Recent evolution of instrumental circular polarization at the 30m telescope

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Abstract

We use the data obtained in the POLAMI program to investigate the instrumental polarization properties of the 30m telescope during 2014 — 2017. We confirm the increase of instrumental circular polarization reported since 2015 at 3mm wavelength, and we show that the increase occurs in well–defined steps. Each step is associated with major hardware changes in the Nasmyth cabin. Unwanted reflections from the new larger Nasmyth mirrors up to and including M4 may be the cause.

Background

Several polarization programs on the 30m telescope rely on the stability of the instrumental circular polarization V_i. Since the installation of EMIR in 2009, V_i was indeed observed to be rather stable in both the 3 and 1mm bands [1, 2]. Since 2015 however various reports indicate that V_i has increased from values near zero by $\sim 3\%$ at 3mm wavelength. Several investigations were made into possible causes for this increase, but no malfunction of the digital correlator or the XPOL procedures have been identified.

The polarization data of the POLAMI program [1] which continued to monitor a sample of AGN in irregular intervals may be expected to shed some light on this issue. The data taken after August 2014 and up to the end of 2017 were recently reduced, and we here present the aspects pertinent to V_i.

Observations

The Stokes Q, U, and V data analyzed here were calibrated with the standard hot/cold loads. The resulting antenna temperatures refer to the Nasmyth system before any polarization specific correction. All data are included which do not have obvious technical problems. The target sources are all point–like and therefore free of any contamination due to polarized sidelobes. They are not yet filtered, however, for atmospheric instabilities or observational error. The observed antenna temperatures of Q, U , and V contain contributions from system noise, atmospheric fluctuations, instrumental polarization (IP), and intrinsic source polarization. Except for IP, these contributions average out to zero, particularly after screening for atmospheric disturbances and if a large and heterogeneous sample of sources is used as with POLAMI. In Stokes V where contributions from the source are mostly very small, this procedure allows to derive the IP to better than 0.3% at 3mm wavelength, a feature successfully used in [2].

The 3mm data of Stokes V, in percent of Stokes I, are shown in Fig. 3. The striking result is the *step-wise* increase of V_i during 2015. Four segments can be distinguished, inside of which V_i is constant within observational error. Each step is clearly associated with a major technical activity in the Nasmyth cabin. The potentially relevant activities are listed in Tab. 1 and marked as vertical dotted lines in the figure.

The biggest step is labeled *newOptics* and it is followed by two smaller steps labeled *NIKA2* and *OMT*. After mid 2016 no more steps are visible, but accuracy is lower there because observations are more scarce and somewhat more affected by unfavorable atmospheric conditions.

The *newOptics* activity involved the installation of larger mirrors M3, M4, M5, and M6. Mirrors 4—7 were moved very close to the metal cabin wall (Fig. 1). The optical path to the XPOL calibration unit (Fig. 2) had also been moved by 5cm closer to the wall. EMIR and its attached warm optics was not

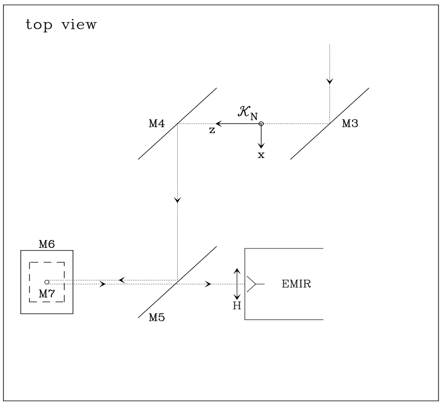

Figure 1: Nasmyth optical elements on the path to EMIR, viewed from above. Mirror M7 and EMIR are located at a level below the other elements. The cabin wall referred to in the text is to the left.

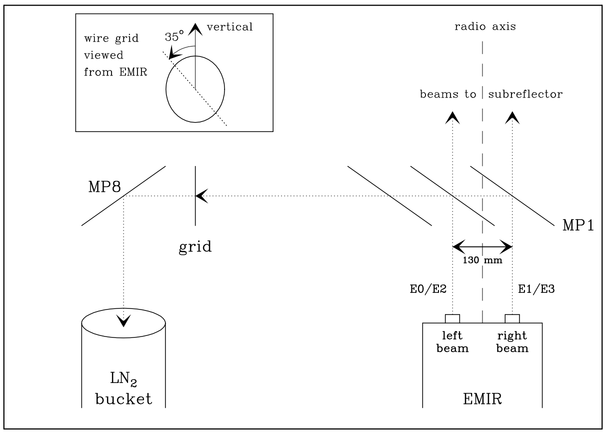

Figure 2: XPOL phase calibration unit (top view). Mirror labelled MP1 is located between M7 and M6 (Fig. 1), and it intercepts the EMIR beam during the phase calibration scan.

Table 1: Technical activities potentially related to polarization properties. Adapted from a listing by S. Navarro. The right column gives the change of $V_{\rm i}$, in percent, associated with each activity.

	date	MJD	activity	change of $V_{\rm i}$
1	19–Sep–2014	56919	replacement of EMIR cold head	< 0.3
2	10–Apr–2015	57122	new Nasmyth mirrors, translation of XPOL cal. unit	$-0.25 \to +1.04$
3	29–Sep–2015	57294	Installation of NIKA2 cryostat	$+1.04 \to +1.85$
4	26–Nov–2015	57352	new E090 module (OMT)	$+1.85 \to +2.85$
5	24–Sep–2016	57655	replacement of EMIR cold head	< 0.3
6	20–Apr–2017	57863	change of compressor	< 0.3
7	17–Oct–2017	58043	partial warmup of EMIR	< 0.3
8	24–Oct–2017	58050	complete warmup of EMIR	< 0.3
9	21–Nov–2017	57655	replacement of EMIR cold head	—

moved. At the second step, the NIKA2 cryostat was installed. Nasmyth mirrors had to be unmounted and re–aligned repeatably, but EMIR and the XPOL calibration unit were not touched. At the third step, EMIR received a new 3mm module which incorporates an ortho–mode transducer (*OMT*). This last step has the smallest amplitude, even if it is associated with the modification affecting 3mm polarization most profoundly. No effect on 3mm $V_{\rm i}$ is seen due to modifications of the cryo chain (cold head, compressor, etc).

The 1mm data obtained by POLAMI in parallel to the 3mm data do not exhibit any significant step in circular polarization during 2014 —2015. Only a step of low statistical significance is suggested within ca. 2 months of the cold head replacement in 2016.

The other Stokes parameters Q and U are well behaved during the whole period of 2014—2017 and small ($< 1.5\%$). Their evolution is also free of any major steps at both wavebands. The only marginally significant step occurred in Stokes U at the installation of the OMT module. But note that the accuracy of our IP derivation is reduced (we estimate $\sim 0.5\%$) because (1) the scatter of U is much higher than of V (due to the often strong linear polarization of the sources) and (2) there are fewer data after mid 2016.

Discussion

We quantified the reported increase in the 3mm circular polarization and showed that the increase occurs in 3 well defined steps on dates of major hardware changes in the Nasmyth cabin. The increase is limited

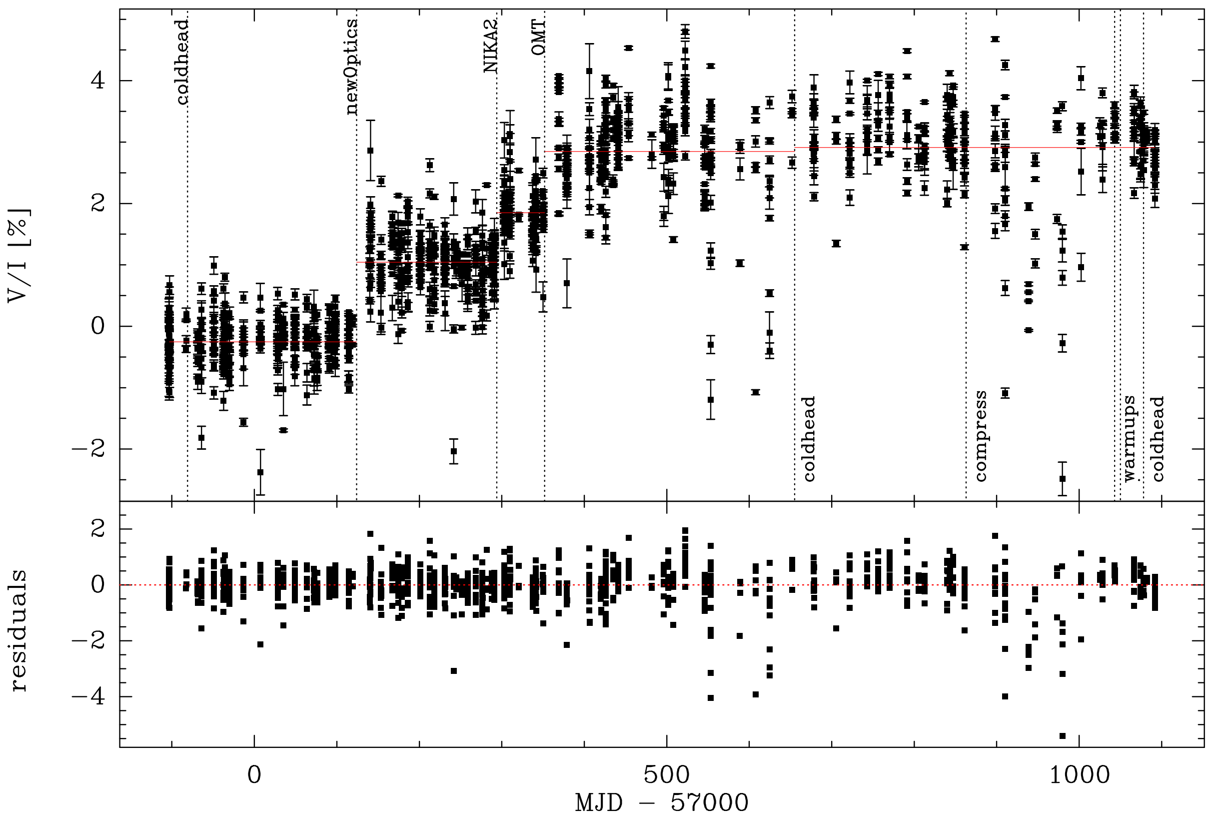

Figure 3: Evolution of instrumental circular polarization at 3mm wavelength. Data are taken from the POLAMI program. See references [1, 2] for details of source selection, observing procedures, and data reduction. The abscissa is in Modified Julian Dates, MJD. Zero corresponds to 12–Sep-2014. Vertical dotted lines indicated the dates of major hardware modifications in the Nasmyth cabin (see Tab. 1). Red lines are fits to the data in each of the 4 clearly distinguishable segments.

to Stokes V at 3mm. Even if we cannot pinpoint to the precise cause of the annoying increase of $V_{\rm i}$, our data narrow down the area in which the problem occurs.

In the scheme of XPOL, Stokes V is derived from the cross-correlation of incoming horizontally (H) and vertically (V) polarized radiation [3]. Since all data used here are from point sources, issues of polarized side lobes can be ignored. For the present purpose we can also ignore any IP generated by tracking errors, wind or anomalous refraction, as they are equally likely to produce positive or negative $V_{\rm i}$. A false Stokes V signal is then produced either (1) by false, i.e. of instrumental origin, incoming H and/or V power or (2) by a faulty instrumental phase.

Mechanism (2) is readily ruled out as the main cause, since it would generate Stokes V power at a fixed fraction of Stokes U. We see however in Fig. 3 that $V_{\rm i}$ is rather constant, at least within each of the identified segments, irrespective of the vastly different linear polarizations of the sources and their time–variable projection in the Nasmyth system. The false Stokes V therefore comes at a fixed fraction of Stokes I, not Stokes U. This argument rules out a malfunction of the phase calibration unit as the primary cause of the increased $V_{\rm i}$. We cannot exclude at this point, however, a small systematic phase error, possibly introduced by the translation of the unit toward the cabin wall. This point needs further investigation which is beyond the scope of this note.

We therefore conclude that the observed increase of $V_{\rm i}$ originates as a faulty contribution to the flux density (Stokes I) of the source. A possible mechanism is power reflected rather than absorbed by the receiver, and subsequently reflected from the surroundings back into the receiver. In order for the reflected signal to be registered as Stokes V, the reflection must introduce a phase between the reflected H and V.

It therefore appears rewarding to inspect the new optical components upward from the receiver for presenting reflective surfaces with the right orientation. The absence of a significant correlation of $V_{\rm i}$ with elevation indicates that the reflection occurs before M3. We may further speculate that there are not many reflecting surfaces, as they would likely generate different phases which would then quickly diminish the correlated power. The fact that the increase of V_{i} is only observed at 3mm and not at 1mm appears plausible in this scenario owing to the much larger beam area at 3mm.

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References

[1] I. Agudo, C. Thum, S. N. Molina, C. Casadio, H. Wiesemeyer, D. Morris, G. Paubert, J. L. Gómez, and C. Kramer. POLAMI: Polarimetric Monitoring of AGN at Millimetre Wavelengths - I. The programme, calibration and calibrator data products. *M.N.R.A.S.*, , 474:1427–1435, February 2018.

[2] C. Thum, I. Agudo, S. N. Molina, C. Casadio, J. L. Gómez, D. Morris, V. Ramakrishnan, and A. Sievers. POLAMI: Polarimetric Monitoring of Active Galactic Nuclei at Millimetre Wavelengths - II. Widespread circular polarization. *M.N.R.A.S.*, , 473:2506–2520, January 2018.

[3] C. Thum, H. Wiesemeyer, G. Paubert, S. Navarro, and D. Morris. XPOL - the Correlation Polarimeter at the IRAM 30-m Telescope. *Publ. Astr. Soc. Pac.*, , 120:777–790, July 2008.