# ON THE ABSOLUTE ALIGNMENT OF GONG IMAGES

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## ABSTRACT

In order to combine data from the six instruments in the GONG network the alignment of all of the images must be known to a fairly high precision ($\sim 0^\circ.1$ for GONG classic and $\sim 0^\circ.01$ for GONG+). The relative orientation is obtained using the angular cross-correlation method described by (Toner & Harvey, 1998). To obtain the absolute orientation the Project periodically records a day of drift scans, where the image of the Sun is allowed to drift across the CCD repeatedly throughout the day. These data are then analyzed to deduce the direction of Terrestrial East-West as a function of hour angle (i.e., time) for that instrument.

The transit of Mercury on Nov. 15, 1999, which was recorded by three of the GONG instruments, provided an independent check on the current alignment procedures. Here we present a comparison of the alignment of GONG images as deduced from both drift scans and the Mercury transit for two GONG sites: Tucson (GONG+ camera) and Mauna Loa (GONG Classic camera). The agreement is within $\sim 0^\circ.01$ for both cameras, however, the scatter is substantially larger for GONG Classic: $\sim 0^\circ.03$ compared to $\sim 0^\circ.01$ for GONG+.

Key words: Mercury transit; drift scans; Sun; alignment.

## 1. INTRODUCTION

The GONG telescope design is such that the solar image rotates during the day. To compensate, and prevent smearing of the recorded image, the CCD is mounted on a "camera rotator". In principle, the required camera rotation rate can be calculated, and the camera rotator can be programmed to track the rotation of the solar image such that solar north is fixed along the row direction. In practice, misalignments of the telescope structures and optical elements lead to a residual rotation that is not accounted for in the calculation. The Project uses drift scans to measure this residual rotation.

## 2. DRIFT SCANS

Drift scans are obtained via the following procedure:

1. Using the latest estimated directions, rotate the CCD to place Terrestrial East-West along the diagonal, thus maximizing the length of the drift-line.
2. Offset the solar image to place the north limb of the Sun at the eastern corner of the CCD.
3. Turn off the camera rotator and telescope tracking.
4. Record four 1-minute integrations as the solar image drifts across the CCD.
5. Re-acquire the Sun at the center of the CCD.
6. Repeat steps 1-4, this time using the south limb of the Sun.
7. Re-acquire the Sun at the center of the CCD.
8. Continuously repeat entire process for the rest of the day.

The analysis of the drift scans proceeds as:

1. Dark and clamp correct each drift image, then co-add each set of four (see Figure 1).
2. Using standard edge detection techniques, find the drift line.
3. Fit the drift line and determine its angle, $\alpha$, relative to the assumed east-west line.
4. Apply corrections for refraction (see Figure 2) using the following formula (Woolard & Clemence, 1996, pp 94):

$$d\alpha = k \tan z \, \{\cos q \, \frac{\sin q \tan z - tan\Delta}{1 + \sin q \tan z \tan \Delta} + \tan \delta \sin q\}$$

where:

$d\alpha$ is the angle needed to correct for refraction

$k$ is the refraction constant in degrees given by:

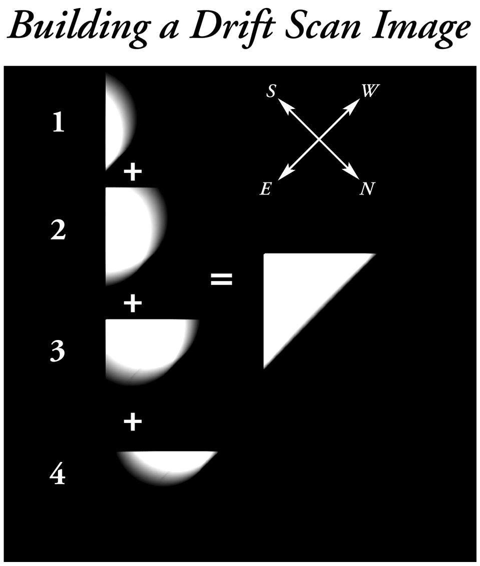


*Figure 1. "Schematic" showing how a drift image is generated.*

$$k = 60.4(P/(1013.25 * (0.962 + 0.038 * T)))/3600$$

with:

P = the barometric pressure in millibars

T = the outside temperature in degrees C

$z$ is the Sun's Zenith distance

$q$ is the Sun's Parallactic angle

$\delta$ is the Sun's declination

$\Delta$ is the "distance" between the Sun at minute 4 relative to the Sun at minute 1 of a drift scan image set.

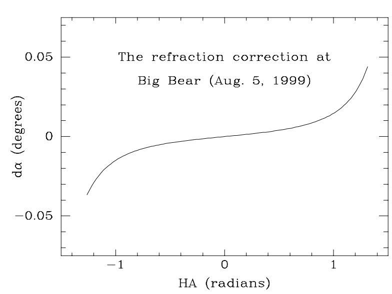


*Figure 2. An example of the refraction correction at Big Bear.*

5 Finally, since the Sun's declination changes during the time it takes to record a drift scan image, the drift-line will not, in general, be exactly east-west. Therefore, a correction for this must be computed and applied to the drift scan results (see Figure 3).

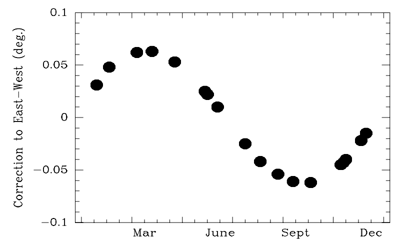


*Figure 3. This plot shows how the east-west correction varies during the year.*

## 3. THE TRANSIT OF MERCURY

The transit of Mercury on Nov. 15, 1999 was recorded by three of the GONG instruments: Tucson (GONG+ camera), Big Bear (GONG Classic camera), and Mauna Loa (GONG Classic camera). Since drift scans were obtained at Mauna Loa on Nov. 13/14 1999 and at Tucson on Nov. 16, 1999 data from these two sites were processed. Sample images are shown in Figure 4.

The images were processed using the following procedure:

1 Process drift scan images to determine the direction of Terrestrial East-West. Combine this with the "known" Solar P-angle to obtain the direction of Solar North in the observed images.

2 Dark, clamp and flat-field the solar images recorded just before, during, and just after the Mercury transit.

3 Determine the image geometry using the GRASP tasks GEOM and HGEOM. This combination of routines provides estimates for the image shapes, sizes, and positions to within $\sim 0.01$ pixel (see Toner & Jefferies, 1993).

4 Perform an image restoration using the algorithm described in Toner, Jefferies, & Duvall 1997. NOTE: During this step the GONG classic images were Fourier interpolated by a factor of four.

5 Register the images to a common shape, size and orientation. (Assuming the drift scan results are correct, place Solar North at the top, Solar East on the left)

6 Average images from before and after the transit (i.e., Mercury-free images) to produce a "clean" reference image.

7 Use the Mercury-free reference image to remove the limb-darkening from each image with Mercury transiting the disk (2nd $\rightarrow$ 3rd contact).

8 Compute the angle between the line passing through the center of the solar disk and solar north and the line passing through the center of the solar disk and the center of Mercury's disk for each minute. This is the "measured" angle.

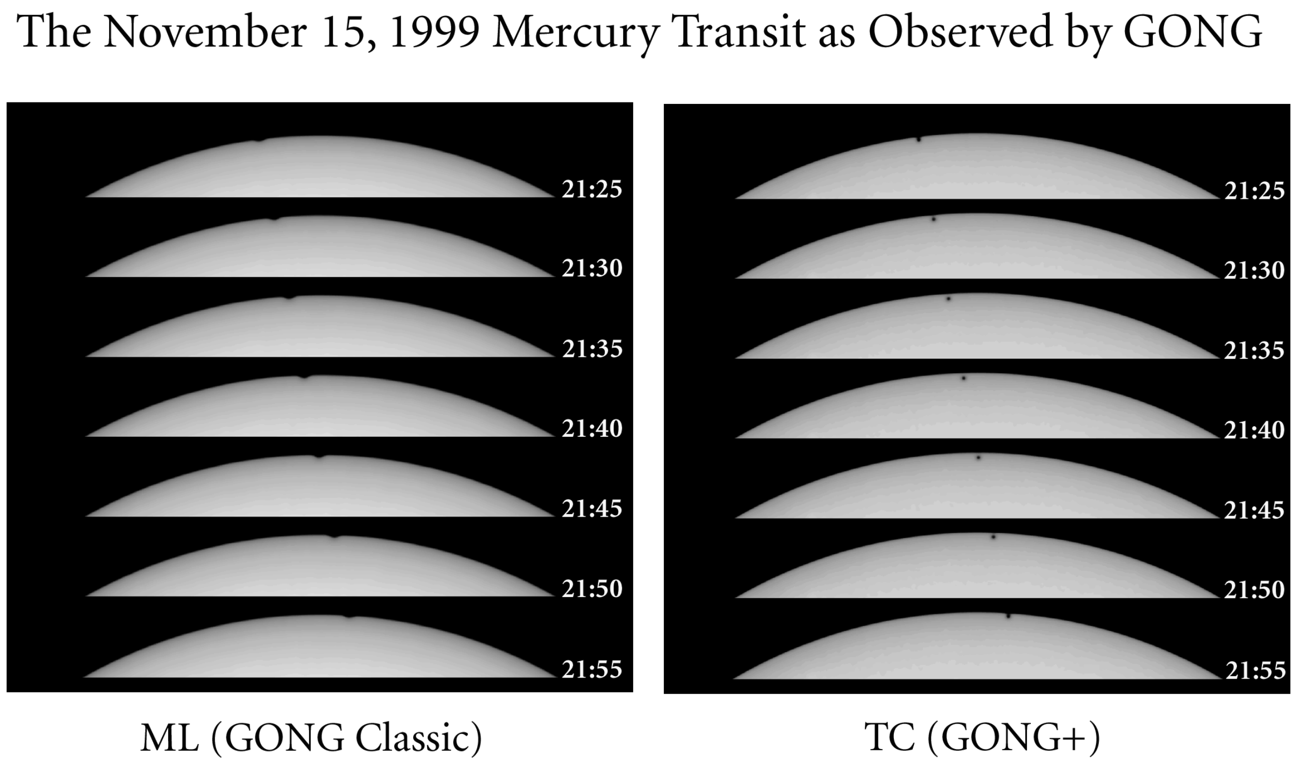


*Figure 4. The November 15, 1999 Mercury transit as recorded at ML (left panel) and TC (right panel). The UT time is shown along the left-hand side of each panel. Solar North is at the top, Solar East on the left.*

9 Obtain ephemerides for the Sun and Mercury using JPL's Web based **Horizons** program found at:

**http://ssd.jpl.nasa.gov/horizons.html**

10 Compute the P-angle for Mercury using the ephemerides and the following set of equations from Woolard & Clemence, 1966, pp 25-26:

$$cosP\ sin\Delta \ = \ cos\delta_\odot\ sin\delta_M - cos(\alpha_M - \alpha_\odot)\ sin\delta_\odot\ cos\delta_M$$

$$sinP\ sin\Delta \ = \ sin(\alpha_M - \alpha_\odot)\ cos\delta_M$$

$$cos\Delta \ = \ sin\delta_\odot\ sin\delta_M + cos(\alpha_M - \alpha_\odot)\ cos\delta_\odot\ cos\delta_M$$

where:

$P$ is the position angle of Mercury

$\alpha_\odot$ & $\delta_\odot$ are the Right Ascension and Declination of the center of the solar disk.

$\alpha_M$ & $\delta_M$ are the Right Ascension and Declination of the center of Mercury's disk.

$\Delta$ is the distance between Sun-center and Mercury-center.

11 Correct for the Solar P-angle, giving the "predicted" angle.

12 Compare measured and predicted angles.

## 4. RESULTS

The final results comparing the measured and predicted angles are tabulated in Table 1 for TC and Table 2 for ML.

The bottom line:

**Mean difference TC:** $0^\circ.010 \pm 0^\circ.009$

**Mean difference ML:** $0^\circ.013 \pm 0^\circ.030$

## 5. DISCUSSION

This investigation spurred a complete re-write of the drift scan analysis code. The code is much more robust now, can process both GONG Classic and GONG+ drift scans and has incorporated the correction for the Sun's changing declination during the recording of drift scan images.

Other changes that resulted from this investigation include:

- Improvements to the angular cross-correlation code which determines the relative rotation angle between simultaneous images recorded at different sites. The revised code can now work with a mixture of GONG+ and GONG Classic data (which is needed during the deployment phase of GONG+). Also, when using only

*Table 1. The Measured and Predicted Angles for TC (GONG+ camera)*

| UT HH:MM | Measured (Deg.) | Predicted (Deg.) | Difference (Deg.) |
|---|---|---|---|
| 21:25 | 6.986 ± 0.018 | 6.976 | 0.010 |
| 21:26 | 6.629 ± 0.019 | 6.623 | 0.007 |
| 21:27 | 6.266 ± 0.018 | 6.269 | -0.002 |
| 21:28 | 5.922 ± 0.019 | 5.914 | 0.008 |
| 21:29 | 5.563 ± 0.019 | 5.560 | 0.003 |
| 21:30 | 5.206 ± 0.019 | 5.205 | 0.001 |
| 21:31 | 4.840 ± 0.019 | 4.849 | -0.009 |
| 21:32 | 4.497 ± 0.019 | 4.494 | 0.003 |
| 21:33 | 4.151 ± 0.019 | 4.138 | 0.013 |
| 21:34 | 3.787 ± 0.019 | 3.782 | 0.005 |
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| 21:35 | 3.445 ± 0.019 | 3.426 | 0.019 |
| 21:36 | 3.084 ± 0.019 | 3.070 | 0.014 |
| 21:37 | 2.731 ± 0.019 | 2.713 | 0.018 |
| 21:38 | 2.357 ± 0.019 | 2.357 | 0.000 |
| 21:39 | 2.023 ± 0.019 | 2.000 | 0.023 |
| 21:40 | 1.640 ± 0.019 | 1.644 | -0.004 |
| 21:41 | 1.287 ± 0.019 | 1.287 | 0.000 |
| 21:42 | 0.938 ± 0.019 | 0.931 | 0.007 |
| 21:43 | 0.589 ± 0.019 | 0.574 | 0.015 |
| 21:44 | 0.229 ± 0.019 | 0.218 | 0.011 |
| 21:45 | -0.127 ± 0.019 | -0.139 | 0.012 |
| 21:46 | -0.487 ± 0.019 | -0.495 | 0.008 |
| 21:47 | -0.837 ± 0.019 | -0.851 | 0.014 |
| 21:48 | -1.201 ± 0.019 | -1.207 | 0.006 |
| 21:49 | -1.554 ± 0.019 | -1.563 | 0.009 |
| 21:50 | -1.900 ± 0.020 | -1.918 | 0.019 |
| 21:51 | -2.257 ± 0.020 | -2.274 | 0.017 |
| 21:52 | -2.617 ± 0.020 | -2.629 | 0.011 |
| 21:53 | -2.975 ± 0.019 | -2.983 | 0.008 |
| 21:54 | -3.323 ± 0.020 | -3.338 | 0.015 |
| 21:55 | -3.671 ± 0.019 | -3.692 | 0.021 |
| 21:56 | -4.025 ± 0.019 | -4.045 | 0.020 |
| 21:57 | -4.374 ± 0.019 | -4.398 | 0.025 |
| 21:58 | -4.734 ± 0.019 | -4.751 | 0.017 |

*Table 2. The Measured and Predicted Angles for ML (GONG Classic camera)*

| UT HH:MM | Measured (Deg.) | Predicted (Deg.) | Difference (Deg.) |
|---|---|---|---|
| 21:25 | 7.163 ± 0.032 | 7.117 | 0.0459 |
| 21:26 | 6.808 ± 0.030 | 6.765 | 0.0434 |
| 21:27 | 6.429 ± 0.031 | 6.412 | 0.0168 |
| 21:28 | 6.103 ± 0.032 | 6.059 | 0.0439 |
| 21:29 | 5.753 ± 0.032 | 5.705 | 0.0474 |
| 21:30 | 5.377 ± 0.031 | 5.351 | 0.0258 |
| 21:31 | 5.032 ± 0.033 | 4.997 | 0.0344 |
| 21:32 | 4.702 ± 0.031 | 4.643 | 0.0592 |
| 21:33 | 4.307 ± 0.031 | 4.288 | 0.0194 |
| 21:34 | 3.969 ± 0.032 | 3.933 | 0.0357 |
| 21:34 | 3.969 ± 0.032 | 3.933 | 0.0357 |
| 21:35 | 3.626 ± 0.032 | 3.578 | 0.0481 |
| 21:36 | 3.246 ± 0.031 | 3.223 | 0.0229 |
| 21:37 | 2.899 ± 0.032 | 2.867 | 0.0315 |
| 21:38 | 2.558 ± 0.032 | 2.512 | 0.0464 |
| 21:39 | 2.187 ± 0.030 | 2.156 | 0.0306 |
| 21:40 | 1.820 ± 0.032 | 1.801 | 0.0198 |
| 21:41 | 1.491 ± 0.033 | 1.445 | 0.0459 |
| 21:42 | 1.124 ± 0.030 | 1.089 | 0.0350 |
| 21:43 | 0.740 ± 0.031 | 0.734 | 0.0066 |
| 21:44 | 0.378 ± 0.032 | 0.378 | -0.0004 |
| 21:45 | 0.050 ± 0.031 | 0.023 | 0.0271 |
| 21:46 | -0.332 ± 0.030 | -0.333 | 0.0005 |
| 21:47 | -0.712 ± 0.031 | -0.688 | -0.0238 |
| 21:48 | -1.033 ± 0.032 | -1.043 | 0.0105 |
| 21:49 | -1.392 ± 0.030 | -1.398 | 0.0062 |
| 21:50 | -1.788 ± 0.031 | -1.753 | -0.0356 |
| 21:51 | -2.123 ± 0.032 | -2.107 | -0.0161 |
| 21:52 | -2.452 ± 0.030 | -2.461 | 0.0095 |
| 21:53 | -2.849 ± 0.031 | -2.815 | -0.0344 |
| 21:54 | -3.208 ± 0.032 | -3.168 | -0.0393 |
| 21:55 | -3.531 ± 0.031 | -3.521 | -0.0091 |
| 21:56 | -3.910 ± 0.030 | -3.874 | -0.0360 |
| 21:57 | -4.279 ± 0.031 | -4.227 | -0.0529 |
| 21:58 | -4.602 ± 0.032 | -4.578 | -0.0234 |

GONG+ data, simulations indicate that the relative angle between images can be determined to better than 0.01 degrees.

- The routine which determines an optimal solution for the camera offset equations simultaneously for all sites has been updated. The new code can now use the results of multiple drift scans at different sites and will force the rest of the Network to be consistent with these.

- Tests are under way to investigate the possibility of doing regular drift scans remotely from Tucson in order to provide more frequent "reality" checks on GONG's alignment. We are also investigating the effectiveness of doing noon drifts at every site weekly or bi-weekly.

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