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EARLINET Raman Lidar PollyXT: the neXT generation

by R. Engelmann et al.

The paper describes the history and setup of a series of apparently very similar lidar systems called Polly and recent technical improvements of the now called PollyXT.

The paper is appropriate for publishing in AMT and will be very important as a reference for future publications of measurement results with these systems. It is well organized and well written.

But in the view of this importance and in the hope that many valuable investigations will be performed and published with the help of these instruments, it is unacceptable that many details are missing (described below) which are essential to understand and to win confidence in the performance of these lidar systems.

Note 1: Because this paper will probably be used as a reference for future papers of the different groups running the systems and maybe as a technical reference by persons which newly start to work with the systems, it is very important to clearly indicate which of the individual improvements apply to which of the systems listed in Table 1.

The presentation of a case study at the end is dispensable for this important technical work. Instead "calibration" measurements should be presented, which support the range and accuracy claims in such a way that they don't have to be repeated in follow-ups with more detailed analyses of atmospherical measurements than in the case study.

Details:

Title: The title makes it seem like PollyXT is or will be the standard lidar system for EARLINET. If this is not intended, EARLINET should not be mentioned in the title.

P7742 L20 *The alignment of the laser beam through the external second and third harmonic generators (SHG, THG, E2 in Fig.) was improved ...*
Which effect does the improvement have on the lidar signals? If there was no effect, would it be worth mentioning it?

P7743 L10 *The laser-beam overlap with the receiving telescope is monitored with a triggered camera (CAM)...*
What does triggered mean?
How is the *overlap* determined by the CAM?
What is the resulting alignment accuracy?

P7743 L21 (compare P7744 L23) *Small PMT modules of Hamamatsu (type: P10721-110) are used for all wavelengths,...*
Is it H10721-110 or P10721-110 ?

P7744 L7 *In contrast to the former systems...*
Which are the former systems? (see Note 1 above)

P7744 L7 *For example, the deformation of the mounting of the primary mirror is depicted in Fig. 4.*
The deformation in Fig. 4 looks rather like the one when the mirror is looking horizontally.

P7744 L19 *A new photon-counting data acquisition hardware developed at the Max Plank Institute for Meteorology in Hamburg has been applied to all recent Polly systems.*
What means *recent Polly systems* (see Note 1 above)?

P7744 L21 *The aim of the development was a small and low-cost data acquisition for scientific lidar measurements with high dynamic range.*
What means high dynamic range?

P7744 L26ff
Please make the paragraph better understandable for the readers which are not experts in electronics:
What means flip-flop circuit?
What is a level transition?
What is the histogram?
Why should the pulse discrimination level be controlled, and what is the achieved improvement or accuracy?
What does it mean that the power supply is controlled?
What does *handling eight channels* mean?

P7744 L26 *An optical trigger taken from laser stray light starts the histogram counter which is synthesized in an FPGA.*
What is a histogram counter and what means synthesized?
How are the lidar signals retrieved from the histograms?
Does the averaging *over a predefined time period* mean the range bin or the temporal averaging of the lidar signal?

The descriptions of the electronics are not probably not understandable by the general reader, and if not expanded, they could be skipped. However, it would be of interest which effects or improvements for the lidar signals are achieved by each of the devices compared to "usual" systems?

P7745 L20 *When using photon counting dead-time effects can be an issue...*
Dead time effects are always an issue.

P7745 L23 What does *electronic transients at the discrimination level* mean?

P7745 L25 *Measurements showed that the typical dead times with respect to the paralyzable theory are on the order of 2–3 ns (depending on the individual PMT)*
Do you mean with *individual PMT* only individual *H/P10721-110* or different types?

Fig. 6: Caption: *a defined light ramp ...*
Why does the light ramp have to be defined?
The comparison is between the measurements with a strong and a weaker neutral density filter. The strong filter pulse is the reference, howsoever the real pulse shape is.

Fig. 6: Inset: I am astonished about the time scale in ns. If this was true, the temporal resolution of the DAQ would be in the sub-ns range.

Fig. 6: The figure is not easy to understand intuitively, because two things are combined, i.e. the measurements (black line values over blue line values of the insert) and the correction function, and because the ordinate label does not mention the low light measurement (black line; factor ~100). The black identity line is also misleading, because it is intuitively interpreted as the truth, but the correction is deviating from it. According to the figure caption (*resulting correlation*), the axis label should be something like "black line Mcps (x 100) over blue line Mcps". Or the axes are exchanged and "blue line Mcps over black line Mcps (x 100)" are plotted, with and without polynomial correction, so that the corrected blue line values agree with the identity line.

P7746 L10 *From this data it was found that the paralyzable theory is not always adequate for count rates higher that 40 Mcps and differences to such a model occur.*
What does *not always* mean (sometimes yes, sometimes no?), and which differences occur?

Doesn't paralyzable mean that the measured Mcps decreases again with the true Mcps increasing above a certain threshold? Either this regime is not considered here (what about the ambiguity then? What about clouds?), or the behavior of the system is closer to the non-paralyzable theory.

What is the corrected maximal count rate (typically)?
With which max. error does the polynomial fit?
How high is the dynamic range, which is emphasized on P7744 L21.
Furthermore, it might be interesting for the readers to get statistical information about the variability among the obviously large number of PMTs investigated for the several Polly systems.

P7746 L11 … higher than ...

P7748 L1ff How can the values below the full overlap at about 800 m (Fig. 10 at 532 nm) be obtained? Please explain or give a reference.
Can the deviations between Polly and MARTHA/Radiosonde below about 800 m be attributed to the incomplete overlap?

P7748 L7 ... 0.75%.

P7748 L13 *In contrast, the generation of second and third harmonic radiation can significantly decrease the purity of polarization and affect the accuracy of measurements.*
Please explain how this can happen?
But: isn't the opposite true, i.e. that the non-linear effect of SHG and THG is only present at a certain plane of polarization, which should result in perfect linearly polarized light - at least at 355 nm?

P7749 L3 *Hence, the polarization impurity of the transmitted laser beam is well below 0.1 % and sufficiently low for depolarization measurements in terms of EARLINET standards.*
There are more optical components after the Glan-laser polarizer (see Fig. 3). Do they not effect the polarization purity?
How can/has that been verified?
What exactly means polarization impurity?
What does *in terms of EARLINET standards* mean here?

P7749 L21 *...so that the former correction does not induce significant errors...*
and
P7750 L5 *Although the remaining bias from non-ideal beam splitters can be corrected with Eq. (2), it yields another step in the data evaluation and can increase the overall errors.*
Maybe I am misunderstanding something here. Corrections should remove/correct known systematic errors, not induce them.

P7750 L8 *The obtained values for the newest design of Polly are satisfactory …*
What does satisfactory mean?
Regarding *newest design*, please see Note 1 above and bring Table 4 in compliance with the text.

P7750 L8 *...a difference...below 10%....*
10% of what?

P7750 L11ff The described calibration procedure has an error, which is not specified here, and which influences Eqs. 2, 3 and 4, resulting in overall errors of the lidar signal and of the linear depolarization ratio. Furthermore (P7751 L7ff), the absolute calibration also has an error. Fig. 9 shows a variability of the calibration constant C, but it is not clear whether the variability stems from random measurement errors or from variations of the calibration constant. The latter case

would be an argument that the calibration has to be performed regulary and that the actual error of C can be decreased compared to the shown variability. However, the error of C together with the errors of the receiver transmission ratios contribute to the error of the linear depolarization ratio in Eq. 3.
On P7747 L25 it is emphasized that the linear depolarization ratio has to be measured with high accuracy in order to enable the analyses described in that chapter.
Not only therefore it is essential that the errors mentioned above and their influence on the final products are quantified and their determination described in sufficient detail.

P7753 L14 *...the height of complete overlap is not as essential as the equality of the overlap function for the separate detection channels...*
Please explain or give references.

P7753 L4 *From EARLINET work-shops in the past years it emerged that such a compromise to cover measurements in the entire troposphere with only one receiver telescope is almost impossible.*
Where is the compromise?

P7753 L16 *Therefore, extreme care was taken to guarantee that the optical paths behind the field stop are similar and the spread of incident angles of the radiation is less than 1° at the interference filters.*
The first statement is just qualitative. What does *similar* mean, and which are the quantitative consequences with respect to the products of the signal ratios?
The second statement (1°) is also not related to its effects on the signal products (see comment to P7754 L10 below).

P7753 L28 The NA of the fiber should be mentioned.

P7754 L6 *The scrambler consists of a sapphire ball lens (personal communication, I. Serikov, 2012) of 2 mm diameter...*
To what does *personal communication* refer? Do you mean *proposed by Serikov* or similar?

P7754 L10 *Figure 10 shows the simulated and experimentally determined overlap functions for the far-range and near-range receiving telescopes.*
How was the simulation done?
Are the experimental overlap values derived according to Eq. 3 of Wandinger and Ansmann (2002)?
It would be nice to see in Fig. 10 a bit more than 900 m height, and is it possible to use a different colour for the far and near range curves in the overlap plot?
As the overlap function is in general a smooth function, the curves could be smoothed to better show the agreement at the higher ranges, and/or another measurement could be used with longer averaging time and lower noise.

The basic assumption for the determination of the overlap function according to Wandinger and Ansmann (2002) is that the overlap functions for the Raman and elastic channels are the same. While for 532 nm the overlap function of the large telescope retrieved with the Wandinger and Ansmann (2002) method can be checked with the 532 nm near range telescope (it would be nice to see this in Figure 10), this is not possible for 355 nm and 1064 nm. But Figure 11 shows backscatter coefficients at 355 and 1064 nm down to about 300 m, and linear depolarization ratios at 532 and 355 nm down to about 100 m.

How is this possible with a field of view of 1 mrad for the large telescope?

According to Table 2 different interference filter bandwidths are used with 1 nm bandwidth for the elastic and 0.3 nm for the Raman channels. Furthermore, the spectral transmission of dichroic beam-splitters with steep filter edges is sensitive to the incidence angle, and also polarizing beam splitters can exhibit such an angle sensitivity. On P7753 L18 the maximal incidence angle in the parallel beam path is given as 1° for the large telescope. Is this the value for the nominal 1 mrad field of view?

Estimating the distance of the telescope and laser axes with 250 mm, the backscattered laser light from 100 m range has an incidence angle at the telescope of 0.25 m / 100 m = 2.5 mrad. With the telescope magnification of Ftelescope / Fcollimator = 900 mm / 50 mm = 18 (with estimated focal length F of the collimating lens of 50 mm) we get an incidence angle of 2.5 mrad * 18 = 2.9° at the interference filters in the receiver optics. Depending on the laser alignment it could be more.

This shows that it is important to somehow verify the assumption of identical overlap functions for the signal ratio products – and to include more information about the receiving optics in Table 2.

For example, if the overlap function is wrong by 5% and the backscatter ratio is 2, the retrieved aerosol backscatter coefficient using the overlap correction is already wrong by about 10%.

How is the overlap function for 1064 nm achieved? At this wavelength no signal ratio or Raman method can be applied.

In summary: the overlap function and the way how it is achieved should be presented for each channel for which it is actually used, together with its uncertainties. But perhaps there are other ways to verify certain signal ratio products in the overlap regime.

Table 2 is incomplete:

Are all laser pulse energies (not power!) the values after the THG?
Which SHG and THG crystals are employed?
Laser beam radius and divergence?
Is the beam divergence FWHM?
Telescope secondary mirror diameter, distance from primary, and obscuration?
Telescope axis distance from emitted laser beam axis?
Is the field of view FW?
Diameter of collimation lenses and focal length?

P7756 L24 *The system combines latest EARLINET lidar quality standards in a stand-alone design.*
Similar: P7749 L4
Which are these standards? Can you give a reference?

Figure 11 shows error bars for all products without any comments or explanations what they mean and how they are achieved.