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## Abstract

The Wide Field Survey Telescope (WFST) is a 2.5 m optical telescope that has been in operation since September 2023. Located on Saishiteng Mountain in Qinghai Province, WFST benefits from excellent natural atmospheric seeing conditions. However, the impact of the existing telescope dome on the astronomical seeing of WFST has not yet been characterized, which unavoidably affects the imaging performance of the telescope.

During the WFST maintenance period, two differential image motion monitors with identical configurations—one installed inside the dome and the other outside—were employed for seeing monitoring. Astronomical seeing measurements were carried out simultaneously inside and outside the dome under different dome ventilation configurations to quantify their influence. Statistical analysis of the seeing data obtained under these various ventilation conditions shows that appropriate air convection within the dome can improve the in-dome seeing to approach the level of the out-dome seeing, thereby enhancing the imaging quality of WFST.

# Full Text

## Preamble

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**Preliminary Dome Seeing Analysis for the 2.5 m Wide Field Survey Telescope**

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## Abstract

The Wide Field Survey Telescope (WFST) is a 2.5 m optical telescope that has been in operation since 2023 September. Located on Saishiteng Mountain in Qinghai Province, the WFST benefits from exceptional atmospheric seeing conditions. However, the effect of the existing telescope dome on the astronomical seeing of WFST has not been characterized, which inevitably affects the imaging performance of the telescope. Two differential image motion monitors of the same configuration, one located in the dome and the other outside the dome, were used for seeing monitoring during the maintenance period of the WFST. Astronomical seeing measurements were conducted simultaneously inside and outside the dome under different dome ventilation configurations to quantify their effects. Statistical analysis of the seeing data collected under different ventilation conditions indicates that proper air convection in the dome can improve the in-dome seeing to reach near the level of the out-dome seeing and thereby improve the image quality of the WFST.

**Key words:** turbulence -atmospheric effects -telescopes

## 1. Introduction

The Wide Field Survey Telescope (WFST) is a dedicated photometric surveying telescope equipped with a 2.5 m diameter primary mirror, an active optics system, and a mosaic CCD with 0.73 gigapixels on the primary focal plane for high-quality imaging over a 6.5-square-degree field of view [?, ?]. The WFST is located at an altitude of 4200 m on Saishiteng Mountain near Lenghu Town in Qinghai Province. The observation conditions of the Lenghu site have been monitored since 2018, showing a median value of seeing of 0.75″ [?].

The high altitude, low water vapor, and exceptional seeing conditions of the Lenghu site provide a distinct advantage for WFST among time-domain survey facilities when targeting fainter celestial objects in the northern sky. An active optics system maintains the WFST in a nearly seeing-limited condition by real-time compensation of primary-focus assembly misalignment and primary mirror deformation [?].

The dome of a telescope can shelter the sensitive and delicate instruments inside from the effects of bad weather, such as rain, snow, and dust carried by wind. The dome can also reduce telescope structure vibration and deformation during observations in windy conditions. However, temperature differences and local turbulence within the dome inevitably affect the observation conditions and optical imaging of the telescope. The stratification of atmospheric turbulence and its impact on seeing are generally well understood. At the same time, the unique natural topography and weather patterns of a site introduce slight differences in astronomical seeing. Computational fluid dynamics analysis is an effective avenue to identify dome turbulence in the dome design and construction phases, which has been employed by next-generation ground-based large optical telescopes [?, ?, ?, ?, ?]. Nevertheless, there are multiple currently operational telescopes built before dome seeing was carefully considered in the planning stage.

Researchers utilized stellar image archives from several years to evaluate the impact of the dome on image quality and found that temperature differences, wind speed, and direction contribute to image quality degradation [?, ?]. Efforts have also been dedicated to direct dome seeing measurement of atmospheric seeing and optical aberrations. A dome turbulence sensor based on measuring the angle-of-arrival fluctuations of a narrow beam sampling a representative volume inside the dome has been demonstrated by Bustos and Tokovinin on the 4 m Blanco telescope and applied to dome seeing analysis of the Anglo-Australian Telescope [?, ?]. A localized optical turbulence sensor based on a non-redundant mask imaging interferometer that samples the optical turbulence passing through a measurement cell was developed by Lai et al. and has been tested in the Canada–France–Hawaii Telescope and the University of Hawaii 2.2 m telescope tube [?].

The WFST has been in full operation since first light in 2023 September. The dome of WFST is a 17 m diameter conventional hemisphere with a 4 m wide slit to allow observation, as shown in Figure 1 [Figure 1: see original paper]. Furthermore, turbulence inside the dome has not been characterized with computational fluid dynamics analysis or wind tunnel tests. The existence of the dome inevitably affects the observation conditions and optical imaging performance of the WFST. There are side windows and a ventilator equipped in the dome, but there is no quantitative assessment of their effect on dome seeing. Therefore, a systematic examination of the astronomical seeing of the WFST inside the dome is necessary, as it provides an opportunity to optimize the dome ventilation strategy based on seeing measurements.

## 2. Measurement

The WFST operation and maintenance group began seeing measurements for WFST in 2023 December. The seeing measurements at WFST were conducted intermittently. In the early phase, an automatic differential image motion monitor (DIMM; [**?**]) was first set up outside the dome and then inside the dome. A certain amount of seeing data was accumulated for preliminary analysis. During the maintenance period of 2024, we installed two DIMMs of the same configuration at the WFST site. One DIMM was located in the dome, near the primary mirror of the WFST, as shown in Figure 2 [Figure 2: see original paper]. The other DIMM was situated on an out-dome platform, on the same level as the exterior stair surrounding the dome. The DIMM configurations are listed in Table 1 , the same as those used for optical turbulence characterization at the LAMOST site [**?**] and site testing campaign at the Ali site [**?**]. The two DIMMs we used had previously been used and calibrated at the LAMOST site.

The celestial targets selected for seeing measurement are limited to the zenith region, with zenith distance less than 30° and star magnitude brighter than 2.5 mag. The CCD exposure time is automatically set to 5 ms or 10 ms, depending on the weather conditions. The better the weather conditions, the shorter the exposure time. The seeing value was calculated based on a set of images, typically no more than 200 frames. The final output seeing value is calculated for an average wavelength of 500 nm and corrected to zenith. Simultaneous seeing measurements both inside and outside the WFST dome were conducted from 2024 September 23 to October 13.

An automatic weather station has been installed at the WFST site, with sensors measuring air temperature and pressure, relative humidity, and wind speed and direction. Two additional temperature sensors were placed inside and outside the dome, respectively, to monitor the temperature difference between the inside and outside of the dome. The in-dome temperature sensor is located on the third floor of the dome, where the telescope is situated, and approximately one meter above the floor. The precision of the temperature sensors is $\pm 0.5^{\circ}$C. The weather station has been in operation since the first light of WFST. The temporal resolution of the data from the weather station is 1 minute. The temporal resolution of the additional temperature sensors is 5 minutes.

## 3. Analysis

The data from the weather station were analyzed in combination with the seeing data. The impact of the ventilation facilities included in the dome on the astronomical seeing of WFST has been evaluated carefully by seeing measurements conducted simultaneously inside and outside the dome. The dome rotates in tandem with the telescope during observation; therefore, the effect of the dome slit relative to the wind direction is not considered in this analysis. Comparison and statistical analysis of the results when the ventilation devices are alternated in off-and-on states are presented in this section. First, a statistical introduction to the weather information is given. Then, a qualitative and quantitative evaluation of the impact of the ventilation devices on the dome seeing is presented. Finally, suggestions for the optimization of the dome convection are provided.

### 3.1. Weather Information

Temperature and wind are the two factors that affect the seeing measurement [**?**, **?**, **?**]. We presented the statistical analysis of temperature, wind speed, and wind direction data collected from the meteorological station over a period of nearly one year, from 2023 October 11 to 2024 September 22 (348 days), excluding certain days (21 days and 15 hr) due to power outages. The ratio of the power outage time is 6.2%, which has a limited effect on the statistical average of the meteorological data. The temporal resolution of the data is 1 minute, and we have 380,212 data sets.

The median wind speed during this period was 2.29 m $s^{-1}$, as shown in Figure 3(a) [Figure 3: see original paper]. The recorded maximum wind speed was 16.2 m $s^{-1}$, which occurred at 0:08 on 2024 June 26. Figure 3(b) displays the statistical distribution of wind speeds under different directions, indicating that the dominant wind direction is from the northwest.

The monthly temperature density distribution of the WFST site during this period is presented to reveal the seasonal fluctuation, as shown in Figure 4 [Figure 4: see original paper]. The vertical dashed line in each density map indicates the median temperature of the month. From left to right along the horizontal axis, the temperature increases, and the color in the density maps changes from dark purple to light yellow. From Figure 4, we can see that the temperature at the WFST site gradually drops from September and then slowly rises from January. 2023 December was the coldest month, with a median temperature of $-15.6^{\circ}$C. The recorded lowest temperature was $-28.1^{\circ}$C at 23:56 on 2023 December 14.

Simultaneous seeing measurements both inside and outside the WFST dome were conducted from 2024 September 23 to October 13. Figure 5 [Figure 5: see original paper] features the WFST dome temperature difference $\Delta T$ when astronomical seeing measurements were conducted both inside and outside the dome. The maximum $\Delta T$ is $5.0^{\circ}$C, and the median is $2.2^{\circ}$C. The larger $\Delta T$ normally occurred at the beginning of the seeing measurement when the dome was just open, and it gradually became stable, usually one hour or less after the dome opening, depending on the dome convection condition.

### 3.2. Seeing Measurement without Active Venting Configurations

The dome without active venting configurations makes the atmosphere inside very different from the outside, especially when strong wind activities are around. From the results of our seeing measurement conducted inside the dome, the in-dome seeing positively correlated with the out-dome wind speed under the condition that the dome ventilator is off and the side windows are closed, as shown in Figure 6 [Figure 6: see original paper].

The wind speed influences the temperature difference between the inside and outside of the dome through the dome opening. Calm air would lead to heat accumulation in the dome. Moreover, a sudden moderate breeze would increase the atmospheric difference between the inside and outside of the dome when there is no active venting. A continuous light breeze would decrease the temperature difference and help equilibrate convection between the inside and outside of the dome through its opening. The blue asterisks in the upper panel of Figure 6 are the in-dome seeing values corrected to the zenith. The time section, divided by the black vertical dot-dashed lines in the figure, indicates whether the side windows were closed or open during this period. In the lower panel of Figure 6, the magenta asterisks are the wind speed outside the dome, and the green asterisks are the temperature differences between the inside and outside of the dome.

We collected and classified seeing data conducted at three positions at the WFST site: the out-dome ground, the out-dome platform, and the in-dome platform. The in-dome seeing data are included when there was no active venting in the dome, during which the dome ventilator was off, and the side window was closed. The out-dome platform is about 2.5 m above the ground, to the north-northwest of the dome. A statistical analysis of the data from the three positions is shown in Figure 7 [Figure 7: see original paper]. The seeing measurements were conducted at different times from the three positions. There were 1191 data sets gathered from the out-dome ground during the early observation phase, and the median seeing was 0.74″. The median seeing was 0.71″ of the 4783 data sets gathered from the out-dome platform, slightly better than that of the out-dome ground. This improvement may be attributed to the absence of near-surface turbulence, which affected the out-dome ground measurement. There were 8897 data sets collected from the in-dome seeing measurement without active venting. The in-dome median seeing was 1.17″, which was 0.46″ worse than the median seeing of the out-dome platform, quantifying the influence of the dome on the seeing measurement.

### 3.3. The Side Windows' Influence on Seeing Measurement

There are six side windows, symmetrically distributed about the dome slit and located at the cylindrical part of the WFST dome. The side window is 1.65 m in height and 1.90 m in width, with an effective ventilation area of about 3.10 $m^2$. We can open or close the side windows through remote control by moving them along the horizontal sliding rail. All six windows were opened or closed during testing to assess the effect of the side windows.

We used two DIMMs of the same configuration to conduct seeing measurements simultaneously inside and outside the dome. The inside DIMM was located on the in-dome platform, near the primary mirror of the WFST. The outside DIMM was positioned on the out-dome platform, north-northwest of the dome and 2.5 m above the ground. The ventilator was in the off state. By comparing the data gathered from simultaneous seeing measurements inside and outside the dome, we find that opening the side windows can improve the in-dome seeing. As shown in Figure 8(a) [Figure 8: see original paper], when the outside wind speed is higher than 5.0 m $s^{-1}$, the improvement of the in-dome seeing is obvious and prompt, approaching the seeing of the out-dome.

Meanwhile, closing the side windows will deteriorate the in-dome seeing synchronously and increase the seeing difference between the inside and outside of the dome. When the wind became lighter, i.e., lower than 2.5 m $s^{-1}$, the effect of the side window on the seeing measurement also exists but is not so evident as when the wind is vigorous, as shown in Figure 8(b).

A steady breeze can decrease the temperature difference between the inside and outside of the dome. However, better astronomical seeing is usually observed in calm air.

We gathered data from 2024 September 23 to October 2, during which we tested the influence of the side windows on the seeing measurement by operating two DIMMs simultaneously inside and outside the dome. A statistical analysis of the data is presented in Figure 9 [Figure 9: see original paper]. The out-dome median seeing was 0.79″. With the side windows closed, the in-dome median seeing was 1.73″. Meanwhile, the in-dome median seeing with the side windows open was 1.24″, which is much smaller than the condition with the side windows closed but still significantly larger than the out-dome seeing. From this analysis, we can conclude that opening the side windows can improve dome convection, and there is still room for further optimization.

### 3.4. The Ventilator' s Influence on Seeing Measurement

There are three groups of ventilators equipped for the WFST, and one leads to the third floor of the dome where the telescope is located. The ventilator promotes air convection inside the dome through suction. The inlet of the ventilator sits on the third-floor ground of the dome near the cylindrical wall of the dome. When the dome slit or side windows are open, the ventilator discharges the air drawn from the dome to the downwind outlet about 30 m away. The control of the ventilator can be achieved in the observation room located in the dome basement.

From 2024 October 2 to October 7, we tested the effect of the ventilator on the seeing measurement with two DIMMs while the side window was closed. As shown in Figure 10 [Figure 10: see original paper], the ventilator operation can noticeably improve the dome convection and reduce the correlation between the in-dome seeing and the out-dome wind speed, even when the wind is gentle.

The operation of the ventilator can effectively decrease the temperature difference between the inside and outside of the dome when the outside wind speed exceeds 2.0 m $s^{-1}$. The correlation between the in-dome seeing and the out-dome wind speed was restored when the ventilator was off. A statistical analysis of the classified data from different ventilation configurations is presented in Figure 11 [Figure 11: see original paper]. During this period, the out-dome median seeing was 0.61″. Meanwhile, the in-dome seeing with the ventilator, respectively, being in off and on states, was 1.20″ and 0.78″. When the ventilator was on, the in-dome seeing was in close proximity to the out-dome seeing.

### 3.5. Dome Seeing Optimization with Side Windows and Ventilator

From 2024 October 7 to October 12, seeing measurements were conducted at WFST with the side windows closed or open while the ventilator remained on. As shown in Figure 12 [Figure 12: see original paper], the ventilator can decrease the correlation between in-dome seeing and out-dome wind. The side windows can improve the in-dome convection when the outside wind is vigorous, even if the ventilator is operating. The combination of the side windows and the ventilator has a more effective result than either one alone. The out-dome median seeing was 0.65″ in this period, as shown in Figure 13 [Figure 13: see original paper]. When the ventilator was on, the in-dome median seeing was 0.85″ with the side windows closed and 0.68″ while the side windows were open. This result indicates that the side windows and ventilator can effectively improve the dome convection, making the in-dome seeing comparable to the out-dome seeing.

## 4. Conclusions

Simultaneous DIMM seeing measurements conducted inside and outside the WFST dome evaluate the influence of the dome ventilation devices on astronomical seeing. Data comparison between the seeing data collected at different convection conditions in the dome provides a qualitative evaluation of the influence of the side windows and ventilator on the seeing measurement. Statistical analysis of the classified seeing data gives a quantitative evaluation of the effect of the dome and its ventilation device on astronomical seeing. The side windows and ventilator of the WFST dome promote the atmosphere equilibration between the inside and outside of the dome and improve the astronomical seeing inside the dome.

These results provide direct guidance on optimizing dome convection and improving the overall seeing of the WFST and should serve as a general reference for other existing or planned facilities.

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