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Operating conditions at submillimeter wavelengths

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Contents

1. Abstract

This report proposes to define operating conditions under which the surface accuracy specification of the ACA 7-m antenna is required. The surface accuracy requirement of the 7-m antenna has been set to be less than 20 μm rms from the early phase of the ALMA project even though the 12-m antenna is required to have a surface accuracy less than 25 μm under the primary operating conditions. The surface accuracy of 20 μm rms improves aperture efficiency noticeably only for submillimeter observations; 6.5 % at 400 GHz and 43 % at 950 GHz. Such submillimeter observations are expected under low wind environment. We therefore propose that the surface accuracy of the ACA 7-m antenna shall be less than 20 μm only at night during the primary operating conditions to optimize between the actual required performance and development cost. We argue that this proposal does not bring significant scientific loss judging from the AOS environmental data.

2. Background

The ACA system is designed to enhance the wide-field imaging capability of ALMA namely high fidelity, and it consists of an array with 12 7-m antennas in closely packed configuration and four 12-m antennas as single dishes for total power measurement and calibration.

In order to obtain high fidelity, Tsutsumi et al. (2004) examined the significance of the Atacama Compact Array (ACA) in wide-field imaging of ALMA through imaging simulations. They found that the pointing errors at submillimeter waves seriously degrade fidelity of an image and that the atmospheric phase fluctuation also plays a major role. In other words, to keep high image fidelity at submillimeter wavelengths, both the ACA 12-m

antennas and ACA 7-m antennas have pointing errors not exceeding 0”.6. On the other hand, the image fidelity is not so degraded at millimeter wavelengths if the pointing error is as bad as 1”.2.

In the current antenna specification, the offset pointing requirement is not exceeding 0”.6 under the primary operating conditions, which is defined in the ALMA antenna specification given as follows:

Ambient temperature T: -20 ºC < T < 20 ºC.

Wind and thermal conditions:

Daytime:

- Wind 6 m/s average wind, spectral content to be obtained by scaling the Simiu spectrum, S(u). Equivalent wind speed, including the effect of wind gusts, to be used for quasi-static calculations, shall be 6.4 m/s. For dynamic calculations, two cases are to be analyzed: 6 m/s average wind with variable component S(u); 6 m/s average wind with variable component 4*S(u).
- Solar flux Full solar heating from any direction, Solar flux up to 1290 W/m2.
- Tº gradients: Temperature change in ambient air temperature in 10 minutes 0.6 °C, change in ambient air temperature in 30 minutes 1.8 °C

Nighttime:

- Wind 9 m/s average wind, spectral content is the Simiu spectrum, S(u). Equivalent wind speed, including the effect of wind gusts, to be used for quasi-static calculations, shall be 9.5 m/s. For dynamic calculations, two cases are to be analyzed: 9 m/s average wind with variable component S(u); 7 m/s average wind with variable component 4*S(u).
- Tº gradients None.

Precipitation: None

3. Primary Operating Conditions during Daytime at AOS

We investigate under what conditions is expected during daytime at AOS from available environment data. For convenience, we define daytime as 10.5 – 22.5 hr in UT.

In the primary operating conditions, the offset pointing requirement of the ACA 7-m antenna shall be met both day and night. The larger wind speed is set at night (9 m/s) than daytime (6m/s) in the primary operating conditions (see section 2). The wind condition, however, is known to be severer during daytime than night as shown in Figure 1. Between 14 - 23 hr in UT, the median wind velocity exceeds 6 m/s specified in the primary operating conditions. The 3rd quartile wind velocity is never below 6 m/s. In other words, the wind speed is much larger under actual daytime conditions than those specified in the primary operating conditions.

The ALMA antenna will have a large pointing error in such windy conditions because wind force exerted on the antenna structure is proportional to square of the wind speed. The median wind velocity between 14 and 23 hr in UT ranges from 7 to 11m/s, which exceeds the wind velocity of 6 m/s in the primary operating condition. As a result, the ALMA antenna, which is supposed to meet the ALMA pointing spec during the daytime primary operating condition, would not meet the requirement of 0”.6 in offset pointing error and would have estimated pointing errors of 0”.7 – 1”.5.

Since high frequency observations need a better pointing accuracy than 0”.6 (Tsutsumi et al. 2004), such large pointing errors degrade the image fidelity. Therefore the high frequency observations may not be allocated under the above windy conditions during daytime. On the other hand, most of time during night meets the wind velocity less than 9m/s defined in the primary operating conditions.

We have to point out that low wind velocity is expected in the first few hours (10.5-13.5 hr) in the morning seen in Figure 1. In particular, before UT 12hr, the wind is as low as at night although this is a small fraction in the daytime.

We also note that the atmospheric phase fluctuation is also worse in the daytime particularly after 14 hr in UT than at night. (see Evans et al. 2003).

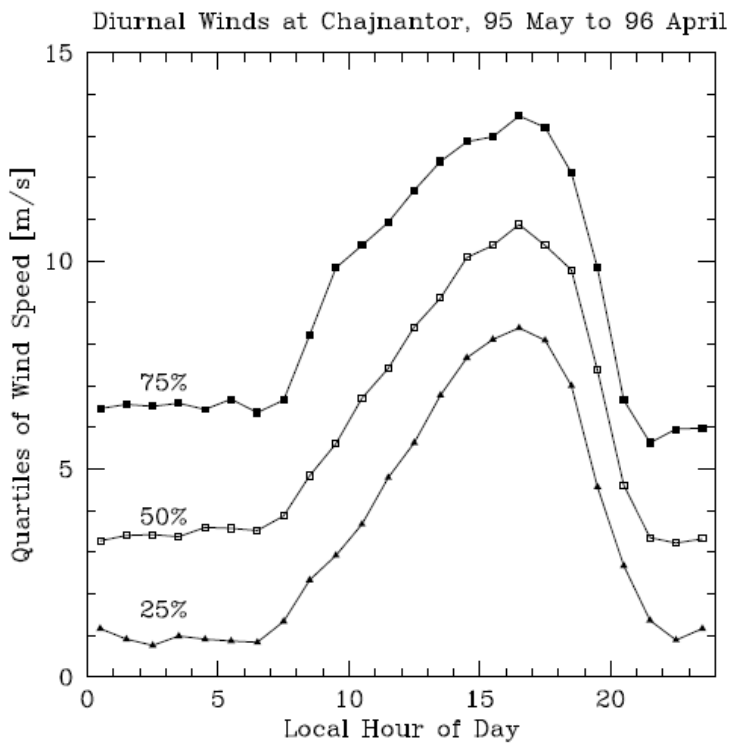

Figure 1: Quartiles of wind speed at Chajnantor as a function of local time (1995 May - 1996 Apr). UT is 4 hours ahead of the local time.

4. Surface Accuracy of ACA 7-m Antenna

As clarified above, low frequency observations such as band 7 or lower will be expected during daytime while high frequency observations will be mostly expected during nighttime.

We quantitatively compare the two different surface accuracies of the ACA 7-m antenna by following Ruze formula assuming that the surface error is random. Figure 2 shows the results of the calculation in cases of 20 and 25 μm rms.

Figure 2 demonstrates that the relative sensitivity difference between 20 and 25 μm rms is significant only at high frequencies. The difference is less than 5.5 % at 370 GHz, 6.5 % at 400 GHz, and 43 % at 950 GHz. Hence, if the surface accuracy specification is 25 μm rms during daytime and 20 μm rms at night, there is not a significant impact on ALMA science.

It is true that we will lose good conditions early in the morning in winter when low atmospheric opacity and stable phase condition is realized. In such a case, the ACA 7-m antenna can still have a good surface accuracy of probably 20 μm rms if the observations are optimized to be conducted near the rigging angle (e.g. 45 deg). This may naturally happen because the ACA 7-m antennas need to avoid shadowing in a compact configuration. Consequently, we suppose that we will not lose large gain even if we set the surface accuracy specification of 25 μm rms during daytime primary operating condition.

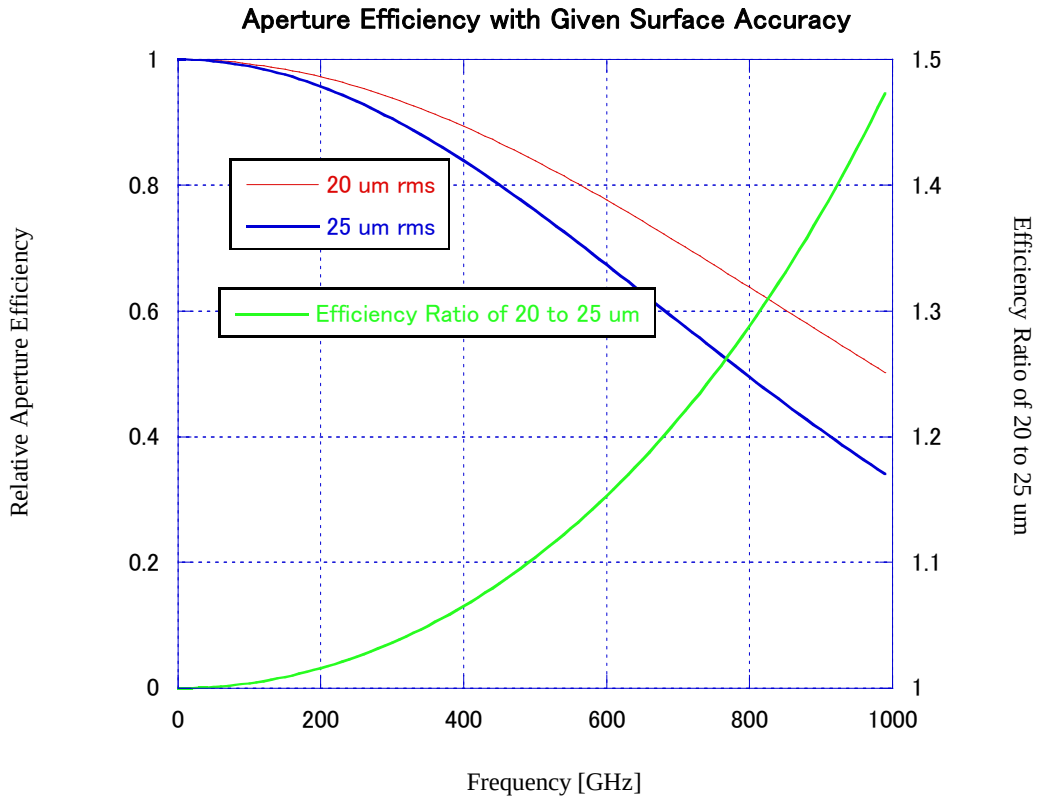

Figure 2: Aperture efficiency difference between 20 (red line) and 25 (blue line) μm rms. Efficiency ratio of 20 to 25 μm is denoted by a green line.

5. Proposal to ACA 7-m Antenna Specification

We propose that the ACA 7-m antenna shall achieve less than 20 μm accuracy during nighttime in the Primary operating conditions. Thus, in the technical specification, the phrase of surface accuracy will be modified as below. The red characters are different from the ALMA 12-m antenna specification.

5.5 ANTENNA SURFACE ACCURACY REQUIREMENTS

The total antenna surface accuracy during daytime in the Primary Operating Conditions shall be < 25 micrometers Root-Sum-Squared (RSS). The total antenna surface accuracy during Primary Operating Conditions shall be < 20 micrometers Root-Sum-Squared (RSS).

References

ALMA Memo 159, 1996, “Wind Velocities at the Chajnantor and Mauna Kea Sites and the Effect on MMA Pointing” by M.A. Holdaway et al.

ALMA Memo 471, 2003, “Site Properties and Stringency” by Neal Evans et al.

ALMA Memo 488.1, 2004, “Wide-Field Imaging of ALMA with the Atacama Compact Array: Imaging Simulations” by Tsutsumi et al.

E.O.D.