Astronomical Output Analysis for the GoRhyme Product

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The analysis focused on evaluating the astronomical consistency of the verification data provided for the GoRhyme Star Chart product. To do this, three levels of information were compared: the values included in the Excel files sent by Kelly, the results recalculated by our scripts, and, when possible, independent external references obtained manually with Stellarium Web and NASA JPL Horizons.

The comparison was not framed as a search for perfect numerical agreement, but as an assessment of accuracy applied to the actual use of the product. GoRhyme Star Chart does not deliver tables to the final user: it generates a printed star chart from a date, a time, and a location. Therefore, the important point is to determine whether the detected differences could visibly or significantly affect the position of stars, planets, and the Moon within the chart, or whether they remain within a reasonable margin for an art product with an astronomical basis.

For this reason, two levels of interpretation must be separated. First, the numerical difference: how far the script is from the Excel file or from an external reference. Second, the visual impact: whether that difference would perceptibly change the position of a star, a planet, or the Moon in the final chart.

Difference Calculation

For stars, azimuth and altitude were compared. Altitude was calculated using a simple absolute difference:

$$\Delta h = |h_{\text{cal}} - h_{\text{ref}}|$$

For azimuth, a circular angular difference was used because azimuth runs from 0° to 360°. This avoids artificial errors when one value is near 359° and the other is near 0°:

$$\Delta A = |((A_{\text{cal}} - A_{\text{ref}} + 180^\circ) \bmod 360^\circ) - 180^\circ|$$

Angular separation was also calculated, combining azimuth and altitude into a single geometric measure. This measure is useful because it summarizes the real distance between two positions in the sky:

$$\Delta\theta = \cos^{-1}\left[\sin(h_{\text{cal}})\sin(h_{\text{ref}}) + \cos(h_{\text{cal}})\cos(h_{\text{ref}})\cos(A_{\text{cal}} - A_{\text{ref}})\right]$$

This equation gives the angular separation between the calculated position and the reference position on the celestial sphere. Here, h is altitude and A is azimuth. The subscripts cal and ref refer to the calculated value and the reference value. The result, $\Delta\theta$, is a single angular error that combines both azimuth and altitude differences into one geometric measure.

For planets and the Moon, the same azimuth and altitude differences were used, together with absolute differences for illuminated percentage, phase angle, and apparent magnitude. The current tolerances are: 0.5° for azimuth and altitude, 1% for illumination, 1° for phase, and 0.1 magnitudes for apparent magnitude.

Star Results

For stars, the automatic analysis worked with 28 cases. Of these, 27 correspond to evaluable stars and 1 corresponds to a special catalog case, HIP 0, which does not represent a real star and is therefore documented separately.

Of the 27 evaluable cases, 22 passed the automatic validation and 5 were marked as FAIL. The passing cases show very solid results: the average angular separation was approximately 0.000954°, equivalent to about 3.4 arcseconds. The worst approved case had an angular separation of approximately 0.005549°, about 20 arcseconds. These values are far below the defined tolerance of 0.1°.

This means that, for most of the verified stars, the script not only remains within tolerance, but does so with a wide margin. For a printed star chart, differences of this size should not be visually relevant.

The cases marked as FAIL are cases 8, 21, 24, 25, and 26. In these cases, the average angular separation is approximately 0.423°, and the maximum reaches 0.584°. These values exceed the 0.1° tolerance, which is why they appear as automatic failures.

However, the manual review with Stellarium Web changes the interpretation of several of these FAIL cases. In case 8, Polaris in Sydney, Stellarium Web is much closer to the script than to the Excel file. The main difference is in the expected altitude from the Excel file. This suggests that the issue is probably in the expected reference value, not in the script calculation. It should also be mentioned that Stellarium Web does not allow entering latitude and longitude directly, only a city name.

Something similar occurs in case 21, Canopus in Singapore. Stellarium Web is close to the script and far from the Excel file in altitude. This again indicates that the expected Excel value may be shifted or calculated under a different configuration.

In case 25, Canopus in Samoa, Stellarium Web is also much closer to the script than to the Excel file. The difference relative to the Excel file is large, while the difference relative to the script decreases substantially. This again points to a discrepancy in the reference or in the original configuration.

Case 24, Vega in Bethlehem with a negative year, remains pending for stronger external validation because Stellarium Web did not allow the BCE year to be loaded correctly. This case should not be used as final evidence against the script without checking it with a tool that correctly handles BCE dates.

Case 26, Canopus in Tonga, also requires caution because the manual comparison with Stellarium Web did not use exactly the same coordinates as the Excel file. When coordinates change, especially for low stars or for sensitive areas of the sky, altitude can change substantially. Therefore, this case should not be interpreted as a clean comparison until the exact location is confirmed.

Interpretation for Stars

The Excel results for stars are mostly consistent with the verifications performed. Most cases remain well within the defined tolerance, indicating that the azimuth and altitude positions included in the Excel file are adequate for the objective of the product. In the cases marked as FAIL, the differences appear to be concentrated in specific situations: some cases depend strongly on the exact observer location, and Stellarium Web does not always allow precise coordinates to be entered, but may instead use a city or approximate location. This can shift the observed altitude, especially for stars close to the celestial pole or objects low above the horizon. In addition, in some cases Stellarium Web is closer to the values calculated by the script than to the values in the Excel file, suggesting that these discrepancies do not necessarily indicate a problem with the Excel file.

Planet and Moon Results

For planets and the Moon, the Excel file *Planet and Moon Chart.xlsx* was used. It contains 15 cases with several numerical properties per case. At this stage, the analysis focuses on the variables relevant to the current product: azimuth, altitude, illuminated percentage, and phase angle. Since the product does not currently focus on apparent magnitude, that variable is excluded from the main interpretation.

No case exceeds the defined tolerance in azimuth, altitude, illuminated percentage, or phase angle. The maximum errors against the Excel file were approximately 0.0054° in azimuth, 0.4191° in altitude, 0.0458% in illumination, and 0.1344° in phase. All these values remain within the tolerances used for planets and the Moon: 0.5° for position, 1% for illumination, and 1° for phase.

This means that, according to the Excel file and the current criterion, the planets and the Moon are correctly positioned. Illumination and lunar phase also remain within tolerance, which is important because the Moon phase has a direct visual impact on the chart. The observed differences do not appear large enough to compromise the artistic representation of position or phase.

The manual comparison with NASA JPL Horizons reinforces this interpretation. Against Horizons, the script shows very small average errors: approximately 0.00078° in azimuth, 0.00056° in altitude, 0.0057% in illumination, and 0.0645° in phase. These values indicate very strong agreement with an independent external reference for topocentric position and phase.

In some cases, the Excel file is farther from Horizons than the script, especially in altitude. The average Excel–Horizons altitude error is approximately 0.086°, while the average script–Horizons altitude error is approximately 0.00056°. Even so, those Excel differences remain within the tolerance defined for the product, so they do not represent an important visual problem for a printed star chart.

The general reading is that the planet and Moon data are adequate for the objective of the product when the variables that matter at this stage are evaluated: position, illumination, and phase. Apparent magnitude can be reviewed later if the final design decides to use it to control the relative size or brightness of the planets, but it should not affect the main conclusion about astronomical position and lunar phase.

General Conclusion

Overall, the verification results support the astronomical consistency of the data reviewed for the GoRhyme product. The variables that are most important for the visual output of the chart, namely azimuth, altitude, lunar illumination, and lunar phase, remain within the defined tolerances in the great majority of the evaluated cases.

For the star data, most cases show very small angular separations, far below the tolerance of 0.1°. These differences are not expected to be visually meaningful in a printed chart. The few cases marked as FAIL appear to be concentrated in specific situations involving reference values, approximate locations in Stellarium Web, BCE date handling, or coordinate sensitivity. They should be reviewed individually, but they do not indicate a general failure of the verification data.

For the planet and Moon data, all evaluated cases remain within tolerance for the variables used in the current analysis: azimuth, altitude, illuminated percentage, and phase angle. The comparison with NASA JPL Horizons also supports the accuracy of the topocentric positions and phase-related values. This is especially relevant because the Moon phase and the placement of visible planets directly affect the visual credibility of the final chart.

Based on these results, the data reviewed are suitable for supporting the astronomical accuracy of the product in its current intended use. The product can be considered well positioned for an artistically accurate printed star chart, provided that the few flagged cases are treated as specific review points rather than as evidence of a broader problem.