RINGO3 Data Problems and Solutions

20th March 2014

RINGO3 was brought into service in early 2013. However late in 2013 we discovered a significant problem with the instrument which will affect all data taken before then, and still has residual effects on data taken post December 2013. This problem affects polarimetry (but not photometry derived from the sum of all 8 rotor positions).

Background

All polarimeters suffer the effects of instrumental polarisation and depolarisation which can be characterised by the observation of non-polarized and polarized standard stars respectively. It was discovered in the early days of the RINGO photometer that the best instrumental stability and easiest calibration was obtained by always observing at a constant Cassegrain mount rotator angle (FITS keyword ROTANGLE). This was done to ensure that all optical surfaces are orientated the same with respect to each other when observing targets but also standards (so that the latter can be used to calibrate the former). The orientation on sky (the telescope sky position angle) was found not to matter. This however turns out not to be the case for RINGO3.

The RINGO3 webpages describe the basic process of combining flux measurements at the 8 rotor positions that RINGO3 data is taken at to derive the instrumental Stokes parameters q and u. The correction of these Stokes parameters for instrumental polarisation can either be done by ratioing the flux measurements at the 8 rotor positions with the corresponding measurements for a zero-polarised standard or by subtraction of the derived q and u values from the non-polarised standard from those of the object of interest.

Following this correction for instrumental polarisation, the polarisation of a source could then be calculated via

MEASURED_POL = SQRT (q^2 + u^2)

and the measured position angle (THETA) of a source can be calculated via

THETA = 0.5 ARCTAN2(u,q). (*this is equivalent to THETA = 0.5 ARCTAN(u/q) but use of ARCTAN2 means the sign will always be correct*).

To convert this measured position angle to a true position angle(E of N) on sky (TRUE_PA) it was therefore necessary to take account of the telescope sky position angle (FITS keyword ROTSKYPA):

TRUE_PA = SKYPA - THETA + K

where K is a constant.

The value of K can be derived from observations of a number of polarized standards of known TRUE_PA. The value of K changes when the instrument is disassembled and reassembled but is stable between those times. For example between 2011-03-20 and 2012-04-28 the value of K for RINGO2 was 88 degrees.

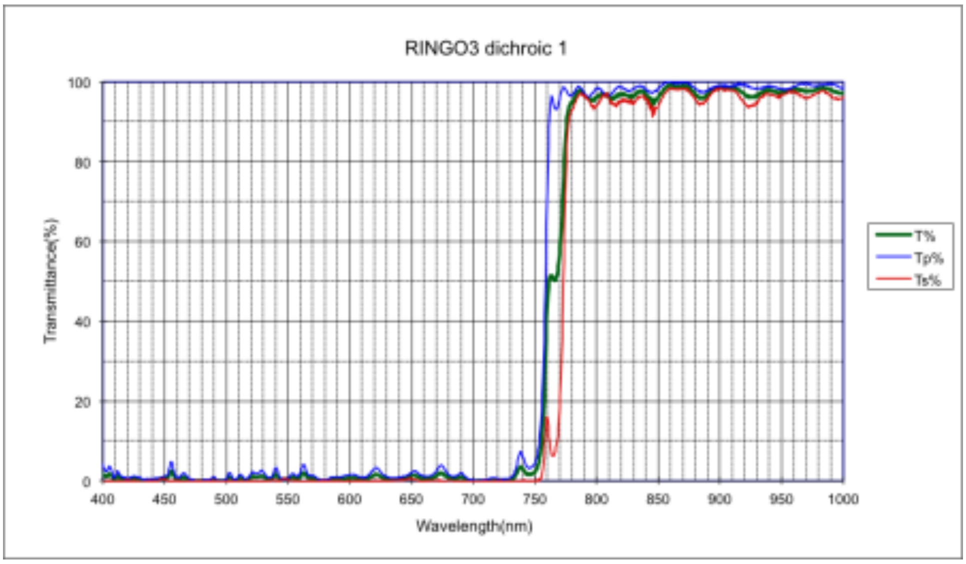
To convert MEASURED_P to a TRUE_P (i.e. correct for instrumental depolarization) the measurements of the polarized standards could be used again. In this case

TRUE_POL = MEASURED_POL / F

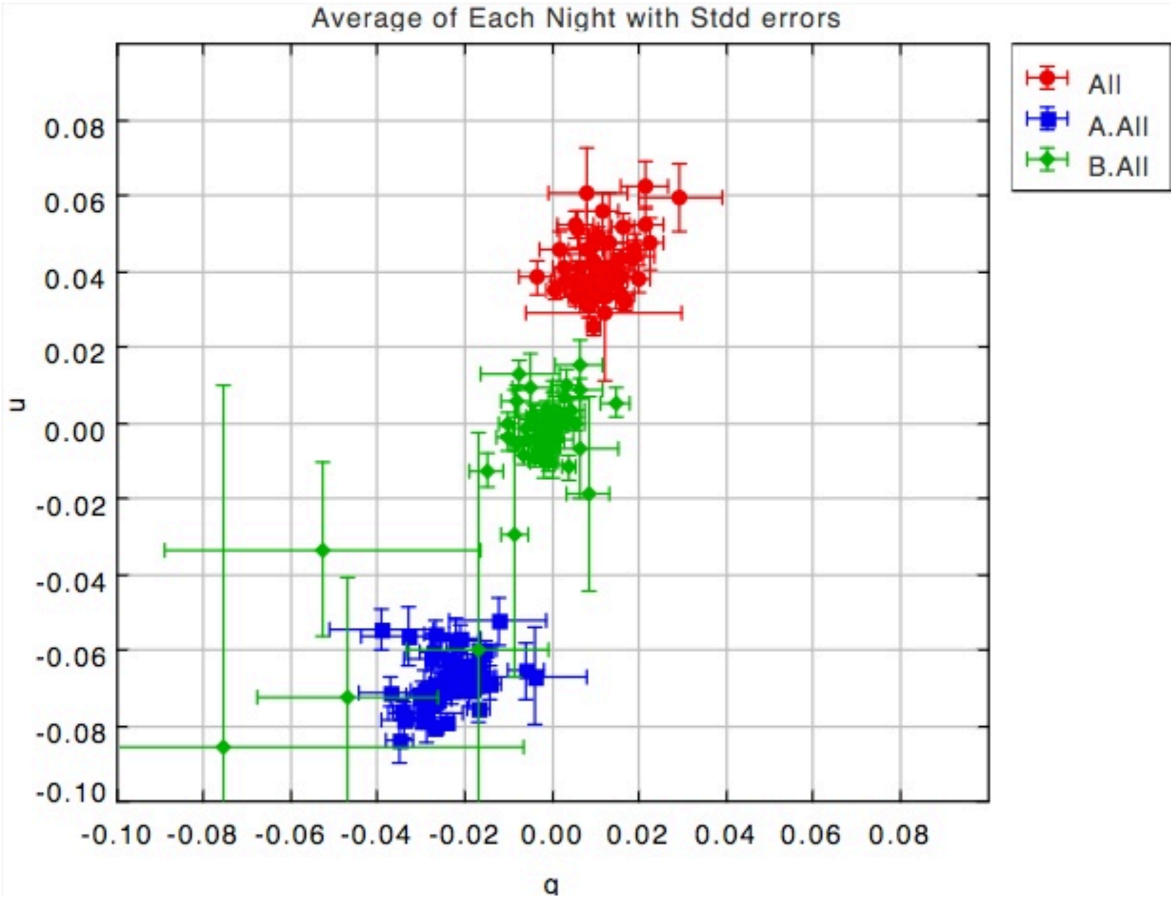
where F is a constant factor (=0.75 for RINGO2).

RINGO3 pre Dec 2013.

RINGO3 incorporates three dichroic mirrors in order to split the beam after the rotating polaroid onto three cameras (“d”, “e” and “f”). The beam out of the polaroid will of course be very heavily polarized, and therefore some interaction between the different transmission of the dichroic mirrors depending on the polarisation angle of that output beam was expected. The graph below shows the difference in cutoff wavelength for two beams with polarisation 90 degrees apart (p and s).



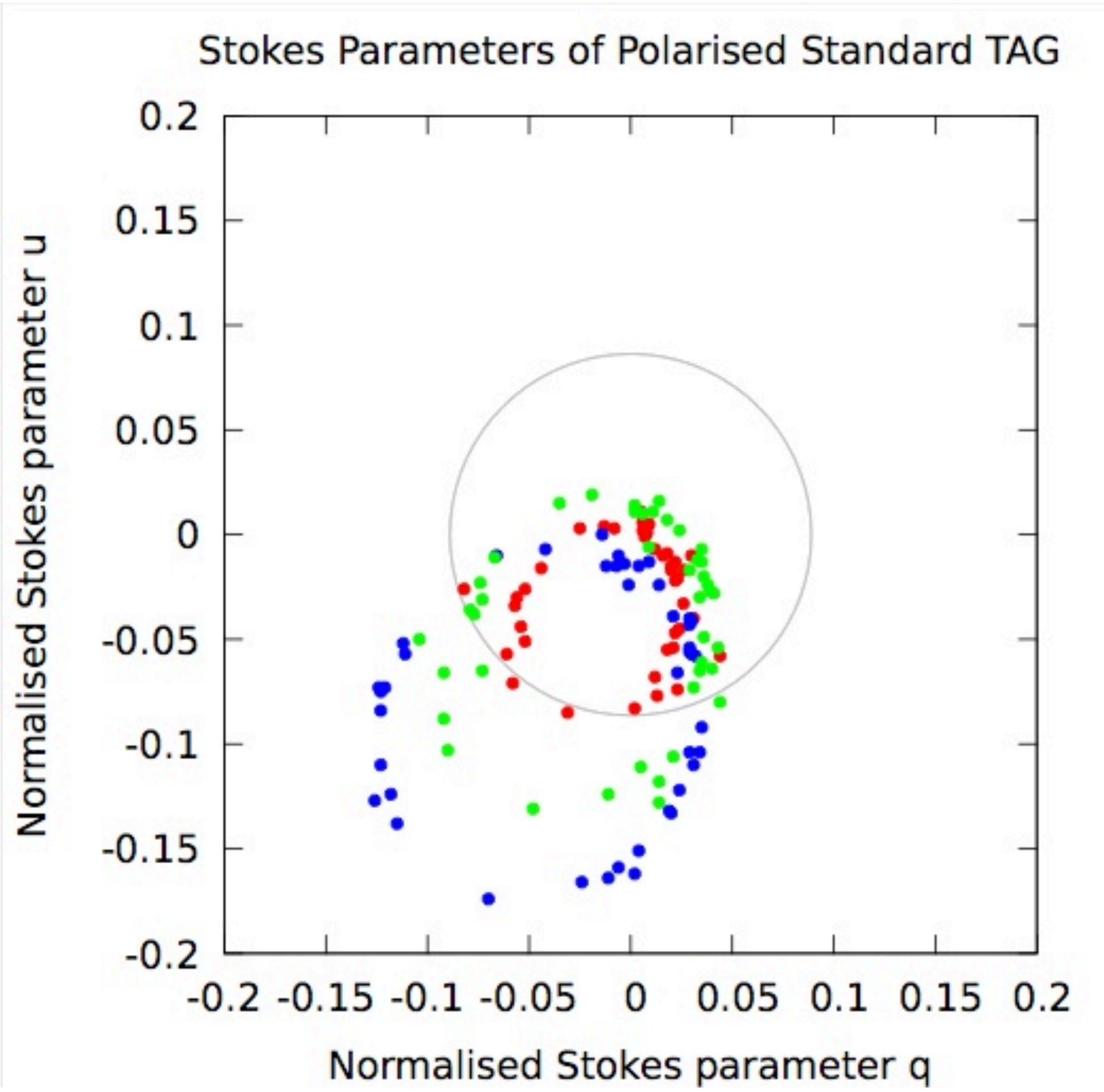
Our initial attempt to characterise this problem used non-polarized standard stars. These showed that as expected the three cameras had different (but constant) offsets in instrumental polarisation when observing those targets:



We therefore assumed that the interaction between the rotating polaroid and dichroic mirrors was well understood and that the procedures outlined in the previous section would be applicable again.

However, towards the end of 2013 we became suspicious that this was not the case when users were reporting difficultly in calibration of the instrumental depolarisation and position angle offset K from the observations of polarized standards. We therefore carried out an analysis of this ourselves for many observations obtained at the same rotator mount angle (ROTMOUNT) but many different sky angles (ROTSKYPA), and discovered that the position of a polarized object in the q,u plane following correction for a constant instrumental polarisation was not as we had previously found with RINGO2, which in that case was a simple circle around the origin at q=0, u=0.

For RINGO3 we have found that the origin of that circle is a function of the polarisation of the original source. The following q,u plot is shows measurements of the same polarized source (VI Cyg 12) at different sky angles before any correction for instrumental depolarization. VI Cyg 12 has P~7-8% (this will be a function of wavelength). The colours of the points correspond to the rough wavelengths of the cameras (d=red, e-blue, f=green).



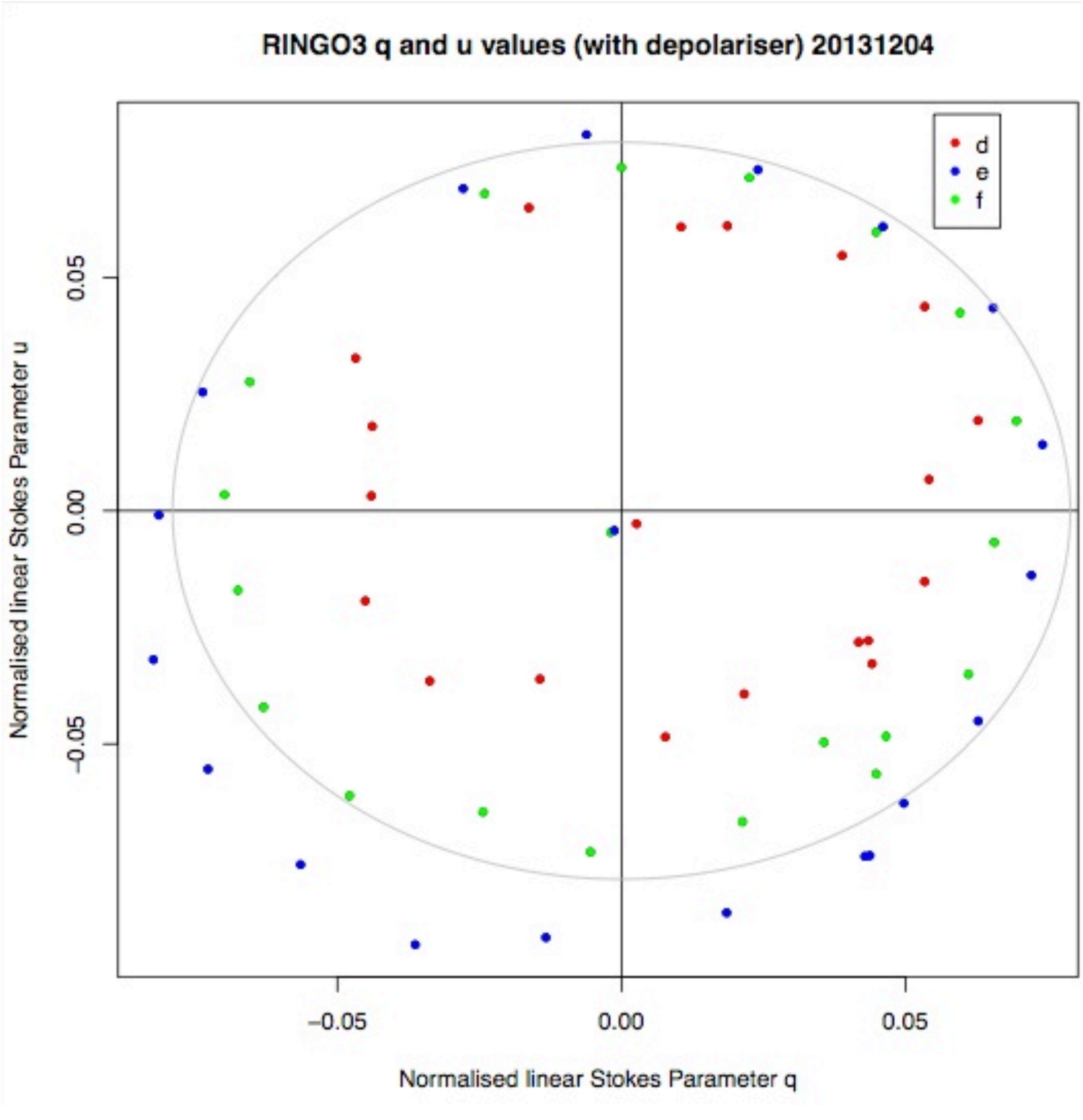
As can be seen the radius of the circle reflects the degree of polarisation as expected, however unless you know the location of the origin of the circle (which appears to be a function of the degree of polarisation) then you can not measure the degree or angle of polarisation correctly.

Therefore for measurements of stable sources, which have been observed over many nights (and therefore at many different sky angles) one can plot a q,u diagram and fit a circle through the points to determine the origin and hence the true values of the q and u offset from that origin. However, for objects which are variable from night to night there is a degeneracy between position on the instrumental q,u plane and its actual q and u.

The bottom line is that it may not be possible to do polarisation measurements on pre-December 2013 RINGO3 data where the source is variable. Simple photometric measurements (where the total flux from all 8 rotor positions is summed) should be unaffected by this problem, and so multi-colour light curves are still possible to produce.

RINGO3 Dec 2013 onwards

To address this problem, in early December 2013 a depolarising Lyot prism was fitted between the output of the polaroid and the first dichroic mirror in RINGO3, since once the beam has passed through the polaroid, it is only its intensity that we are interested in. An initial reduction of data taken at a selection of mount angles and corrected for instrumental polarisation via the usual procedures seems to show that this has mostly corrected the problem. The following plot shows observations of the same polarized standard as the previous one (plus an observation of a zero polarized standard at the 0,0 origin). The q,u values for the polarized standard VI Cyg 12 can now be seen to be more concentric with the origin, with a maximum deviation of about 1% in polarisation from the true origin.



We therefore believe that data taken post Dec 2013 with a single cassegrain mount angle (ROTMOUNT) of zero degrees should be able to be calibrated to about 1% in polarisation.

If a greater polarimetric precision is required, then we recommend observing at three different mount angles (ROTMOUNT -60,0 and +60 degrees) in a single observing group. We believe this should allow fitting a circle through the three data points in the q,u plane and so estimate the offset from the 0,0 point to the origin of the polarisation circle. The precision of this procedure has not yet been tested, but we will update this document in the next few weeks with the outcome of out internal testing of this approach.