Astronomical Image Quality Prediction based on Environmental and Telescope Operating Conditions

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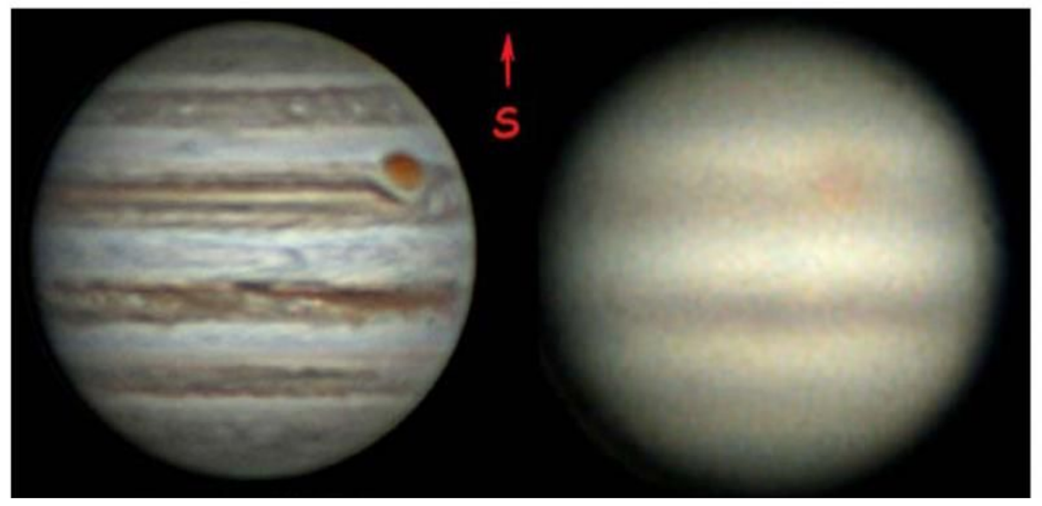
Abstract: Intelligent scheduling of the observations made at ground-based astronomical observatories is massively challenging. Observing time is greatly over subscribed and atmospheric conditions are constantly changing. We propose to guide observatory scheduling using machine learning. Leveraging a 15-year archive of exposures, environmental, and operating conditions logged by the Canada-France-Hawaii Telescope, we construct a probabilistic model that accurately predicts image quality (IQ). Further, by optimizing the opening and closing of twelve vents placed on the dome, we predict a reduction in dome-induced turbulence and an improvement in IQ of 0.05-0.2 arc-sec. This translates to a reduction in exposure time (and cost) of ~10-15%. **Our study is the first step toward data-based optimization of the multi-million dollar operations of current and next-generation telescopes.**

Background

- Image quality (IQ) is one of the most important factors affecting the scientific return of ground-based optical telescopes.
- IQ depends on atmospheric and environmental conditions; air turbulence causes degradation in IQ.
- Telescopes need to schedule observations according to IQ requirements, but IQ is difficult to forecast.



Good IQ Bad IQ

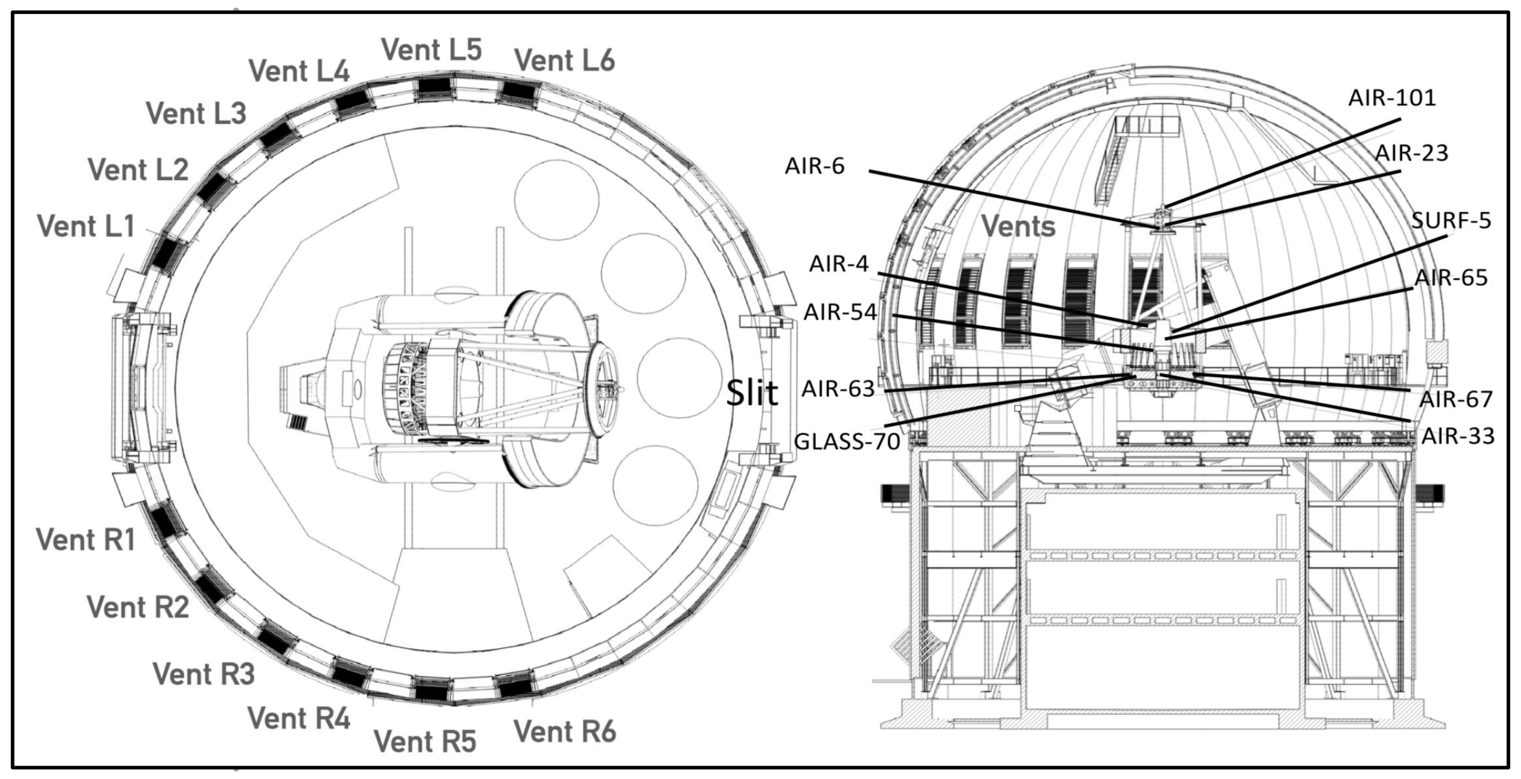
Take Aways

- We are able roustly to predict IQ using a data-driven model at an accuracy ~0.065" (10% of CFHT IQ).
- We use this model to explore actions that improve IQ. Our model predicts possible improvement in IQ of ~10% by optimizing the vent configuration.

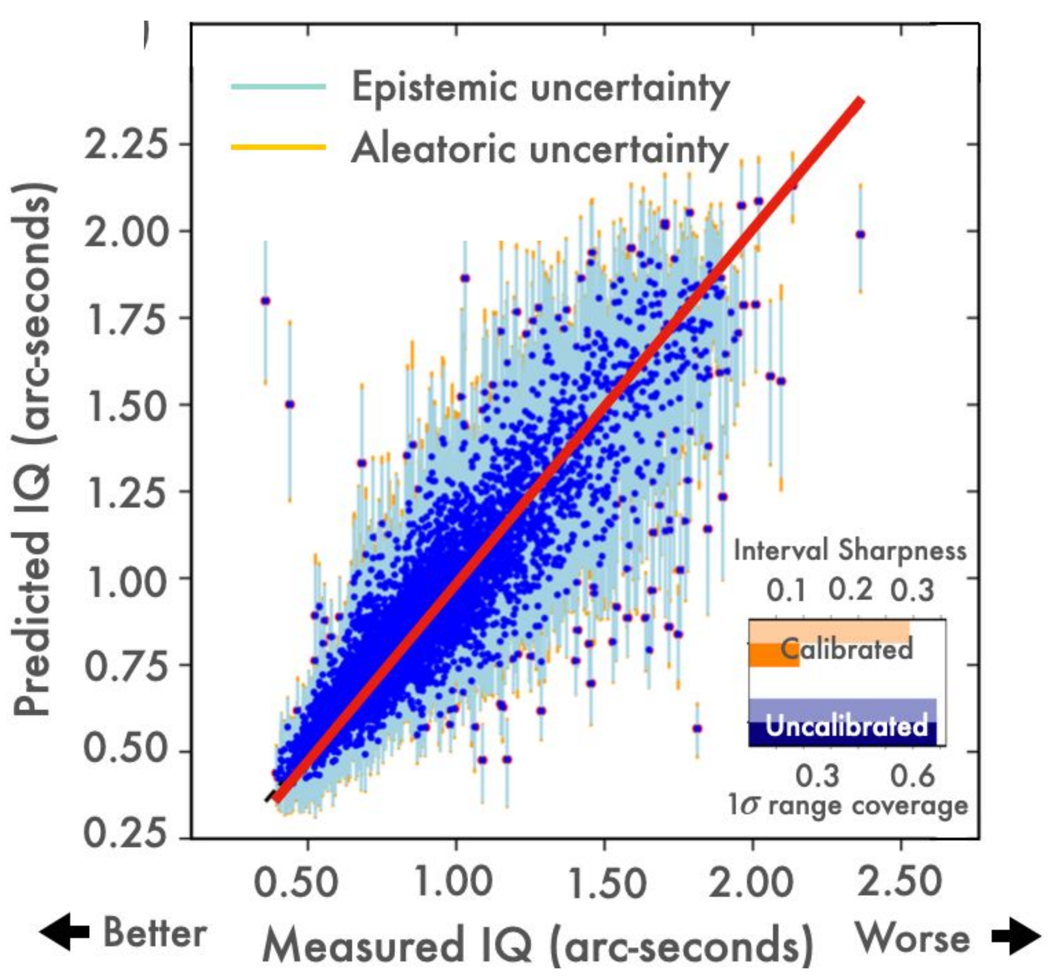
Data

- ~60,000 samples with 119 features each.
- IQ from stellar profiles on processed exposures.
- Independent features: 103 environmental (temp, humidity, pressure, wind velocity and direction), 12 vents (open/closed), 4 observational (time-of-day, exposure duration, altitude, azimuth).

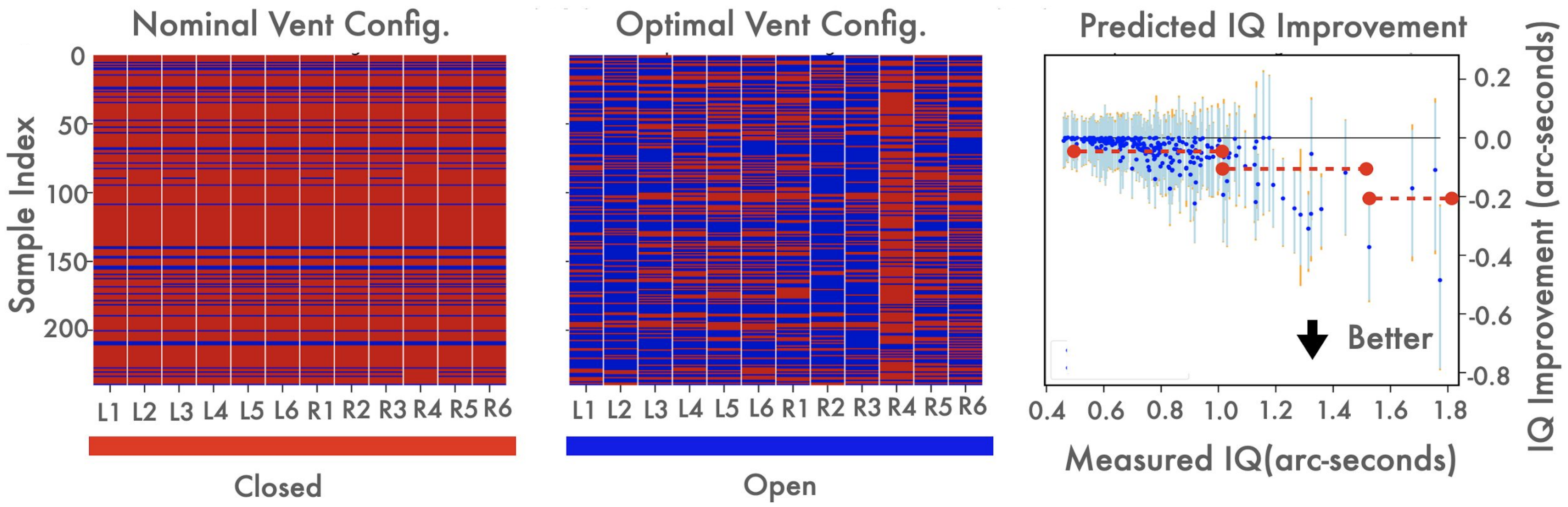
Results



Left: Photograph of CFHT, looking northwest toward Maui. **Right:** Schematic of CFHT. The twelve actuable dome vents are marked. These were installed in 2012 to accelerate thermal equilibrium between the telescope structure and ambient air, and to flush pockets of settled thermal anisotropy from the air within the dome.

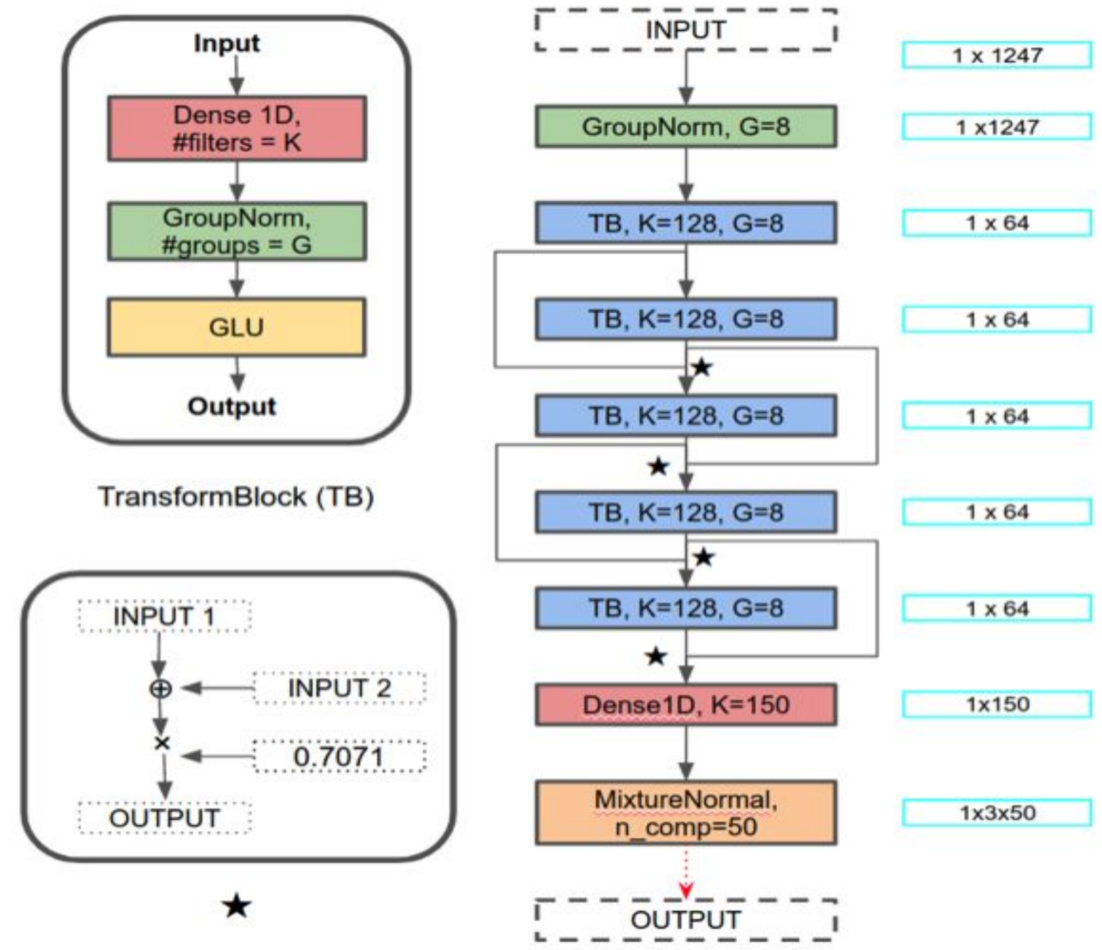


1) **Left:** Predicted vs. measured IQ. Inset shows improvement in predicted aleatoric uncertainties upon **post-hoc probability calibration.**
2) **Below:** *Left Panel* - Nominal vent configuration in effect when data was collected, for a randomized sample of 250 exposures. Vents have historically been mostly all closed or all open. *Middle* - Predicted IQ-minimizing vent configuration for each of the 250 exposures. *Right* - The improvement (decrease) in predicted IQ.
   a) **Excellent IQ (< 0.5''):** Possible improvement in IQ is marginal. In this regime atmospheric turbulence, over which we have no control, dominates IQ.
   b) **Middling IQ (> 0.5''):** By optimizing vent configuration we can substantially improve the (predicted) IQ. The improvement ranges from about 0.05'' for a nominal IQ of 0.5-1.0'', to about 0.1'' for a nominal IQ of 1.0-1.5'', and to 0.2'' for a nominal IQ >1 ''. This range of IQ captures most observations; it is rare to ha nominal IQ <0.5''.



Architecture

- Mixture Density Network (MDN) with Gated Linear Unit (GLU) activations.
- Input: Sample with 119 features. Outputs: Predicted mean MPIQ, aleatoric uncertainty in MPIQ, and epistemic uncertainty in MPIQ.



Conclusions and Future Work

Through the implementation of an MDN, we find that ancillary environmental and operating parameter data are sufficient to predict IQ accurately. By varying the configuration of the dome vents in response to extant environmental conditions, we predict that IQ can be improved by about 10% across all regimes, with larger gains when the nominal IQ value is large. Assuming an SNR-driven observing model, this translates to a reduction in observation time and costs of up to 10-15% (about 1M USD a year). This study is an important first step towards active and automated control to improve telescope IQ and, eventually, to implement real-time scheduling through dynamic vent configuration.

Vary vent configurations to validate results

Acknowledge natural time-dependencies in data and explore alternative architectures

Use generative modeling for feature imputation and outlier detection