MANUAL MERIDIAN FLIP PROCEDURES

RE-DISCOVERING A LOST TECHNIQUE

By Roger A. Firth and Stephen P. Holmes, March 2022

ABSTRACT

Observers using a German Equatorial Mount can discover to their cost that, when tracking a target across the meridian, it is possible for the telescope body to collide with the structure of the mount or tripod. To avoid this possibility, it is necessary to re-set the alignment of the mount so that the telescope body is moving away from it as tracking continues rather than towards. This procedure involves a rotation in both Right Ascension and Declination, and is called a Meridian Flip.

As we show in this paper, on practical & theoretical grounds and with verification by means of observational experimentation, to carry out a manual Meridian Flip one must, irrespective of the Declination of the target being viewed or the meridian being crossed:

1) Rotate the telescope in Right Ascension by exactly 12hrs.

2) Adjust the Declination of the telescope by an amount given by the following very simple Rule:-

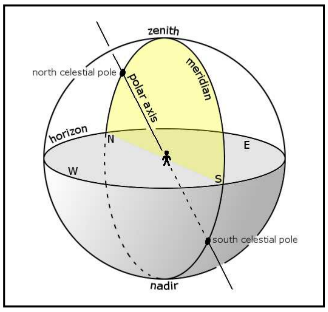
If D is the original Declination of the target, rotate through the nearest 90 marker on the setting circle until you reach the same value of D on the other side of the marker.

CONTENTS

1. Introduction

The term Meridian Flip is often recognised, but is poorly appreciated by amateur & professional astronomers alike. In the twenty first century the Meridian Flip is executed almost exclusively via mounts with computer-control (so called “GoTo” mounts) using software utilizing sophisticated guidance & tracking systems. For those without such a facility, knowledge of how much rotation in the two axes is required to perform a flip manually is vital but seems to be unknown by a significant proportion of the astronomical community. This paper seeks to present a clear explanation of the necessity for a Meridian Flip; to determine by experiment & practice the amount of rotation required; to show by tests performed on actual celestial targets that the deductions thus made are correct; to give a straightforward rule for the required rotation in both Right Ascension and Declination for any target in any part of the sky, and thereby to remove the mystique which surrounds the Meridian Flip and thus to make it available as a simple and useful adjunct to the armoury of astronomers who do not have access to a “GoTo” mount.

2. What exactly is a Meridian Flip?



The Meridian is an imaginary line rising into the sky from the due north point of the observer’s local horizon, passing through a Celestial Pole and descending again to the due south point of the horizon (see diagram). It thus divides the sky into Western and Eastern halves. Note that the analyses which follow apply only to the northern hemisphere, and so the Pole in question is the Northern Celestial Pole, located very close to the star Polaris. However – the final conclusions as to the axial rotations required to perform a Meridian Flip apply equally to observations in both northern and southern hemispheres.

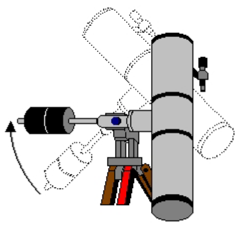
When using a telescope on a German Equatorial Mount (the type commonly found on most amateur and many professional set-ups), a problem can arise when traversing in Right Ascension (RA) across the meridian. When looking to the north, a target originally to the west of the meridian becomes lower in the sky as time passes and so must be observed with the telescope body (known as the Optical Tube Assembly, or OTA) to the left of the mount as it is only on this side that the field of view of the telescope will become lower as RA increases. As both the target and the OTA continue to move downwards, the OTA is in danger of colliding with the mount or tripod structure. When looking to the south, a target to the east of the meridian will rise in the sky as time passes, requiring the field of view of the OTA to do the same, but because the geometry is different the field of view will rise with increasing RA whether the OTA is to the left of the mount or to the right. However, if it was to the left it would be well below the counter-weight for much of its travel and so lie close to the tripod, possibly causing the collision we are trying to avoid. In practice therefore, the OTA must lie to the right of the mount when observing to the south, and so will start to descend as the target crosses the meridian from east to west with the same possibly dire consequences as for observing to the north. The Meridian Flip is a procedure designed to avoid these problems.

Note that a collision cannot occur when tracking an object across the northern meridian from east to west (i.e. when the object is above Polaris in the sky) because in this situation the OTA will be to the right of the mount and well above it for all of its travel, moving initially upwards and then downwards. It is only when the downwards travel takes the OTA below horizontal that problems might occur. Clearly, a transit across the southern meridian from west to east simply cannot occur, as (in the northern hemisphere) all celestial objects move from east to west when seen to the south.

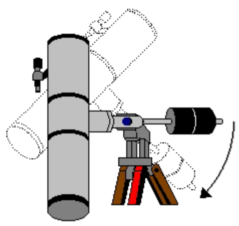
It must be emphasised that whether the OTA will collide with the mount or tripod on crossing the meridian depends on the exact details of the mount and the Declination of the object being observed. For example, if the mount stands on a pillar (whether down to the ground or as an extension to the tripod) a collision is less likely as the pillar, having a relatively small cylindrical or square cross-section rather than the large and effectively pyramidal cross-section of a tripod, is less of a hindrance to the free movement of the telescope. The Declination is important as this affects the angle of the OTA relative to any potential obstruction, which changes the likelihood of it hitting anything as it descends. It is easy to be caught out when crossing the meridian though, so it is important to be ready for trouble and then know how to perform a flip even if the procedure is rarely used.

3. The basic theory behind a flip

The general idea behind a Meridian Flip is to re-position the OTA from (when looking to the north) below and to the left of the mount to above and to the right. Similarly, when looking to the south the OTA goes from below and to the right to above and to the left. In both these positions, the OTA will rise with further rotation in RA rather than fall, thus avoiding a collision. This is shown diagrammatically by the following diagrams:-



This is the situation just before a flip when crossing the southern meridian. The faint drawing in the background shows the position somewhat before the flip, with the telescope looking at a target to the east of the meridian. In order to track the target the mount is rotating around the RA axis in the direction shown by the arrow. If the OTA rotated much further than the position shown by the bold drawing there would be a strong likelihood of it crashing into the tripod. A meridian flip is thus required.



This is the position just after the flip. The telescope is still observing the same object but because its further rotation around the RA axis, again as shown by the arrow, will now take the OTA up & away from the tripod a collision has been avoided. The faint drawing shows the position a little later, with the target now across the meridian into the western part of the sky. Note that it is not necessary to wait until the OTA is below the level of the counter-weight to do the flip – it is often easier to carry it out at the point when the support shaft is level, as shown in these diagrams.

It should be clear from these diagrams that two operations need to be carried out to complete the flip – the mount must be rotated in Right Ascension (RA) to get the OTA on the other side of the tripod while the OTA is rotated in Declination (Dec.) to get it pointing at the same area of sky as before. These two operations are in principle separate movements but it can be found that, depending on the Declination of the target, in order to avoid the OTA striking the tripod during the flip (exactly what we are trying not to do!) the major part of the RA rotation must be done first, followed by the Dec. adjustment, and then the RA rotation completed. This issue is not inevitable, but one has to be ready for the possibility.

It should also be clear that the required amount of RA rotation is always the same – 12 hours exactly (i.e. 180°). To avoid the OTA striking the tripod, this rotation must be in the opposite sense to that in which the telescope was moving previously i.e. in an anti-clockwise direction (as viewed from the north-facing side of the tripod – the red "leg" in the diagrams above) when observing in the northern hemisphere. The amount of adjustment in Dec. is not so easy to determine however. The authors carried out extensive Internet searches in an attempt to find the correct procedure but drew a blank. The overwhelming majority of the "hits" were for automated methods only applicable to computerised mounts, and most of the others were for methods to avoid doing a flip in the first place. Those that gave any details of the Dec. rotation at all often just quoted a value of 180°, which it is easy to show is not correct. Worryingly, this fallacy was also stated in the instruction manual for the EQ3/EQ5 equatorial mount! This lack of information prompted the authors of this paper to determine from first principles what the correct value should be. This work is detailed in the next sections of the paper.

4. Re-discovering manual flips

Investigations proceeded in two very different directions. One of us (RF) tried a graphical approach while the other (SH) tried the practical.

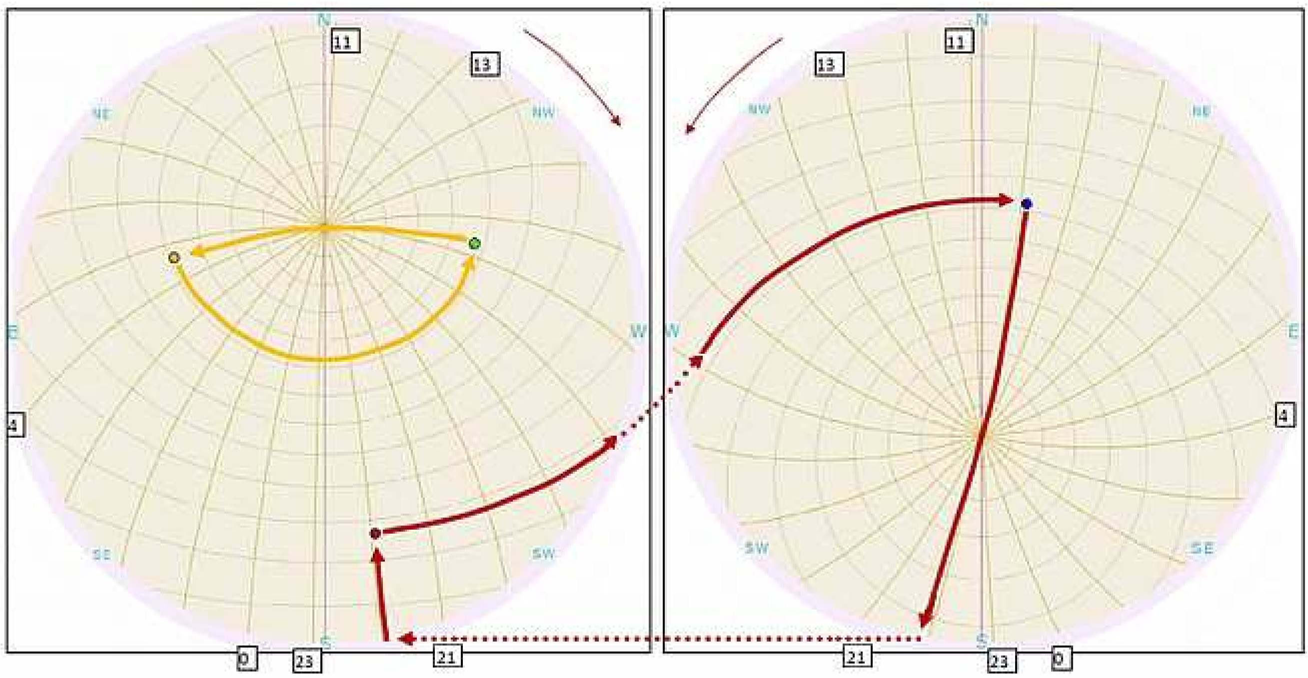
The graphical approach consisted in plotting on charts marked with RA and Dec. circles two points whose Right Ascensions differed by 12hrs but whose Declinations were the same. The trajectory required to go from one point to the other in RA and then back to the first one in Dec. (to mimic the operation of a flip) was then deduced. This was done for targets to both the north and the south.

The practical approach involved setting up an OTA plus mount indoors and experimenting with different flip procedures until one was found which achieved the required outcome. The amount & direction of adjustment in Dec. was then tabulated for various hypothetical target positions and a general formula deduced.

The results of these investigations are described and analysed on the following pages.

4.1 The graphical approach

The charts produced are shown below, created using planetarium software Stellarium v0.20.3, adjusted for the latitude & longitude of the observing station (Derby UK, approx 53.0°N 1.5°W), and set at 18:00UT on the date of the later test observations (10th December 2021). Each chart represents half of the "celestial sphere", the left one showing the dome of the sky above the observer (in the Northern hemisphere), the right one the sky below their feet, hidden from them by the Earth. Each chart is marked with a Right Ascension / Declination grid; the arrows at the top of the diagram indicate the direction in which RA increases for each of the charts. To avoid clutter, only selected values of RA are marked.



Looking first at the yellow trace on the left-hand chart, the yellow dot to the left represents the position of star 58 Persei, a target in the northern sky. The yellow arc below shows the effect of carrying out a 12hr rotation in Right Ascension, which takes you to the green dot on the right. The yellow arc above then shows the adjustment in Declination which must be made in order to get back to the original position i.e. to complete the flip.

Looking now at the red trace, which begins on the left-hand chart, the red dot above the arrowhead represents the position of Jupiter, a target in the southern sky. The doubly-curved red line leading away from Jupiter to the right shows the effect of carrying out a 12hr rotation in Right Ascension, which takes you to the blue dot in the top part of the right-hand chart. The red arc proceeding downwards from this dot, which then continues back onto the left-hand chart, shows the adjustment in Declination which must be made in order to get back to the original position i.e. to complete the flip.

It is easier to see what is going on with the yellow trace, which is that the rotation in Declination for a northerly target must be through the North Celestial Pole [the Dec = +90° point], and must end up at the same Dec. value on the other side of the Pole.

Careful examination of the red trace will show that the situation is in fact exactly the same for a southerly target except for the fact that the rotation must now be through the South Celestial Pole [the Dec = -90° point].

It is therefore possible to establish a straightforward rule for the adjustment in Declination:

If D is the original Declination of the target, rotate through the nearest Celestial Pole until you reach the same value of D on the other side of the Pole.

4.2 The practical approach

A number of arbitrary Declination values were chosen and, with the OTA pointing in a number of equally arbitrary Right Ascension directions to the north and to the south, the angle of the OTA was measured for each of the situations with a home-made inclinometer. The mount was then rotated by 12hr in Right Ascension and the Declination adjusted, in the direction requiring the minimum amount of rotation each time, until the OTA was at the same angle as before (and therefore aimed at the same hypothetical target). The new Declination was then read and compared with the original value.

When the results were checked, it was clear that everything was consistent with three formulae giving the required amount of rotation in Declination.

Where D is the original Declination these are:-

> For a target in the north: rotate anticlockwise (as see from the counter-weight) by (180 – 2D) degrees.
>
> For a target in the south: if D is positive, rotate clockwise by (180 – 2D) degrees. If D is negative rotate anticlockwise by (180 + 2D) degrees.

Only one formula is given for north because, from the UK, it is not practical to track negative Declination targets looking North.

4.3 Unifying the rules

Although the rules derived above look very different they are actually versions of the same rule but expressed in different ways. In fact, further analysis shows that they are somewhat more complicated than necessary. The term “nearest Celestial Pole” can be expressed more simply as “nearest 90 degree marker on the Declination setting circle”, removing the need to determine which marker represents which Pole. Furthermore, although it is less obvious, the “practical approach” rules can be simplified in the same way as in every case a rotation for the required angle in the specified direction will always move the Declination pointer from a given value through the nearest 90 degree marker until it reaches the same value on the other side.

We therefore end up with just one very simple rule which is that, irrespective of the Declination of the target or the meridian being crossed:-

If D is the original Declination of the target, rotate through the nearest 90 marker on the setting circle until you reach the same value of D on the other side of the marker

5. Testing the technique

Once the rule had been derived it was clearly necessary to verify it by testing it against actual astronomical targets. This was done by RF, imaging using an electronic viewfinder of his own design mounted on a manual German Equatorial mount. The procedure was simple: locate and image the target; perform a flip; image what the viewfinder now sees, and finally compare the two.

5.1 The targets

Four targets were selected upon which a “flip” would be executed. 23 Ursa Majoris (also known as Alhaud VI) & Jupiter were both near the meridian, one in the north & one in the south. The other two targets were well away from the meridian, Venus near the horizon & 58 Persei nearer the zenith. It was felt that such a choice would indicate the dependence (or otherwise) of the technique on sky position. The actual position of the targets in the sky is shown in the chart given in the Appendix to this paper (where 23UMa and 58Per are shown as Marker 1 & Marker 2 respectively)

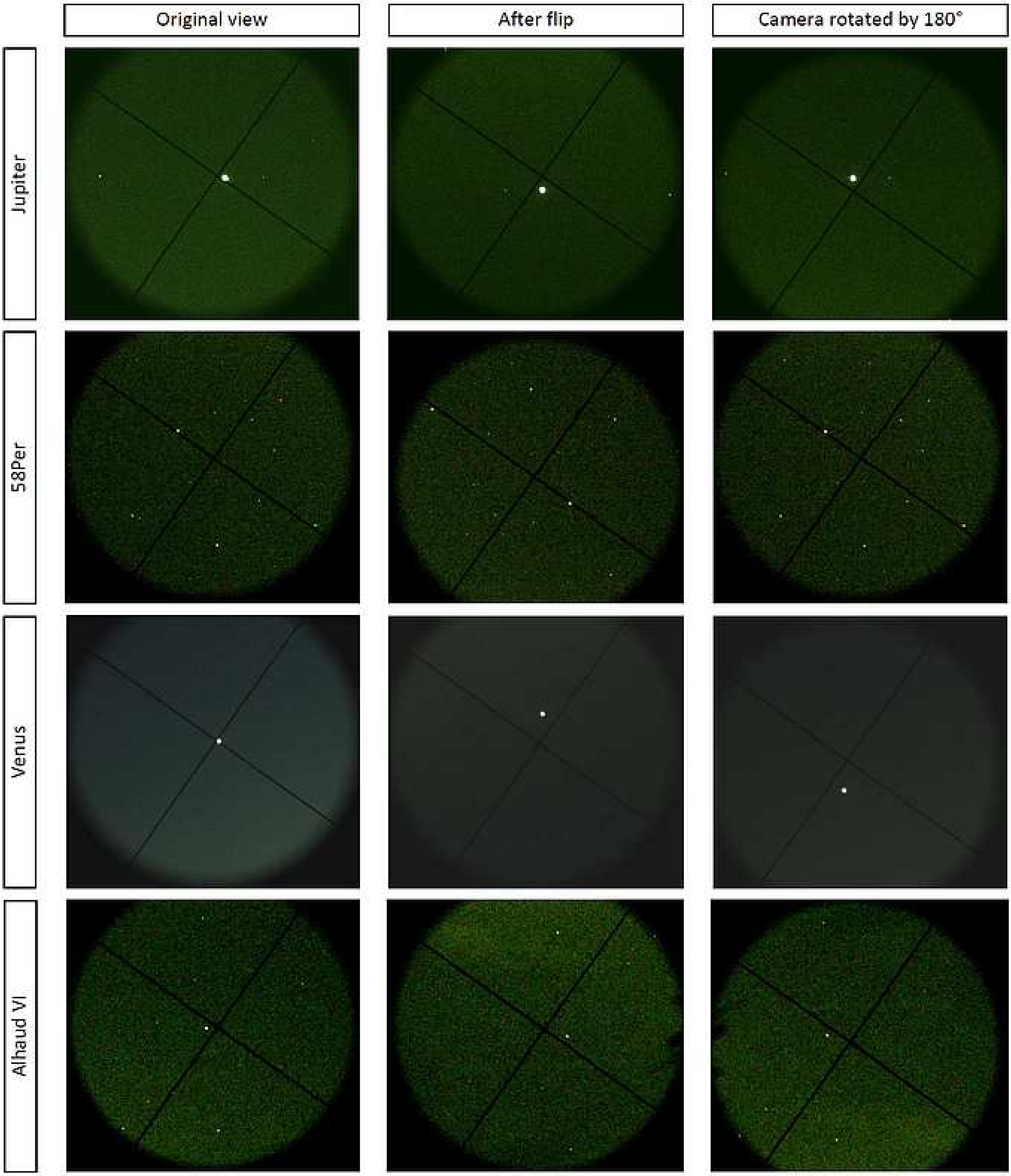
The RA & Dec. of each target are given in the table below, plus the reading from the Declination setting circle of the telescope at the time the tests were carried out (10th December 2021, 18:00 UT). The agreement of the measured and actual Declination values shows that no significant undetected discrepancies existed in the telescope mount alignment.

Target	**Right Ascension**	**Declination**	**Measured Dec.**
Jupiter	21hr 57min 30.19sec	-13° 32' 55.0"	-13.5°
58 Persei (Marker 2)	04hr 38min 11.66sec	+41° 18' 30.0"	+42.0°
Venus	19hr 49min 17.47sec	-22° 52' 38.9"	-22.5°
23 Ursa Majoris (Marker 1)	09hr 52min 31.21sec	+58° 56' 12.7"	+59.0°

The image captures are shown on the next page. The first two columns show the views before and after the flip, the third shows the “after” view rotated by 180° to compensate for the fact that by rotating by 12hrs in RA and adjusting in Dec. the OTA has itself been rotated by 180° along its long axis.

The images, and those on page 7, were captured using a home-built electronic viewfinder/imager of novel design, with a very wide field-of-view and good sensitivity. This makes it ideal for capturing images to be used during a “star-hopping” manoeuvre to verify the current position by either manual means or the use of plate-solving systems. Further details can be obtained by contacting Roger Firth at the email address given at the bottom of page 9.

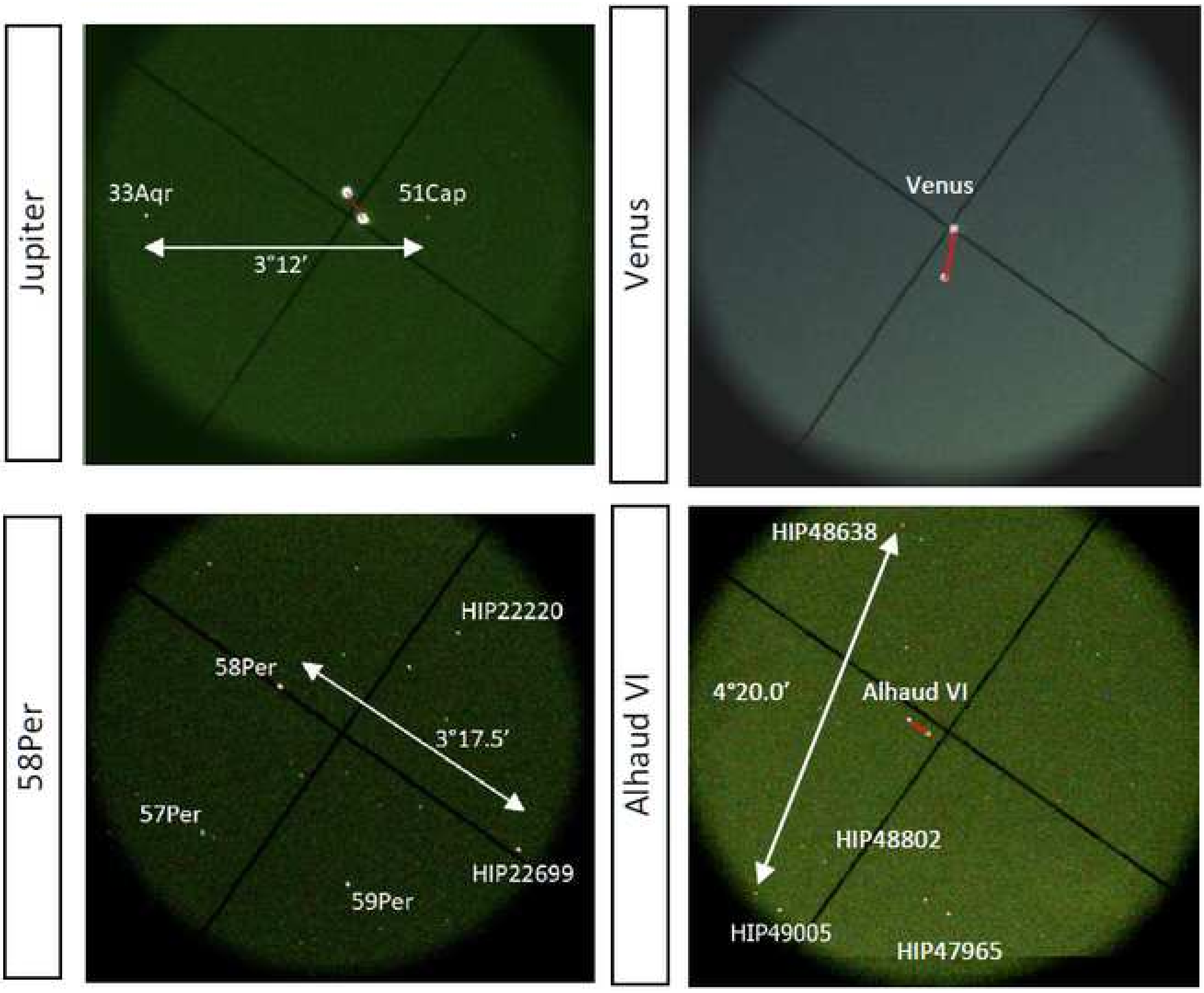
5.2 The images



By comparing the first and third columns it is clear that the procedure has achieved the desired aim: the telescope has been flipped while remaining directed towards the original target. By comparing the pointing error between the first & third images with the known distance between stars visible on the images an estimate of the error can be made – see below. This varies from 0.556° for Venus to a remarkable 0.018° for 58Per, giving an average error of 0.29° or 4.9% of the field-of-view: clearly, small enough for the flipped view to be easily recognised and re-centred. The residual error may be due to such things as inaccurate tripod levelling, inaccurate polar alignment, human errors in reading & operating setting circles, and sidereal rotation while the flip was in progress.

5.3 Calculating the re-positioning error

The detailed error calculations are given below. The images were created by overlaying those from columns 1 & 3 above, centred on the black optical crosshairs, and using the brightest pixels from each. Each image has been annotated, and the relevant data transferred to a spreadsheet.



	CalibrationStar				CalibArc		CalibArc								PosErr				PosErr			
Target	Ax	Ay	Bx	By	°	'	°	Px	1°= px	fov Lx	fov Ly	fov Rx	fov Ry	fov°	Ax	Ay	Bx	By	px	°	'	%fov
Jupiter	328	338	584	340	3	12	192	256.0	80.0	275	335	730	341	5.7	239	151	253	174	26.9	0.336	20.2	5.7
58Per	449	738	665	887	3	17.5	197.5	262.4	79.7	311	195	698	466	5.9	178	573	179	574	1.4	0.018	1.1	0.3
Venus										45	64	440	342	6.0	244	252	251	208	44.6	0.556	33.4	9.4
Alhaud VI	206	470	79	796	4	20	260	349.9	80.7	46	510	445	793	6.1	211	642	227	654	20.0	0.250	15.0	4.2
Avg									80.2					5.9							17.4	4.9

The left green region shows, for each target, the pixel coordinates for each calibration star & the theoretical arc separation of the two calibration stars. The next pink boxes show the calculated "pixels per degree" ratios. The next green boxes list the pixel coordinates for the upper left and lower right intersections of the black crosshairs with the edge of the circular field of view. The next pink column shows the calculated field of view. The final set of green boxes show the pixel coordinates of the two targets separated by the red pointing error lines. The final pink section shows the re-pointing error in various units. At the bottom of the sheet, various averages are calculated.

5.4 Conclusion

Given the highly successful outcome of these tests, the authors were confident that the procedures they had discovered were correct.

6. The procedure in detail

So, in step-by-step form, to carry out a Meridian Flip one must:-

1) Note the current RA value, unlock the RA clutch & RA setting circle, and set the RA circle to exactly 0 hrs. This makes rotating by exactly 12hrs much easier.
2) Rotate the mount anti-clockwise (as seen from the north) in RA until the setting circle reads exactly 12hrs, or a large fraction of that if the problem alluded to in the first paragraph of this section is anticipated.
3) Lock the RA clutch & setting circle.
4) Note the current Dec. value and unlock the Dec. clutch.
5) Rotate the mount in Dec. by the correct amount in the appropriate direction, then lock the Dec. clutch.
6) Unlock the RA setting circle.
7) If the full RA rotation was not carried out at 2), unlock the RA clutch and complete the full 12 hours of rotation. Lock the RA clutch.
8) Reset the RA circle to the value noted in 1) and lock the circle.

And that completes the flip. If you are using a finderscope or eyepiece, the field of view should now be identical to that before the flip. As mentioned above, in practice it will probably be slightly out but the error should be small (±0.2°), and easily compensated for.

Note however that, as shown in the test images above, the image will be rotated by 180° and so if you are using a camera you will need to either rotate the camera or apply a rotation in the capture software to restore the same view as before.

7. Other applications of the flip

While the usual reason for needing to apply a flip is transit across the meridian, its use is not limited to near the meridian, nor does the procedure vary depending upon location in the sky, and so it can be useful in other situations where the physical orientation of the telescope setup is important. Amongst its applications are; making finderscopes easier to use by reducing the use of ladders and physical contortions of one's neck & back, making the main OTA easier to use (in a similar manner), and enabling heavy cameras and associated cabling to be more easily accommodated. These can all be potentially improved using the technique, not to mention the improvements to operator safety also achieved.

8. Final conclusions

Our researches amongst local, national & international astronomy institutions, both online and by personal email communication, revealed not one single individual who is cognisant of these procedures. The same applies to professional astronomy authors. This is not to say that there is no-one who remembers it, but it does suggest that few know the correct procedure. Given that it underpins much modern automated guidance software, and the fact that it is a simple procedure, we feel it should be made more widely available for amateur astronomers to use, especially those on a tight budget.

We feel it is important to make it clear that the Meridian Flip is not merely a component of automated tracking systems but is a simple technique in its own right, available to anyone with a German Equatorial Mount. As we have intimated, its use is not limited to near the meridian, nor does the procedure vary depending upon location in the sky.

Lastly, the whole point of this exercise was to rescue a "lost" technique, which we feel we have done.

9. Summary

To carry out a manual Meridian Flip one must, irrespective of the declination of the target being viewed or the meridian being crossed:

1) Rotate the telescope in Right Ascension by exactly 12hrs.

2) Adjust the Declination of the telescope by an amount given by the following very simple Rule:-

If D is the original Declination of the target, rotate through the nearest 90 marker on the setting circle until you reach the same value of D on the other side of the marker.

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10. Acknowledgments

We are grateful to the astronomers who were prepared to discuss this work with us, not least to Brother Guy Consolmagno, S.J., President of the Vatican Observatory, for his generous support.

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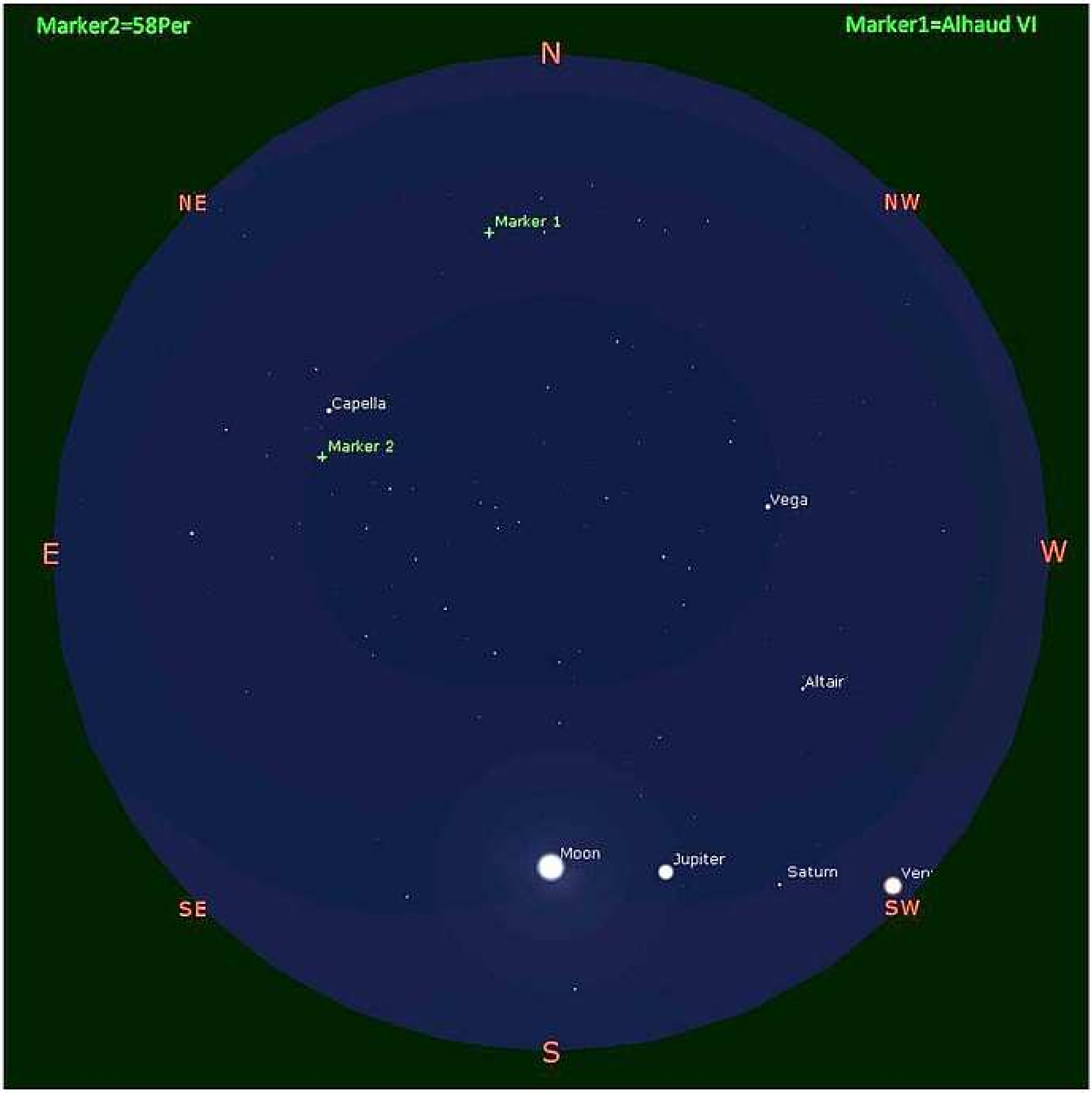
APPENDIX



The chart above shows the sky location of the four targets mentioned in the paper, together with other celestial objects of interest. As with the other charts and data, it is set to show the situation as seen from the observing location (Derby, UK) on the date of the test observations (10th December 2021, 18:00 UT).