An Experimental Study of Stitching Interferometry for the *SPICA* Telescope

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ABSTRACT

For optical testing of the *SPICA* telescope, we require sub-aperture stitching interferometry, because an accurate autocollimating flat mirror (ACF) with a size comparable to the telescope (3.2 m) is hardly available. Therefore we use small ACFs which rotate with respect to the optical axis of the telescope to cover the full pupil of the telescope. We verified the feasibility of the sub-aperture stitching interferometry by performing real optical measurement. At cryogenic temperatures, in particular, ACFs can be deformed due to thermal contraction. Since surface figure errors of ACFs can make errors in the sub-aperture stitching result, we propose a new method to mitigate the effects of the ACF errors. We evaluated the feasibility of this method by performing an experimental study utilizing the 800-mm telescope and a 300-mm ACF with a designed large deformation. As a result, we find that this method is applicable for the optical test of the telescope, although it needs to be further developed.

1. INTRODUCTION

The *SPICA* telescope has a diameter of 3.2 m, mirrors of which are made of silicon carbide (SiC) or its related material. The telescope has requirements for its total weight to be lighter than 700 kg and imaging performance to be diffraction-limited at 5 μm at the operating temperature of 6 K. The design of the telescope system has been studied by Europe-Japan telescope working group led by ESA with European industries (Castel et al. 2012). According to the current plan, optical testing of the telescope at temperatures below 100 K and acoustic and vibration tests will be performed in Europe. Then the telescope will be delivered to Japan for the final optical testing of the telescope assembly at temperatures below 10 K.

The total wave-front error (WFE) of the telescope is required to be smaller than 350 nm rms for high-resolution observations. Thus we need to evaluate the surface shape of the telescope precisely. Since an accurate autocollimating flat mirror (ACF) with a size comparable to the telescope (3.2 m) is hardly available, it is difficult to measure the full aperture of the telescope at one time. Instead we adopt sub-aperture stitching interferometry for the optical test of the telescope; small ACFs which rotate with respect to the optical axis of the telescope are used to measure sub-aperture WFEs, and then sub-aperture datasets thus derived are stitched to the full-aperture WFE of the telescope. It should be noted, however, that ACFs can be deformed by thermal contraction at cryogenic temperatures. Surface figure errors (SFEs) of ACFs can make errors in the sub-aperture stitching result and they are difficult to be measured directly in the test.

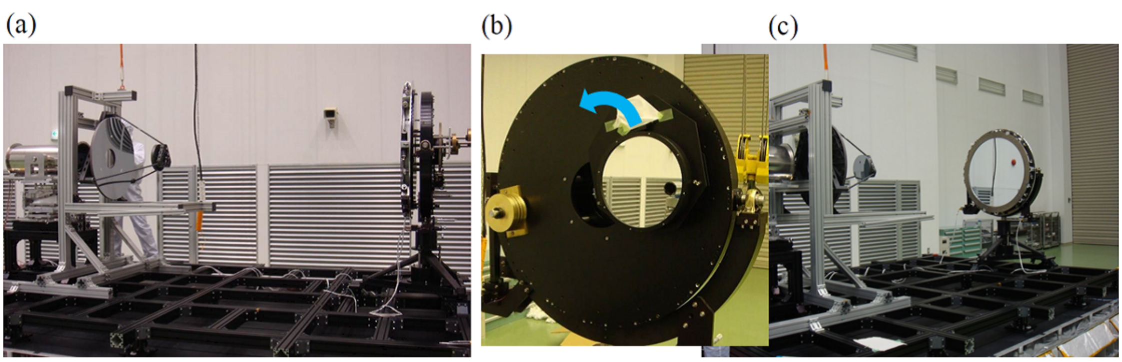

Figure 1. (a) Configuration for the sub-aperture stitching measurement. The telescope and interferometer are set on the left-hand side, while the 300-mm ACF is set on the right-hand side. (b) The 300-mm ACF used in the sub-aperture stitching measurement. The ACF is rotated by a step angle of 22.5 degrees in a counterclockwise direction. (c) Configuration for the full-aperture measurement. The 900-mm flat mirror is placed on the right-hand side.

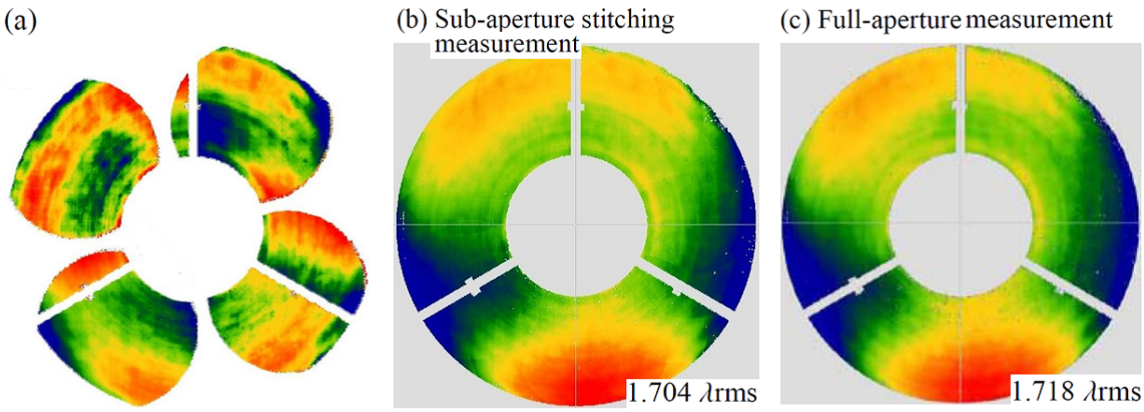

Figure 2. (a) Sub-aperture WFE maps at four radial positions. (b) The WFE map of the telescope obtained by stitching the sub-aperture datasets. (c) The WFE map of the telescope obtained by the full-aperture measurement using the 900-mm ACF.

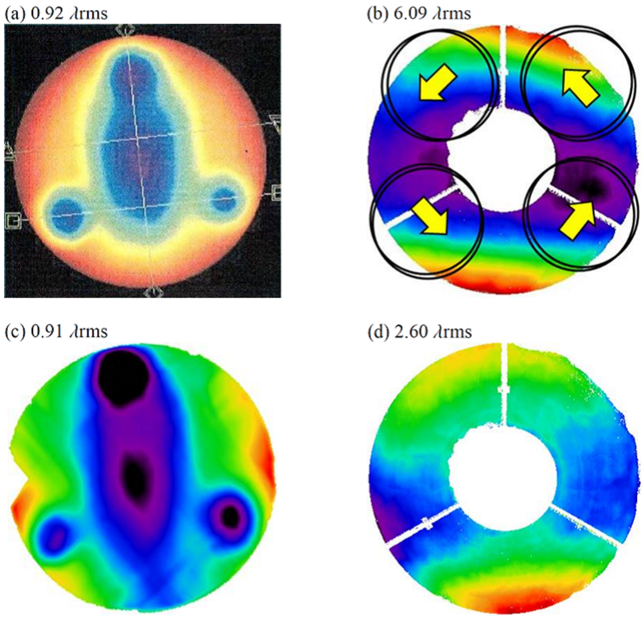

Figure 3. (a) SFE map of the ACF with a designed large deformation. (b) The WEF map of the telescope obtained by the sub-aperture stitching measurement using the deformed ACF, shown together with the positions and directions of the small movements of the ACF. (c) The SFE map of the ACF reproduced by our method. (d) The resultant WFE map of the telescope obtained by the sub-aperture stitching measurement after the correction of the ACF errors.

In this paper, we report an initial result of our experimental study for the sub-aperture stitching interferometry, and then we discuss how to mitigate the effects of ACF errors by proposing a new method.

2. MEASUREMENTS

We have verified that the sub-aperture stitching interferometry is applicable to the optical test of the telescope by performing the real optical measurement of the telescope (Kaneda et al. 2012). Figure 1 shows the configurations for our measurement. We utilize the 800-mm lightweight telescope all made of the C/SiC called HBCesic, which is a candidate mirror material for the *SPICA* telescope (Suganuma et al. 2010). For the ACF, we use the 300-mm glass mirror which has a high-precision flat surface (0.016 λrms). Here and hereafter, λ is the He-Ne laser wavelength of 632.8 nm. An optical interferometer is used to measure the WFEs of the telescope. The ACF is rotated by a step angle of 22.5 degrees with respect to the optical axis of the telescope to perform sub-aperture stitching measurement as described above. In order to evaluate the sub-aperture stitching result, we also utilize the 900-mm glass flat mirror, which can cover the full aperture of the telescope at one time, to compare the results obtained by the sub-aperture stitching and full-aperture measurement.

Figure 2a shows sub-aperture WFE maps of the telescope. The WFE maps of the telescope obtained by the sub-aperture stitching and the full-aperture measurement are shown in Figures 2b and 2c, respectively. As can be seen in the figures, the results show an excellent agreement with each other.

Stitching Interferometry for the *SPICA* Telescope

As described above, ACFs can be deformed at cryogenic temperatures, causing additional stitching errors by propagation of their SFEs. Therefore, prior to the sub-aperture stitching, we need to estimate the SFEs of the ACFs and subtract them from the sub-aperture WFEs. We estimate the SFE of the ACF independently of the WFE of the telescope by small movements of the ACF in the x- and y-axis directions (i.e., analogous to a shearing method). According to our current test plan, each ACF has one degree of freedom for rotation with respect to its center, and thus we can fix the orientation of the ACFs in the inertial frame while rotating. In this configuration, small rotations at 0 and 90 degrees are equivalent to small movements in the x- and y-axis directions, respectively. We calculate the difference, between the WFE maps before and after the movement of the ACF for each direction to estimate the SFE of the ACF. Details of our algorithm will be reported in a separate paper.

3. RESULTS

In order to check the validity of our new method, we fabricated an ACF with a designed large deformation as shown in Figure 3a. Figure 3b shows the sub-aperture stitching result obtained by using this ACF, where we can see that the SFE of the ACF seriously affects the sub-aperture stitching result, and therefore we cannot evaluate the WFE of the telescope correctly.

According to the new method mentioned above, we extract the SFE map of the ACF as shown in Figure 3c. As compared with Figure 3a, our result reproduces the original SFE map of the ACF fairly well. Then we subtract this SFE from each sub-aperture dataset prior to the sub-aperture stitching, and Figure 3d shows the sub-aperture stitching result thus derived. As can be seen in the figure, the WFE map of the telescope after the correction of the ACF errors is qualitatively similar to the original one (Figure 2b). Quantitatively, however, we find that there are still residual errors caused by the ACF errors. Checking carefully Figure 3c with Figure 3a, it is seen that the SFE map of the ACF obtained from our method does not reproduce a power component of the original one. This discrepancy may cause such residual errors. Thus we need to develop the algorithm of our method or measurement configurations to remove them.

4. FUTURE PLAN

In order to reproduce the power component of the deformed ACF, we will introduce additional systems to monitor an unwanted tilt of the ACF which can be generated during the small movement. In addition, the above measurement has been performed at an ambient pressure, not at a vacuum pressure. Therefore we will start our experiments at a vacuum pressure and then proceed to measurement at cryogenic temperatures.

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