Draft version October 31, 2019
Typeset using LaTeX **twocolumn** style in AASTeX62

A Measurement of the Distance to Pluto

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1. OBSERVATIONS

Pluto was observed under spectroscopic conditions on UT 2019 September 23 and 24 with the 1 m Nickel Telescope at Lick Observatory. The Nickel was configured with its Direct Imaging Camera—observational parameters are summarized in Table 1.

Images were taken with the Direct Imaging Camera's V-band filter (4700–6300 Å) and the telescope's 6'.3×6'.3 field of view was pointed at the same coordinates on both nights. Each exposure used an integration time of 15 s and was read from the Direct Imaging Camera's CCD-2 with 2x2 binning in the slow readout mode. The integration time was chosen to keep observations efficient, given the detector's ~ 20 s readout time.

Observing conditions were not photometric, but sufficient for our purposes. Scattered cirrus clouds were present on UTC 2019 September 23; the following night was cloud free, and seeing improved slightly. Typical seeing on the Nickel Telescope is about 2".

Before the first night of observations, bias, dark, and (dome) flat frames were taken using the Direct Imaging Camera's CCD-2 in the same configuration as the science images. These calibration images were used for both nights during the data reduction.

Table 1. Summary of the Direct Imaging Camera observations of Pluto.

Date (UT)	2019 Sept 23	2019 Sept 24
Filter	V	V
Airmass	1.98	1.99
Number of images	10	8
Exp. time per image (s)	15	15

Note—The airmass reported here is as measured at the start of the first observation for that night.

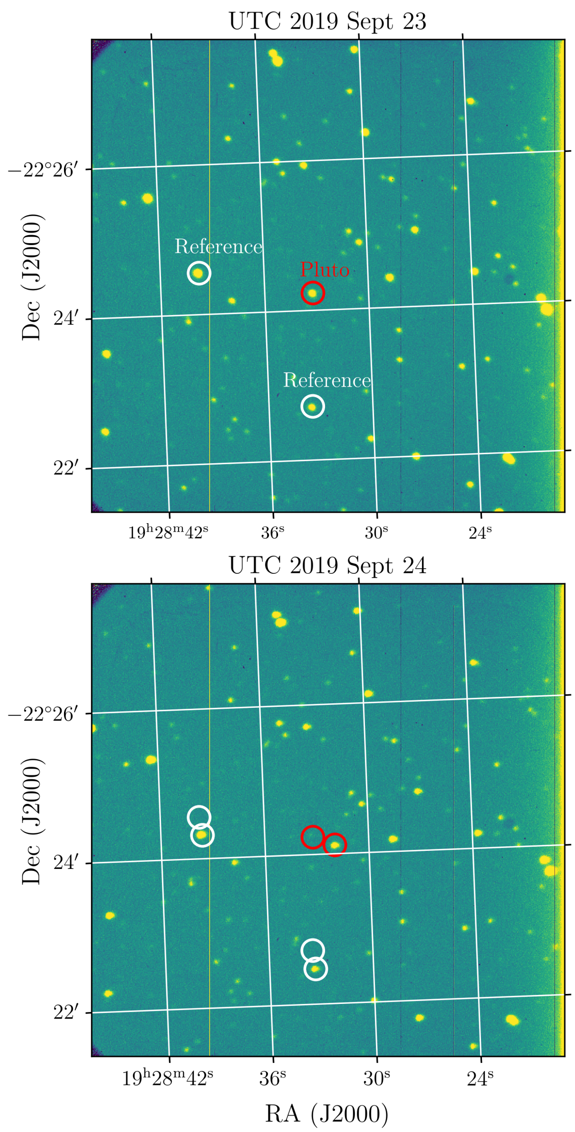

Figure 1. Pluto's displacement is visible by comparing the reduced science images from UTC 2019 September 23 (top) and 24 (bottom). Two reference stars are circled in white to make it clear that pointing error alone cannot account for Pluto's displacement. The locations of the circles from the first image are replicated on the second to show the shifts of each object.

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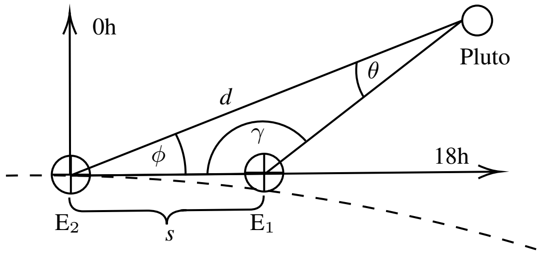

Figure 2. A schematic of Pluto's distance calculation. Earth's location on UTC 2019 September 23 and 24 is labeled by the circled crosses E_1 and E_2, respectively. θ is Pluto's (measured) angular displacement between the two nights of observations. Note that the relative length of s is large in this schematic to make it easier to view, but $s \ll d$.

2. DATA REDUCTION

The raw science images for each night were median combined, dark and bias subtracted, and flat-fielded. Figure 1 compares the reduced images from each night. Note that the telescope was pointed at the same field, but a slight pointing error of about 7".3 is visible in the shift of background stars from night to night.

The coordinates of background stars and Pluto were determined using the `centroid` feature in DS9 (Joye & Mandel 2003). Accounting for the pointing offset, we find Pluto's angular displacement between night 1 and 2, θ, is 20".5.

3. ANALYSIS AND RESULTS

We calculate the distance to Pluto, d, following the schematic in Figure 2. This analysis assumes that Pluto's movement in its orbit is negligible compared to Earth's. We also approximate the arc traveled by the Earth between the two nights, labeled s in Figure 2, to be linear.

Using the law of sines, the distance is given by

$$d = s\frac{\sin(\gamma)}{\sin(\theta)}, \quad (1)$$

where $\gamma = \pi - \theta - \phi$, and $\phi = 0.38$ rads, or 1h 28m 31.8s of right ascension, as measured on UTC 2019 September 24. The arc length between E_1 and E_2, in units of AU, is $s = \frac{2\pi}{365 \text{ Days}} \times 1 \text{ Day} \times 1 \text{ AU}$.

Using Equation 1, we find $d = 65.3$ AU, which is significantly larger than Pluto's true distance of about 40 AU. One factor in our calculation that might contribute to this discrepancy is our assumption that Pluto is stationary. In reality, the line segments originating from E_1 and E_2 meet at a distance behind where we have labeled Pluto in Figure 2, giving us an overestimate of the distance.

REFERENCES

Joye, W. A., & Mandel, E. 2003, in Astronomical Society of the Pacific Conference Series, Vol. 295, Astronomical Data Analysis Software and Systems XII, ed. H. E. Payne, R. I. Jedrzejewski, & R. N. Hook, 489