Current status of PolConvert

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1. Introduction

The ALMA receivers register the signal in a linear polarization basis (X/Y), whereas most VLBI stations register the signals in a circular (R/L) polarization basis. Hence, for a proper calibration and analysis of ALMA-VLBI observations, the ALMA data have to be converted into a circular-polarization basis. The strategy followed in the APP is to apply such polarization conversion *after* the VLBI correlation. This approach minimizes the hardware costs and the implementation efforts.

The program used for the polarization conversion in the APP is called *PolConvert*. Results on the performance of PolConvert applied to APP simulated data, as well as to real VLBI mixed-polarization observations, can be found in Marti-Vidal et al. (2015). In the following sections, we present the current status of PolConvert and show some conversion results for real APP observations.

Although PolConvert is already fully functional, there are a few remaining details to sort out, for the program to be used in an efficient way. These remaining issues are also summarized in this report (Sect. 3).

2. Current status of PolConvert

PolConvert is programmed in C++, using standard libraries and some basic `casacore` API. It currently compiles against the `casacore` version released with CASA 4.3.0. The steps needed to run PolConvert on an ordinary APP observation are summarized below.

1. Calibrate the measurement set (MS) containing the cross-correlations among ALMA antennas. All four Stokes products (XX, XY, YX, and YY) need to be present in the MS. In addition, at least one observation of a polarized source needs to have been performed (in order to derive the X-Y phase offset at the reference ALMA antenna). After the calibration, one should have the following CASA calibration tables (with solutions for all the ALMA antennas):

   - Bandpass, splitting solutions for X and Y.
   - Gain (amplitude), splitting solutions for X and Y, as a function of time.
   - Phase offset between X and Y (as a function of frequency).
   - D-terms (as a function of frequency).

2. Cross-correlate the VLBI data and produce FITS-IDI file(s) containing the ALMA-VLBI visibilities. All four Stokes products (i.e., XR, YR, XL, YL, for the case of the ALMA-related baselines) need to be present.

3. Prepare the PolConvert configuration file (to specify the CASA calibration tables and the FITS-IDI file to be converted) and run the program.

The program is able to read FITS-IDI files directly produced by the `difx2fits` task (part of the DiFX distribution) and use the calibration information stored in the CASA tables to produce a new FITS-IDI file with all the VLBI visibilities in a pure-circular basis. PolConvert is also able to work simultaneously with more than one linear-polarization VLBI station (in case that more VLBI stations with linear polarizers would join the mm/submm VLBI network in a future). For these stations, simple CASA calibration tables can be generated. Alternatively, the polarization calibration can be derived using alternative tasks (i.e., *PolConvertSD*, see next Section).

2.1. Additional software

PolConvert needs additional software, in order to get all the information needed for an optimum calibration. All this alternative software is already implemented.

On the one hand, we need a CASA Python script to produce the ALMA calibration tables (i.e., step 1 in previous section). We have developed a simple calibration script that can be fine-tunned and adapted to different observing conditions and schedules. We can, for instance, change the integration time for the gains and/or the calibration strategy to determine the D-terms and/or the X-Y phase offsets.

On the other hand, if the X-Y phase offset cannot be determined (due to a lack of strong polarization signal in the observations), we need to apply an alternative approach to calibrate and convert the VLBI visibilties. Assuming that the V Stokes (circular polarization) of a calibrator is negligible (or is well known), we can compute all the information needed for a proper polarization conversion using only the VLBI visibilities (Marti-Vidal et al. 2015). We have implemented this strategy in a program called *PolConvertSD*. This program can also be used to calibrate and convert mixed-polarization VLBI visibilities with linear-polarization stations other than ALMA.

3. TODO list

Here we summarize some details that still have to be implemented, in order to have the polarization conversion fully ready for its use by the VLBI community.

1. PolConvert needs to work directly on DiFX output (i.e. SWIN files), rather than only on FITS-IDI files. Although FITS-IDI is a standard format for radiointerferometric observations, critical programs for VLBI analysis (like HOPS) use their own formats, which can be produced from SWIN files. However, some updates to the DiFX correlator (currently being worked out by W. Brisken) need to be implemented first, for PolConvert to have DiFX-to-DiFX format capabilities. Once the new version of DiFX is ready, the new PolConvert implementation should be ready in about $\sim$1 week.

2. PolConvertSD only works in the AIPS environment. Since PolConvertSD is only a backup alternative to PolConvert (i.e., to be used only if the ALMA calibration is incomplete by the lack of an X-Y phase offset), this is currently considered low priority.

3. Antennas that are flagged on-the-fly by the phasing system should not be considered in the calibration. The information about antennas actually included in the phasing is provided in the ASDM. We are currently adding a code to the CASA calibration script

to read this information and save it in ASCII mode, to be read by PolConvert. The implementation should be ready in $\sim$ 1 week.

4. Several aspects of the `casacore` API are changing quite often with the release of new CASA versions. Hence, it may be problematic to maintain PolConvert and keep it compatible with different versions of CASA. A solution to this problem is to *CASAfy* PolConvert (i.e., turn it into a CASA task), which would read the calibration information using the `tb` tool and would inject it into the C++ PolConvert core as a set of ordinary array pointers. For the CASAfication (and testing) of PolConvert, we would need $\sim$2 weeks. At the moment, we do not consider this as a high priority, since PolConvert is already functional under CASA version 4.3.0.

4. Results on real APP observations

Here we show some fringe plots of PolConverted APP visibilities, together with a short description of the observational issues encountered in each case (and how these issues were solved).

4.1. ALMA-APEX in Band 6

- Date of observation: 13 January 2015.
- ALMA-VLBI frequency coverage: 214.1−215.9 GHz.
- Duration of VLBI experiment: 5 minutes.
- Number of ALMA antennas: 36.

The issues found with these data were:

- APEX only observed in one polarization channel.
  - Indeed, this is not a problem for PolConvert, since it only needs to have the ALMA observations in dual polarization. The rest of (circularly-polarized) stations can observe in single-polarization mode with no effect on the polarization conversion.
- Too short observations. Weak cross-polarization signal for ALMA. No leakage nor X-Y phase offset calibration was possible.
  - The ALMA bandpass and gains were applied with PolConvert. Then, we used PolConvertSD to derive the X-Y phase offset from the VLBI visibilities.

In Fig. 1, we show the fringes in the space of multi-band delay and rate: Top, in mixed-polarization basis (i.e., the fringes just coming from DiFX); bottom, after applying PolConvert and PolConvertSD.

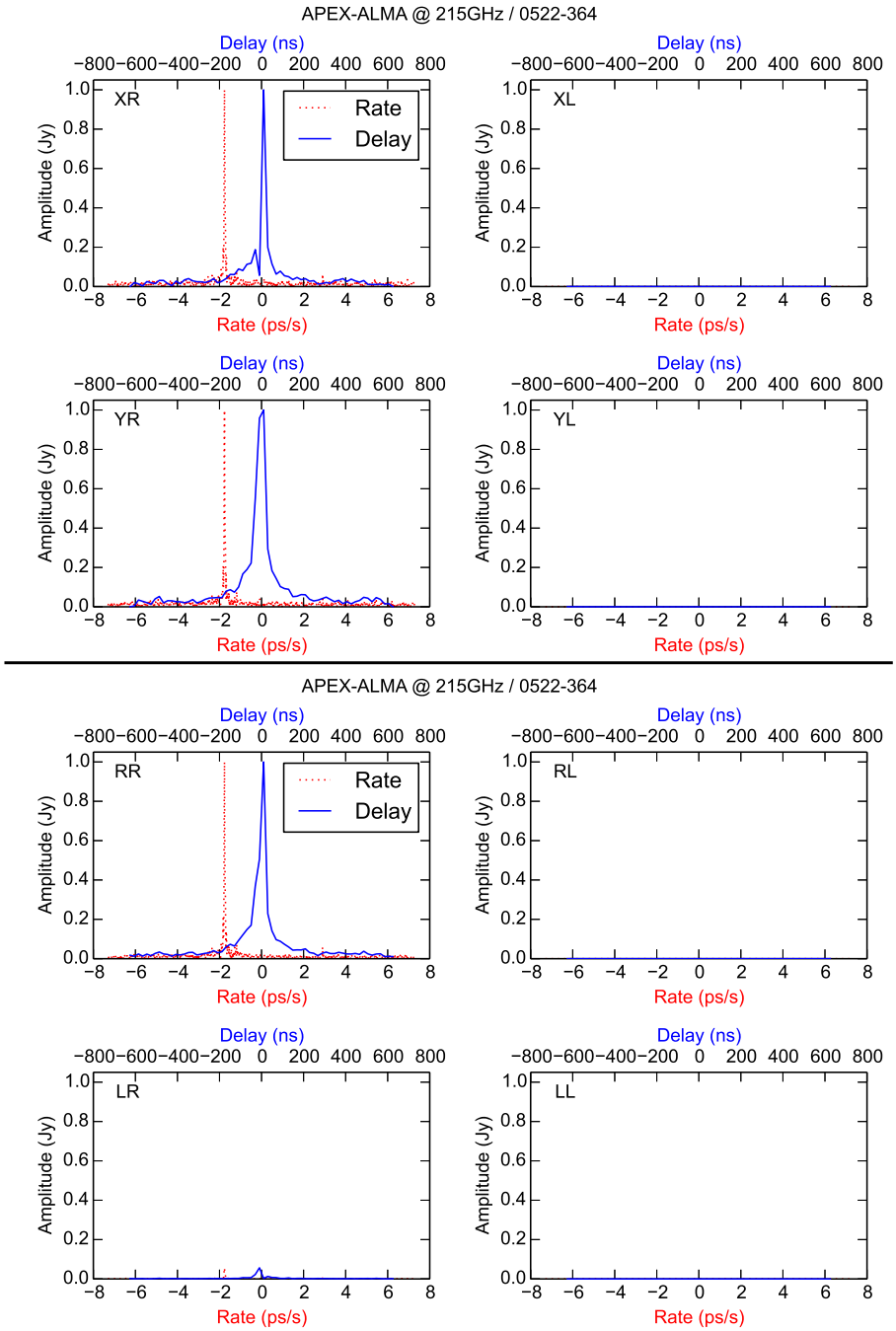

Figura 1: Multi-band fringes at Band 6 between ALMA and APEX. Top, in mixed-polarization basis. Bottom, in circular basis.

4.2. ALMA-Pico Veleta in Band 6

- Date of observation: 30 March 2015.
- ALMA-VLBI frequency coverage: 226.17−228 GHz.
- Duration of VLBI experiment: 2:16 minutes.
- Number of ALMA antennas: 13.

The issues found with these data were:

- Quite noisy fringes (low elevations at both ALMA and Pico Veleta).
  - The ALMA-ALMA cross-correlations were good enough for a successful bandpass and gain calibration, so PolConvert could be applied without problems.
- Too short observations. No leakage could be derived for the ALMA antennas.
  - PolConvert was applied without any leakage corrections. In any case, the effect of these corrections on the phased signal is expected to be small, compared to the effects caused by bandpass, gains, and phase offset.
- Good RR/LL visibilities, but residual artifacts in RL/LR. Several spikes are seen in delay space.
  - These residuals are not understood. However, it is hard to conclude whether they are caused by ALMA or by Pico Veleta. Observations with more baselines are needed for a deeper study of these artifacts (provided they appear in further observations).

In Fig. 2, we show the fringes in the space of multi-band delay and rate: top, in mixed-polarization basis (i.e., the fringes just coming from DiFX); bottom, after applying PolConvert.

5. Conclusions

In its current status, PolConvert is able to calibrate and convert mixed-polarization VLBI visibilities into a pure circular basis, which is is essential for a further analysis of the APP-VLBI data using standard VLBI procedures.

Besides PolConvert, we have developed auxiliary scripts for **1)** computing the CASA calibration tables needed by PolConvert (which are derived from the ALMA-only cross-correlations) and **2)** to apply the conversion in an alternative way, provided that a calibrator with negligible (or well-known) circular polarization has been observed. This latter algorithm can also be applied to VLBI data from stations with linear polarizers other than ALMA.

Although PolConvert is already functional, there are remaining capabilities still to be implemented. The most important one is to work on native DiFX (SWIN) files, rather than only on FITS-IDI files. In any case, this capability is not crucial *in the short term* (and it is planned to be implemented in the following weeks, anyway).

References

- Marti-Vidal I., Roy A., Alef W., et al. 2015, *Proceedings of the 12th EVN Symposium*, **PoS(EVN 2014)034**

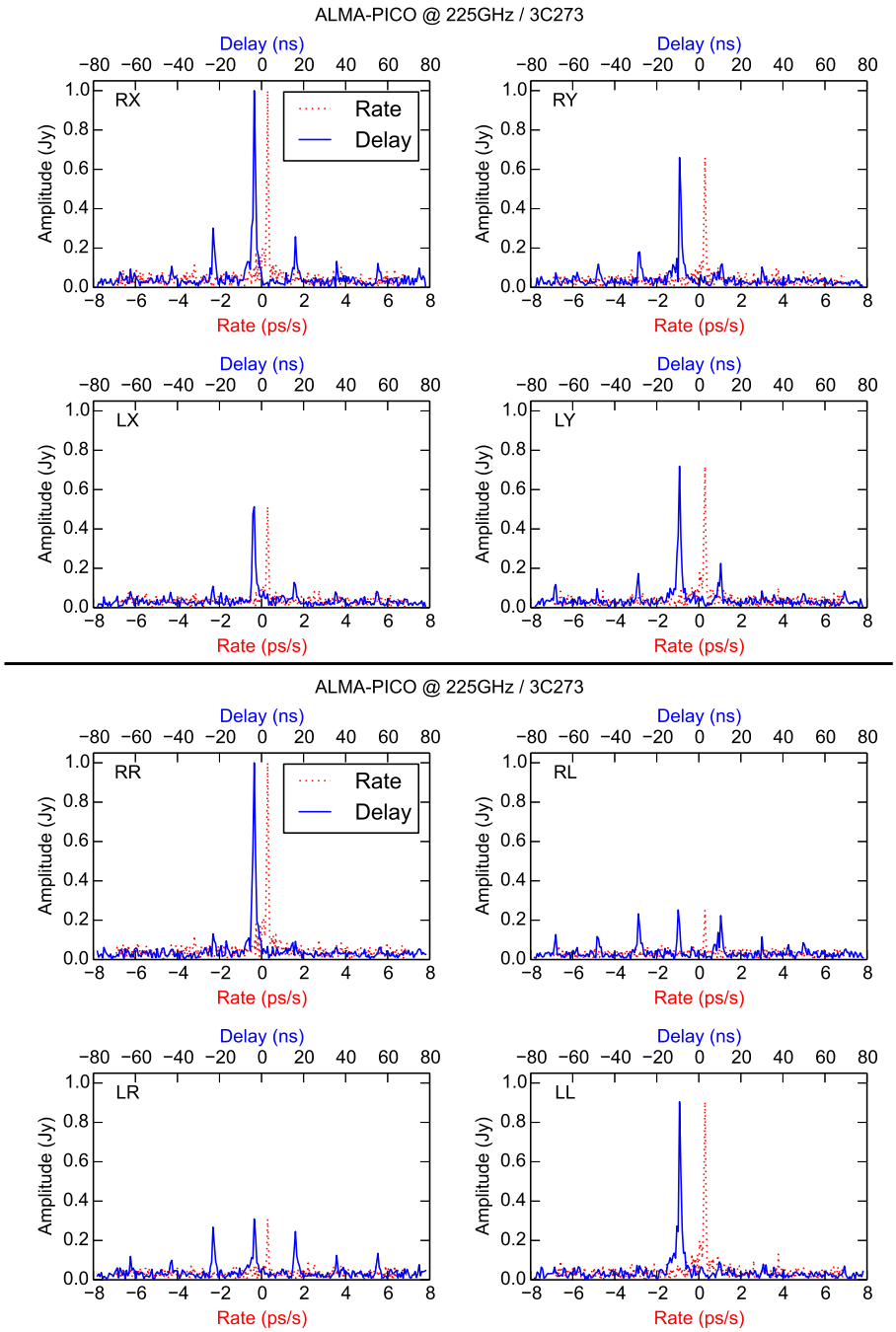

Figura 2: Multi-band fringes at Band 6 between ALMA and Pico Veleta. Top, in mixed-polarization basis. Bottom, in circular basis.