Atmospheric phase correction at the IRAM observatories

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ABSTRACT

Tropospheric phase correction has been used successfully since 1995 at the IRAM Plateau de Bure Interferometer (PdBI) to improve observations in the atmospheric transmission windows at 3mm and 1mm wavelengths. In April 2000, phase correction was achieved at the IRAM 30-m telescope on Pico Veleta during a VLBI experiment. The systems at both observatories are currently based on the total power signal of the 1mm astronomical receivers, and operate only under clear sky conditions. Even so, observations have been improved significantly. A still better performance is expected from the series of dedicated 22 GHz water vapor radiometers (WVRs) which is currently under construction for the PdBI.

INTRODUCTION

Observations at millimeter wavelengths are often limited by turbulent tropospheric water vapor. Single dish instruments experience pointing problems due to anomalous refraction ([1, 2, 3]), while interferometers are mainly limited by excessive atmospheric phase noise due to two additional effects: A loss in sensitivity due to a shorter coherent integration time and a degradation in image resolution. Most high-frequency observatories are situated at high altitudes to reduce the water vapor column they must observe through (and which has an exponential scale height of about 2 km). But even so, the residual water vapor can introduce strong phase fluctuations on timescales of a few seconds, depending on weather conditions.

In order to improve the quality of observations and to increase the available observing time, several connected element interferometers (ATNF [4], BIMA [5, 6, 7], IRAM [8, 9, 10, 11], NMA[12] , OVRO [13, 14] and VLA [15]) are currently developing or already operating atmospheric phase correction systems. New sub-millimeter instruments (ALMA, SMA [16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26]) have included such devices already in the design process. The idea is to measure and correct the phase "piston" for each antenna. This approach can be compared to the advantages of adaptive optics for visible and near-IR telescopes.

Significant improvements are also possible for millimeter VLBI. In this wavelength range, longer coherence times and improved tolerance for adverse weather conditions allow to observe weaker sources. Most source fluxes decrease at high frequencies, so that phase correction would permit to advance towards still shorter wavelengths and thus higher angular resolution for ground-based observatories. As experiments on VLBI tropospheric phase correction have been encouraging ([27, 28] and below), several participating observatories plan to install WVR systems.

IRAM PHASE CORRECTION AT 200-248 GHZ

Tropospheric phase correction has been used successfully since 1995 at the PdBI to improve observations in the atmospheric transmission windows at 3mm and 1mm wavelengths. In April 2000, phase correction was achieved at the 30-m telescope on Pico Veleta during a VLBI experiment [29] and included into the AIPS data

reduction [30]. The improvement in phase noise for Pico Veleta resulted in a better fringe fitting and a 22% peak flux increase in the 86.2 GHz map of the blazar BL Lac (taking five contributing stations into account). Both IRAM instruments are currently applying modeled phases [31, 32, 33] calculated from continuum sky emission in the 1mm band of their astronomical SIS receivers. This corresponds to an inter-line region of the atmospheric water vapor spectrum, which limits the application to clear sky conditions because water vapor and cloud emission cannot be separated. Clouds contribute strongly to the atmospheric emission but only little to the phase fluctuations, so that a clear sky model will over-estimate the phases and rather degrade the result during cloudy weather. To avoid the loss of valuable observations, both corrected and uncorrected data sets are stored and analysed later to decide if the modeled phases should be applied, allowing an optimum choice on scan time-scales (typically 60 seconds). Long-term statistics show that the phase correction improves the observations during 78% of the time. The phase r.m.s. is reduced to about 90 microns per baseline on time-scales of 60 seconds. During early tests of the method [8], models of 1 and 4 seconds time resolution have been compared, to an advantage of the 1 s model.
Besides the restriction to clear-sky conditions, the present system does not allow to track phases over source changes at the PdBI, which reduces the usefulness of the system from full phase recovery to scan-based amplitude improvements (although good recovery is possible under favorable conditions [29]). The reason for this lies in elevation dependent gain variations of the receivers (due to changes in cryogenic pump efficiency and re-distribution of liquid helium inside the cryostats). These two drawbacks have motivated the development oft the 22 GHz WVRs described in the next section. At the IRAM 30-m, the receiver cabin does not tilt due to its Nasmyth optics, so that the gain drifts are avoided. This makes full atmospheric path modeling possible, which includes atmospheric path variations due to source tracking. As this influence is already accounted for in the AIPS fringe fitting, it is sufficient to introduce the residuals of a second-order polynomial fit into the data reduction of each VLBI scan.

IRAM PHASE CORRECTION AT 22 GHZ

The recent development of triple-channel radiometers operating near the 22 GHz water line for the PdBI shows promise to bypass the limitations of the former system. The choice of the three monitoring frequencies was made to suppress both cloud and ground emission (which follow frequency-squared and constant opacity laws around 22 GHz, respectively) while optimizing the sensitivity to water vapor. A high instrumental stability is assured by a thermally controlled, insulated design operating close to ambient temperature.
A matter of concern is the possible interference from microwave communication links, because the necessary bandwidths and channel separations of the WVRs cannot be restricted to protected frequency bands. Previous tests on the Plateau de Bure have shown that the site is still "dark"; during the tests in Grenoble, the well-shielded interior court of the institute was used for on-the-sky experiments. On the roof top, several strong emitters were detected in the urban environment.
Two instruments have already been installed on separate PdBI antennas after undergoing extended tests in the laboratory and on the sky, which indicate that the precision of the correction should be about 60 microns per baseline over 20 minutes. This makes it possible to test the corrections at 22 and 230 GHz against each other and study the performance of the new system with astronomical phases, which requires a calibration of high precision. We plan to refine the preliminary load-based WVR calibrations with the help of the regular astronomical phase reference calibrations on quasars according to the method proposed by [7]. Results of the "on the sky" tests will be available at the time of the URSI conference.

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