise 300-mm ACF. (Right) The 300-mm ACF used in the sub-aperture stitching measurement. The ACF is rotated in a counterclockwise direction.

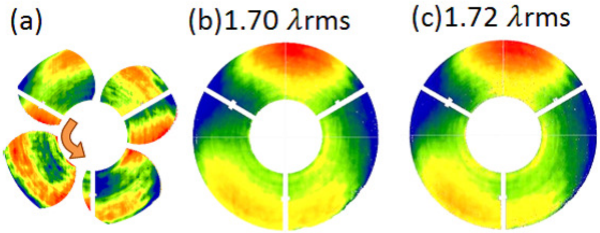

Figure 2. (a) Examples of sub-aperture WFE maps at four radial positions. (b) The WFE maps derived by the sub-aperture stitching and (c) the full-aperture measurement.

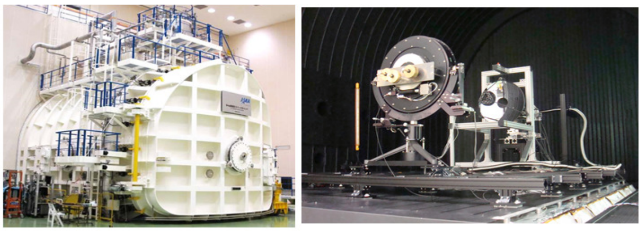

Figure 3. The JAXA 6-m radiometer chamber (outside and inside of the chamber).

2. MEASUREMENT

We utilize the 800-mm telescope all made of C/SiC called HBCesic, which is a candidate mirror material for the SPICA telescope (Suganuma et al., 2010) and a 300-mm high-precision ACF (0.016 λrms) for the sub-aperture stitching measurement. In the sub-aperture stitching measurement, the small ACF is rotated with respect to the optical axis of the telescope by a step angle of 22.5 degrees, which requires 16 radial positions in total to cover the full aperture of the telescope. Then these sub-aperture datasets are stitched to the full-aperture WFE maps of the telescope with the stitching algorithm, which is based on the least square method for the overlapped regions. To verify the applicability of sub-aperture stitching interferometry to optical testing the SPICA telescope, we have compared the sub-aperture stitching measurement (the configuration is shown in Figure 1) with the full-aperture measurement using a 900-mm ACF which can obtain the whole WFE of the telescope at one time (Kaneda et al., 2012).

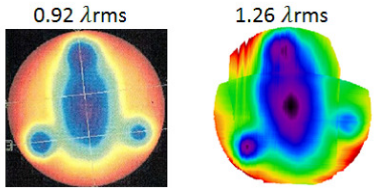

Figure 4. Largely deformed ϕ300-mm ACF. (Left) The SFE of the ACF. (Right) The SFE derived by our new method.

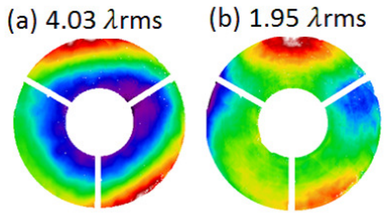

Figure 5. The WFE maps derived with the deformed ACF (a) before correction and (b) after correction.

Figure 2a shows examples of sub-aperture WFE maps measured at four radial positions. Figure 2b and Figure 2c are the WFE maps derived by the sub-aperture stitching measurement (1.70 λrms) and the full-aperture measurement (1.72 λrms), respectively. As can be seen in the figures, they show an excellent agreement with each other.

Using the JAXA 6-m radiometer chamber (Figure 3), we have also performed the sub-aperture stitching measurement in a vacuum (0.45 Pa) at a room temperature as preparation for optical testing at cryogenic temperatures. We compare the sub-aperture stitching result in a vacuum with that in the atmosphere. Both results show an overall agreement with each other, while some differences are observed. These differences may be caused by thermal contraction of the telescope support system due to adiabatic cooling when the pumping was started. As mentioned above, thermal and gravitational defomations of ACFs may degrade the sub-aperture stitching result at cryogenic temperatures. Therefore we have developed a new method to mitigate these effects. We can extract the surface figure errors (SFE) of an ACF independently of the WFE of the telescope by slightly shifting the ACF during the process of the sub-aperture stitching measurement. Then we subtract the SFE of the ACF from each sub-aperture WFE map prior to the stitching. We will report the details of the algorithm in a separate paper.

3. RESULTS

To check the validity of our new method, we designed and fabricated a largely deformed ϕ300-mm ACF (the SFE of this mirror is shown in Figure 4). Figure 5a shows the WFE map (4.03 λrms) derived with the deformed ACF. We confirm that the sub-aperture stitching result is seriously affected by the SFE of the deformed ACF. Then, we mitigate the effect by applying the above method and derive the corrected WFE map (1.95 λrms) as shown in Figure 5b. Comparing this map with that in Figure 2b (1.70 λrms), we find that our new method can mitigate the effects of the deformed ACF to some extent. However, there still remain small differences in the WFE, thus we need to improve our measurement system and the algorithm.

4. FUTURE PLAN

We verify that our new method can significantly mitigate the effects of deformed ACFs on the sub-aperture stitching result, which will be useful for the optical testing of the SPICA telescope. However, this method still cannot reproduce the original WFE map very precisely, which is likely to be caused by alignment errors. Thus we need further development of the measurement system and the algorithm to correct this error. In future, we plan to perform the sub-aperture stitching measurement at cryogenic temperatures.

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