THE Hα LIGHT CURVES AND SPATIAL DISTRIBUTION OF NOVAE IN M81

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ABSTRACT

We present the results of a preliminary Hα survey of M81 for novae conducted over a 5 month interval using the 5’ field-of-view camera (WFCAM) on the Calypso Telescope at Kitt Peak, Arizona. We observed M81 nearly every clear night during this interval, covering the entire galaxy, and discovered 12 novae. Our comprehensive time coverage allowed us to produce the most complete set of Hα light curves for novae in M81 to date. A raw nova rate for M81 gives 23 yr$^{-1}$, which, because of the nature of our survey, is a hard lower limit. An analysis of the completeness in our survey gives a corrected nova rate of 30 yr$^{-1}$. This agrees statistically with the rate of 33$^{+13}_{-8}$ yr$^{-1}$, derived from Monte Carlo simulations using nova light curves and survey frame limits. The spatial distribution of the novae we discovered follows the bulge light much better than the disk or total light according to Kolmogorov-Smirnov tests of their radial distributions. The asymmetry in the distribution of novae across the major-axis line of M81 implies a bulge-to-disk nova ratio of greater than 9 and supports the idea that novae originate primarily in older stellar populations.

Key words: galaxies: individual (M81) — novae, cataclysmic variables

1 INTRODUCTION

Extragalactic novae are particularly appealing objects for studies of close binary evolution. They are the tracer of interacting close binary stars, visible to much greater distances than any other well-studied standard candle except supernovae (novae display $M_V$ up to $-10$). By studying the novae in a nearby galaxy, one can gather a homogeneous sample of objects, all at the same distance, that is not plagued by the selection effects hampering an analysis of the cataclysmic variable (CV) population in our own Galaxy. Given the large fraction of all stars that exist in binaries, the effort to understand binary formation and evolution has widespread implications for understanding stellar populations. There are currently many unsolved problems in the theory of close binary formation and evolution that are difficult to tackle using CVs in our own Galaxy because of the selection effects mentioned above.

The prediction that the nova rate should correlate with the star formation history in the underlying stellar population (Yungelson, Livio, & Tutukov 1997) is one example. This prediction is based on our understanding of how close binaries form and evolve, combined with our understanding of how the mass of a nova progenitor influences the nova outburst. Massive white dwarfs come from massive progenitors. These massive white dwarfs erupt as novae frequently, as they need only accrete a small amount of hydrogen from their companions to explode as novae. This in turn implies that stellar populations with a low star formation rate should have a correspondingly low nova rate; i.e., early-type galaxies with older stellar populations should have a lower luminosity-specific nova rate (LSNR) than late-type galaxies with ongoing star formation.

Efforts have been made to detect a trend in LSNR with galaxy type (della Valle et al. 1994; Shafter, Ciardullo, & Pritchet 2000), but the random errors are too large to date for a meaningful comparison. Typical extragalactic nova surveys are carried out using short runs, and significant assumptions must be made about the mean lifetimes of novae to derive nova rates (Shafter & Irby 2001). It is also rare that an extragalactic survey has been able to spatially cover an entire galaxy and avoid making some assumption about the distribution of novae with light to derive a galactic nova rate. The resulting errors in the nova rates are large, but systematic biases are far more pernicious.

To accurately compare nova rates with the underlying stellar population, we are pursuing a research program that uses the comprehensive time and spatial coverage afforded by a dedicated observatory. We have begun our program with M81 and used 5 continuous months of observing time to produce a survey that requires no assumptions about nova distribution or mean lifetime. Not since Arp (1956) surveyed the central parts of M31 has such extensive, continuous coverage of a galaxy for novae been attempted.

Our survey updates the 5 year photographic survey of M81 for novae reported by Shara, Sandage, & Zurek (1999). They found 23 novae, evenly divided over the disk and central bulge. Significant incompleteness must be present in that survey due to photographic saturation in the bright central regions of the galaxy and due to large gaps in their time coverage. The results we present below show that a comprehensive spatial and temporal survey is required to minimize the systematic effects of incompleteness.

2 OBSERVATIONS

We used the WFCAM 2048 × 2048 pixel CCD on the Calypso 1.2 m telescope at 4 × 4 binning for our observations of M81. This configuration yields a pixel scale of
0\textquotesingle 6 pixel$^{-1}$ and a field size of 5\textquotesingle on a side. The seeing for our observations had a median of 1\textquotesingle 5 and ranged from 1\textquotesingle 0 to 2\textquotesingle 5. In an effort to cover the entire spatial extent of M81 in our search for novae, we divided M81 into 12 fields covering roughly 15\textquotesingle in right ascension and 23\textquotesingle in declination. Figure 1 is an H$\alpha$ mosaic of the 12 fields showing the extent of our spatial coverage, the identification of the fields, and the location of the 12 novae discovered.

All observations were taken through an H$\alpha$ filter with a 30 Å FWHM bandpass. This filter was chosen for several reasons. Because of the longer duration of novae in H$\alpha$ compared with the $B$ band (Ciardullo et al. 1987), we minimize the possibility of missing novae because of inevitable gaps in coverage. The redder wavelengths observed with the H$\alpha$ filter means that our images are less influenced by internal extinction in M81 and less influenced by scattered moonlight during the fuller phases of the moon. To illustrate this point, Figure 2 shows the distribution of frame limits (described in § 4) with days from new Moon. Only within 1.5 days of the full Moon is any effect seen. It is also our goal to explore the H$\alpha$ light curve as a tool for understanding the physics of nova outbursts. So far attempts to do this have failed, but with our dense time sampling the possibility opens up that features of the H$\alpha$ rise, previously poorly observed, may correlate with properties of the nova progenitor.

Each individual exposure was 1200 s, and we attempted to get at least five exposures on a given field in one night for a total exposure time of 100 minutes per epoch. Although most
of our epochs reached this goal, observing conditions varied considerably, and so the number of useful exposures per epoch ranges from two to nine.

Ideally, we would have observed all 12 fields every clear night. This was impossible to achieve with the requirement that we get 100 minutes of exposure per epoch. Thus, we cycled through the 12 fields over the course of a varying number of nights, depending on the time available on a given night subject to weather, M81’s availability, and occasional equipment problems. Guide stars were not readily available for some of the fields or were faint, with the result that the number of usable survey epochs for each field varies from five to 21.

Our survey ran from 2002 December 31 (JD 2,452,638.8) to 2003 June 6 (JD 2,452,796.6), covering a total of 157.8 days. At the end of this time, two novae were still observable in decline in one of the fields (5S). An additional 15 epochs were obtained of this field to follow the declining novae until 2003 June 26 (JD 2,452,816.7), during which time no new novae were discovered in this field. This period from 2003 June 6 to June 26 is not included in our nova rate calculations.

Table 1 summarizes the observations in our survey. The field designations correspond to those in Figure 1, with the exception that field 5S and 2N are unlabeled (but their location is obvious). The fields with “Bulge” in the last column also contain a significant amount of M81’s disk, as can be seen from Figure 1.

### Table 1: Observations

| Field | R.A.   | Decl.  | Epochs | No. Exp. | Hours | No. Novae | Bulge/Disk |
|-------|--------|--------|--------|----------|-------|-----------|------------|
| 1N.....| 09 56 24.6 | 68 58 24 | 19     | 89       | 29.7  | 0         | Disk       |
| 1S.....| 09 56 24.1 | 68 53 44 | 18     | 87       | 29.0  | 0         | Disk       |
| 2N.....| 09 55 31.8 | 69 01 34 | 18     | 82       | 27.3  | 3         | Bulge      |
| 2S.....| 09 55 30.1 | 68 56 52 | 5      | 23       | 7.7   | 0         | Disk       |
| 3N.....| 09 54 39.9 | 69 03 12 | 17     | 79       | 26.3  | 1         | Disk       |
| 3S.....| 09 54 40.6 | 68 58 29 | 10     | 48       | 16.0  | 0         | Disk       |
| 4N.....| 09 56 25.2 | 69 07 35 | 18     | 80       | 26.7  | 0         | Disk       |
| 4S.....| 09 56 25.3 | 69 02 57 | 5      | 25       | 8.3   | 0         | Disk       |
| 5N.....| 09 55 31.1 | 69 10 58 | 6      | 29       | 9.7   | 0         | Disk       |
| 5S.....| 09 55 31.7 | 69 06 14 | 15/21  | 68/94    | 22.7/31.3 | 7         | Bulge      |
| 6N.....| 09 54 39.1 | 69 12 32 | 8      | 36       | 12.0  | 0         | Disk       |
| 6S.....| 09 54 39.4 | 69 07 50 | 21     | 94       | 31.3  | 1         | Disk       |

**Note:** Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

a Except where noted, epochs range from 2002 December 31 (JD 2,452,638.8) to 2003 June 6 (JD 2,452,796.6).

b The additional 15 epochs of field 5S were acquired between 2003 June 6 and 2003 June 26 to follow the declines of novae 11 and 12 (see text). No additional novae were found in these epochs.
11 × 11 pixels to remove point sources and preserve the low-
frequency structure of the image. This was then subtracted
from the original co-added frame, which removed the intensity
gradient of the bulge but preserved the point sources embed-
ded in it. Residual light in the subtracted image within 20′′
of the nucleus made detection of the innermost nova very dif-
cult. This subtraction technique was performed on each co-
added image of the bulge fields, after which they were blinked
against each other. Since most of the novae were detected in
the bulge region, the subtraction proved to be important for
detecting novae in M81.

For each co-added image of each field we determined the
frame limit by using artificial stars and the exact techniques
outlined above for detecting the novae. Closer to the nucleus
of M81 frame limits were derived from the flattened images. For
field 2N an additional set of frame limits was derived near the
position of nova 4. For field 5S two additional sets of frame
limits were derived near the positions of nova 1 and nova 5.

Table 2 summarizes the 12 novae discovered with our
survey. Astrometry was derived for each nova using the
WCSTOOLS package (Mink 2002) and the Guide Star Cat-
alog-II.2 Positions are accurate to better than 2″ based on the
fit residuals to the GSC-II stars. The corrected nuclear dis-
tances were calculated using the equations and parameters
given in Shara, Sandage, & Zurek (1999).

Could our candidates be anything other than novae? Their
positions in M81 rule out foreground or background objects.
We checked the position of each candidate against the list of
known Hubble-Sandage (HS) variables in M81 (Sandage
1984) and found no coincidence. These bright blue HS vari-
ables are the only known non-nova variables that approach the
brightness of our candidates. In fact, the brightest B-band
magnitude for the HS variables in M81 is 19.1 (Sandage
1984) and found no coincidence. These bright blue HS vari-
ables are the only known non-nova variables that approach the
brightness of our candidates. In fact, the brightest B-band
magnitude for the HS variables in M81 is 19.1 (Sandage
1984). These are massive stars and are likely to be much
fainter in the red at the H\textalpha\ band.

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5. NOVA PHOTOMETRY

Since crowding was not an issue, aperture photometry was
used to measure point-source brightnesses in each co-added
image. We used the IRAF APHOT package to measure point-
source brightnesses. Variable seeing was accounted for by
setting the measurement aperture radius in each image to \frac{1}{2} the
FWHM of the stellar profile to maximize the signal-to-noise
ratio. The FWHM was measured from a set of well-isolated
stars in each image.

The photometric calibration was achieved using a two-step
process, which was required because of the negligible overlap
between fields and the lack of H\textalpha\ standards in many of the
fields. The first step was to tie all the frames to a common
system. This was achieved using the R-band photometry of
Perelmuter & Racine (1995). An offset from our instrumental
H\textalpha\ magnitudes to the calibrated R magnitudes was calculated
each epoch of each field using from 18 to 70 stellar sources
per field with an accuracy of better than 0.1 mag. Nonstellar
sources (H \textalpha\ regions) were excluded by virtue of their much
brighter instrumental H\textalpha\ magnitude relative to R than the
stellar sources.

Once all magnitudes were on this common R system, an
offset was needed to the standard AB system, where
m_{H\textalpha} = 0.0 for f_j = 2.53 \times 10^{-9} \text{ ergs cm}^{-2} \text{s}^{-1} \text{ A}^{-1}. For our
filter with a FWHM of 30 A, this gives a zero point flux of
7.59 \times 10^{-8} \text{ ergs cm}^{-2} \text{s}^{-1}. We used the foreground extinc-
tion–corrected and standardized flux measurements of M81
planetary nebulae (PNe) published by Magrini et al. (2001) to
calculate this offset. They used a 90 A FWHM H\textalpha\ filter,
which would include [N ii] if present. Our filter excludes
[N ii], so we had to assume that for the set of PNe used, the
[N ii] fluxes are small. Using our filter zero-point flux, we
converted the fluxes from Magrini et al. (2001) into H\textalpha\ filter
magnitudes for the 107 PNe we were able to measure in seven
of our fields. We then compared these H\textalpha\ filter magnitudes
with the common R system magnitudes for the PNe to cal-
culate an offset between the two systems. We calculated a
mean offset from 78 PNe of $-0.26 \pm 0.13$ mag. We excluded
29 outliers that showed evidence of stronger [N ii] by virtue of
their having a lower instrumental H\textalpha\ magnitude than

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### TABLE 2

**M81 NOVA POSITIONS**

| NOVA | R.A.  | Decl. | FIELD | DETECTIONS | Uncorrected | Corrected |
|------|-------|-------|-------|------------|-------------|-----------|
| 1.....| 09 55 39.2 | 69 04 22 | 5S | 11 | 42 | 84 |
| 2.....| 09 55 21.5 | 69 05 60 | 5S | 9 | 140 | 141 |
| 3.....| 09 54 53.6 | 69 06 49 | 6S | 5 | 274 | 317 |
| 4.....| 09 55 35.3 | 69 03 34 | 2N | 2 | 24 | 24 |
| 5.....| 09 55 28.5 | 69 05 10 | 5S | 10 | 79 | 85 |
| 6.....| 09 55 48.5 | 69 03 05 | 2N | 3 | 96 | 123 |
| 7.....| 09 55 40.5 | 69 03 49 | 2N | 6 | 40 | 66 |
| 8.....| 09 55 46.7 | 69 04 07 | 5S | 8 | 73 | 140 |
| 9.....| 09 55 26.5 | 69 04 44 | 5S | 4 | 61 | 61 |
| 10.....| 09 55 04.4 | 69 03 24 | 3N | 4 | 157 | 304 |
| 11.....| 09 55 34.8 | 69 05 34 | 5S | 14 | 99 | 144 |
| 12.....| 09 55 47.4 | 69 04 44 | 5S | 16 | 91 | 183 |
predicted from the conversion of the flux to H\(\alpha\) filter magnitude. Without individual spectra of the PNe, this exclusion is less than perfect and limited our photometric accuracy.

As a check on this calibration, we found one object that is in both the \(R\) catalog of Perelmuter & Racine (1995) and the H\(\alpha\) flux catalog of Magrini et al. (2001). Object 2111 from Perelmuter & Racine (1995) with an \(R\) magnitude of 19.64 is object 93 from Magrini et al. (2001), which has an H\(\alpha\) magnitude (using the zero-point flux above) of 19.42. This gives an offset of \(-0.22\), in good agreement with our calibration. This calibration should allow comparison of our H\(\alpha\) nova light curves with the M31 H\(\alpha\) light curves of Ciardullo et al. (1990), with one important caveat. Because our filter is 2.5 times narrower, many of the faster novae with expansion velocities greater than 685 km s\(^{-1}\) have overfilled our 30 Å bandwidth. The M31 novae can have expansion velocities up to 1715 km s\(^{-1}\) and not overfill the 75 Å filter bandwidth used by Ciardullo et al. (1990). Because nova ejection velocity is a function of nova luminosity (Shara 1981), a direct comparison of the nova luminosity distribution between M31 and M81 is precluded for this survey.

Table 3 presents our calibrated photometry for each nova at each observed epoch. The errors in column (3) are the 1\(\sigma\) internal photometric errors. The three points in parenthesis for nova 6 are unfiltered magnitudes from the Katzman Automatic Imaging Telescope (KAIT) (Weisz & Li 2003). Filippenko & Chornock (2003) report that the spectrum of this nova exhibited strong double-peaked hydrogen Balmer emission lines and that many Fe \(ii\), Ca \(ii\), and O \(i\) lines also appeared in emission and thereby confirm this object as a nova.

### 6. THE H\(\alpha\) LIGHT CURVES

Figures 3 and 4 present our calibrated H\(\alpha\) light curves for the 12 novae discovered in M81 during our survey. Figure 3 presents the six novae for which we have observed the maximum \(m_{H\alpha}\), while Figure 4 presents the six novae observed days or weeks after maximum \(m_{H\alpha}\). The frame limits are plotted as short horizontal lines with downward pointing arrows, while the solid circles with error bars are the nova observations from Table 3.

A simple linear fit was made to the decline portion of each light curve to calculate the decline rates in \(m_{H\alpha}\) day\(^{-1}\). The thin lines in Figures 3 and 4 show the resulting fits. Table 4 presents the properties of the nova light curves, including the rise time and decline rate for each nova. We consider the H\(\alpha\) rise times to be lower limits because we do not have continuum light curves to accurately define the outburst time.

We cannot compare the brightness distribution of our novae with that in M31 because of the filter overfilling described above, but we can compare the nova decline rates. Figure 5 shows the comparison of our decline rates with the M31 decline rates reported in Ciardullo et al. (1990) and Shafter & Irby (2001). We see that the distribution is similar, but there is an indication of incompleteness in our slowest decline rate bin. Both M31 surveys spanned at least 2 years and therefore had longer overall time baselines. Our survey is continuous, but only covers a 5 month period. At the slowest reported decline rate for an M31 nova of 0.0018 \(m_{H\alpha}\) day\(^{-1}\) (Ciardullo et al. 1990) in 5 months a nova would only change by 0.3 mag in H\(\alpha\) and would not be seen in our survey as a transient point source. In fact, it would take over 500 days before such a slow nova would change by 1 mag. Based on Figure 5 and accounting for small number fluctuations, we estimate that there

### TABLE 3

| Nova | JD (+2,452,000) | \(m_{H\alpha}\) | Err\((m_{H\alpha})\) | Pl. Limit |
|------|----------------|--------------|----------------|-----------|
| 1... | 641.80         | 18.02        | 0.17           | 18.5      |
| 2... | 644.79         | 18.46        | 0.17           | 18.8      |
|      | 653.88         | 18.16        | 0.13           | 18.8      |
|      | 668.78         | 18.50        | 0.11           | 18.9      |
|      | 679.64         | 18.33        | 0.15           | 18.7      |
|      | 689.88         | ...          | ...            | 18.3      |
|      | 693.76         | 18.93        | 0.15           | 19.0      |
|      | 707.60         | 18.69        | 0.25           | 18.7      |
|      | 709.78         | 18.88        | 0.14           | 19.3      |
|      | 711.89         | 19.20        | 0.22           | 19.2      |
|      | 720.78         | ...          | ...            | 18.9      |
|      | 723.79         | 18.88        | 0.17           | 19.0      |
|      | 728.63         | 18.97        | 0.21           | 19.0      |
|      | 735.63         | ...          | ...            | 18.5      |
|      | 753.79         | ...          | ...            | 18.7      |
|      | 758.79         | ...          | ...            | 18.4      |
|      | 769.69         | ...          | ...            | 19.3      |
| 3... | 642.76         | 18.05        | 0.08           | 19.5      |
|      | 652.76         | 18.66        | 0.23           | 19.5      |
|      | 657.74         | ...          | ...            | 18.5      |
|      | 670.78         | 18.87        | 0.11           | 20.0      |
|      | 680.71         | 19.37        | 0.29           | 19.5      |
|      | 705.75         | ...          | ...            | 19.9      |
|      | 707.91         | ...          | ...            | 19.5      |
|      | 710.68         | ...          | ...            | 19.0      |
|      | 718.79         | ...          | ...            | 19.0      |
|      | 721.80         | 19.87        | 0.33           | 20.0      |
|      | 724.89         | ...          | ...            | 19.5      |
|      | 725.61         | ...          | ...            | 19.5      |
|      | 728.79         | ...          | ...            | 20.0      |
| 4... | 639.84         | ...          | ...            | 19.2      |
|      | 643.78         | 18.45        | 0.23           | 19.0      |
|      | 653.77         | ...          | ...            | 18.5      |
|      | 668.68         | 19.66        | 0.54           | 19.7      |
|      | 671.88         | ...          | ...            | 19.5      |
| 5... | 668.78         | ...          | ...            | 19.5      |
|      | 679.64         | 18.72        | 0.15           | 19.1      |
|      | 689.88         | ...          | ...            | 18.7      |
|      | 693.76         | 18.55        | 0.10           | 19.5      |
|      | 707.60         | 18.57        | 0.15           | 18.8      |
|      | 709.78         | 18.55        | 0.09           | 19.5      |
|      | 711.89         | 18.88        | 0.14           | 19.2      |
|      | 720.78         | 18.79        | 0.15           | 19.4      |
|      | 723.79         | 18.29        | 0.09           | 19.4      |
|      | 728.63         | 18.30        | 0.09           | 19.2      |
|      | 735.63         | 18.37        | 0.13           | 18.7      |
|      | 753.79         | 18.98        | 0.18           | 19.0      |
|      | 758.79         | ...          | ...            | 18.9      |
are roughly 10 very slow novae that remain to be detected in the present survey. As we extend our survey in time, we will continue to blink epochs from the season reported here in an effort to discover these very slowly declining novae.

Two of the light curves show that in H\(\alpha\) novae can take a long time to reach maximum brightness; nova 12 took more than 13 days, and nova 5 took at least 50 days. Nova 12 can be compared with nova 26 in Ciardullo et al. (1990), which took ~15 days from outburst to reach maximum. Our nova 5 is unprecedented; its 50 day rise is, as far as we know, the longest ever observed for a nova in H\(\alpha\). Nova 20 from Ciardullo et al. (1990) shows a small decline before reaching maximum light, like our nova 5, and could have taken a similar length of time to reach maximum.

Figure 6 shows a comparison of nova rise times in H\(\alpha\) and the continuum. The H\(\alpha\) data consist of the six novae from this paper (see Table 4) and the three novae with well-observed rises from Ciardullo et al. (1990). The continuum data are from the photographic light curves presented in Arp (1956). Of the 30 novae discovered by Arp, we used 21 for which we could determine a reliable rise time. The continuum distribution has a sharp peak at 1 day but extends out to nearly as long a rise time as the longest one for H\(\alpha\). The H\(\alpha\) distribution shows no peak and does seem to cluster in the range from 3 to 15 days. The arithmetic mean of the continuum rise times is 9.0 days. The arithmetic mean for the H\(\alpha\) rise times is 13.3 days, but it should only be considered a lower limit given that all the rise times from Table 4 are lower limits. For the four novae from Ciardullo et al. (1990) that have both B-band and H\(\alpha\) photometry (including nova Cyg), we see that the H\(\alpha\) maximum always occurs after the B-band maximum. It appears that H\(\alpha\) rise times are generally longer than continuum rise times, but without a large set of light curves in both continuum and H\(\alpha\) for each nova we cannot say more. We hope to remedy this in the next observing season for M81 (see below).

The slow rise times in H\(\alpha\) of some novae may lead to inaccuracy in the calculation of nova rates if only the maximum light and decline rates are used, especially with a survey,
Fig. 3.—Hα light curves of six M81 novae observed to reach maximum $m_{\text{H} \alpha}$. The solid points are $m_{\text{H} \alpha}$, and the frame limits are indicated by the horizontal line with the downward pointing arrow. The open circles for nova 6 are unfiltered magnitudes from the KAIT telescope (Weisz & Li 2003). The thin lines are linear fits to the decline rates for each nova.
Fig. 4.—Same as Fig. 3, but for the novae observed days or weeks after maximum $m_{\text{Halpha}}$. 
such as ours, with many closely spaced epochs. Nova light
curves that cover the rising portion of the outburst and allow
determination of the decline rate are needed for calculating
accurate completenesses and nova rates.

7. COMPLETENESS

Because of the dense time sampling and variable depth of
our survey, we developed an approach to finding the com-
pleteness of each field that is more appropriate than assigning
a single frame limit to the entire survey. With a set of rela-
tively complete H/C11 nova light curves and the frame limit for
each epoch of each field, we can calculate the completeness
for a given field by simulating the random outburst times of a
large sample (10^5) of novae. This approach assumes that we
have a set of H/C11 light curves that is representative of the nova
population in M81.

7.1. Representative Hα Light Curves

Of the 12 light curves reported in this work, three novae
have sufficient coverage of the rising part of the light curve
and have reasonably well-determined decline rates to qualify
for this set: novae 5, 7, and 12 (see Fig. 3). We can combine
these with the Hα photometry of the eight novae listed in
Table 11 of Shafter & Irby (2001) to get a representative set
of 11 Hα nova light curves to use in our random outburst
simulation.

To include the M31 light curves in our representative set,
we need to correct for the difference in galaxy distances and
the difference in filter bandwidths. Using the distance moduli
quoted in Shafter, Ciardullo, & Pritchet (2000), we apply a
correction to the M31 novae of -3.48 mag to place them at

![Fig. 5.—Histogram comparing the Hα decline rates for our M81 novae and the M31 nova of Ciardullo et al. (1990) and Shafter & Irby (2001). Note the incompleteness in our M81 survey in the slowest bin. As noted in the text, this is due to the 5 month overall time baseline of our survey. The M31 surveys had overall time baselines of 2 yr or more.

![Fig. 6.—Histogram comparing continuum and Hα rise times. The continuum rise times, shown by the solid histogram, are from the photographic light curves in Arp (1956). The Hα rise times, shown by the dashed histogram, are from Table 4 and from Ciardullo et al. (1990). The arithmetic mean of the continuum rise times is 9.0 days, while the arithmetic mean for the Hα rise times is 13.3 days. Note that the Hα rise times presented in this work are lower limits.]

| NOVA | MAX \( m_{H/C11} \) | BASELINE (days) | RISE TIME (days) | BASELINE (days) | Pts (N) | RATE \( m_{H/C11} \) \( \text{day}^{-1} \) |
|------|----------------|----------------|----------------|----------------|---------|----------------|
| 1.... | <18.0          | 87             | ...            | 87             | 11      | 0.010           |
| 2.... | 18.0           | 68             | >3            | 65             | 8       | 0.021           |
| 3.... | <18.0          | 79             | ...            | 79             | 5       | 0.027           |
| 4.... | <18.4          | 25             | ...            | 25             | 2       | 0.049           |
| 5.... | 18.2           | 74             | >49           | 25             | 3       | 0.031           |
| 6.... | 17.3           | 19             | >11            | 14             | 2       | 0.129           |
| 7.... | 17.0           | 28             | >5             | 23             | 4       | 0.078           |
| 8.... | <17.8          | 21             | ...            | 21             | 6       | 0.058           |
| 9.... | <18.7          | 13             | ...            | 13             | 4       | 0.058           |
| 10... | <18.6          | 31             | ...            | 31             | 4       | 0.022           |
| 11... | 17.5           | 46             | >8            | 38             | 13      | 0.036           |
| 12... | 17.9           | 22             | >13            | 9              | 9       | 0.087           |
the distance of M81. The filter bandpass we used is 2.5 times narrower than that used by Ciardullo et al. (1990) for the M31 novae, and so they would appear 1 mag brighter in our survey, making the correction +2.48 mag. If the M31 novae had, in fact, been observed with our filter, they would have overfilled the bandpass by varying amounts and therefore been fainter by up to a factor of 2. Spectroscopic observations of M31 novae by Ciardullo, Ford, & Jacoby (1983) show typical emission-line widths of 40–60 Å. However, spectra of novae in M31 reported by Tomaney & Shafter (1992) show the slowest, and therefore faintest, novae to have expansion velocities of less than 685 km s\(^{-1}\), which would not overfill our filter. Since we are interested in calculating the completeness at the faint end, we elect not to apply an uncertain overfilling factor to the M31 novae. Therefore, our total correction to the M31 novae to include them with our M81 photometry through a 30 Å filter is +2.48 mag.

To see whether this set is truly representative of novae in M81, we can compare the range of decline rates in this set (0.0044 to 0.087 mag day\(^{-1}\)) with Figure 5. We see that this range covers the majority of the novae in this figure. By adding the slower novae from M31, we account for the very slow novae we are apparently missing according to Figure 5. We can also compare the range of maximum magnitudes in this set (\(m_{H_0}\) from 17.0 to 20.9) with the maximum magnitudes reported in Ciardullo et al. (1990) for M31. After accounting for the magnitude offset as described above, we see that our set spans the majority of the range of novae in M31. For the following analysis, we will assume that our 11 novae are a representative set for M81.

7.2. Random-Outburst Simulations

We used each nova in this representative set to make a random-outburst simulation for each set of frame limits we measured. This produced 11 simulations for each of the 15 frame limit sets for a total of 165 simulations. To create each simulation, which consisted of 10\(^5\) trials, we used a uniformly distributed random number generator to shift the representative nova light curve in time so that its outburst occurred within the 158 days of our survey. The frame limit set being studied was then compared with each shifted light curve to determine whether it would have been a valid nova candidate in that field. A valid candidate must pass the criteria described above: it must be brighter than at least two frame limits in the set and it must be fainter than at least one of the frame limits to confirm its transient nature. The number of times a simulated nova was identified as a candidate was divided by the number of trials to produce a fractional completeness for that representative nova in the frame limit set being studied.

To compare the randomly shifted nova light curve with the frame limits in the set and determine whether the simulated nova would have been a candidate in the field being studied, the following algorithm was adopted. Any nova magnitude on a frame epoch before outburst was set to 99.9 (i.e., a nondetection). Nova magnitudes on frame epochs between two light-curve points were calculated using linear interpolation. Nova magnitudes on frame epochs after the last point in the light curve were calculated using the measured decline rate for the nova. This is much more accurate than extrapolating beyond the end of the light curve since the last points in a nova light curve tend to be the faintest and therefore the noisiest.

The completeness as a percentage, averaged over the 11 representative novae, is given for the 15 frame limit sets in Table 5 and plotted in Figure 7. Two correlations are apparent. The first and strongest is the correlation with the number of observed epochs. The lowest completeness is obtained for the fields with the smallest number of observed epochs and suggests a substantial incompleteness for these fields. The other correlation is with nuclear distance. For fields 2N and 5S the completeness drops considerably as the distance to the nucleus decreases. For a frame limit set measured at 42" from the nucleus of M81, which is plotted in Figure 7 as a filled diamond, we derive a completeness of 72%. For the closest frame limit set at 24" from the nucleus, plotted in Figure 7 as a filled

| TABLE 5 |

| NUCLEAR DISTANCE* (arcsec) | EPOCHS (N) | COMPLETENESS (%) |
|---------------------------|-----------|-----------------|
| FIELD | Uncorrected | Corrected | |
| 1N | 430 | 444 | 16 | 76 |
| 1S | 669 | 685 | 19 | 80 |
| 2N | 141 | 199 | 18 | 72 |
| 2N | 24 | 26 | 16 | 48 |
| 3S | 423 | 591 | 18 | 41 |
| 3N | 289 | 550 | 17 | 78 |
| 3S | 431 | 841 | 10 | 79 |
| 4N | 355 | 716 | 18 | 78 |
| 4S | 285 | 464 | 5 | 30 |
| 5N | 424 | 564 | 6 | 40 |
| 5S | 140 | 182 | 21 | 89 |
| 5S | 64 | 85 | 21 | 85 |
| 5S | 42 | 84 | 21 | 72 |
| 5N | 591 | 595 | 8 | 50 |
| 5S | 372 | 431 | 21 | 79 |

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* This distance is from the field center unless otherwise noted.

b At the position of nova 4.
c At the position of nova 5.
d At the position of nova 1.
square, we derive a completeness of only 48%. This suggests that a significant incompleteness exists in our survey within 1 arcminute of the nucleus of M81.

The completeness as a percentage, averaged over the 15 frame limit sets, is given for the 11 representative novae in Table 6 and plotted in Figure 8. The effect of maximum magnitude on completeness is readily apparent. This trend is not without scatter, however, because of the complex interaction between the shape of the light curve and the depth of the survey as a function of epoch.

8. THE NOVA RATE

The effects noted above demonstrate that assigning a single limiting magnitude to our survey is overly simplistic. This fact, combined with our dense time coverage, indicates that we can improve on the mean nova lifetime approach of Ciardullo et al. (1990) for calculating the nova rate for M81. A raw global nova rate can be obtained simply by dividing the observed number of novae that erupted during the survey by the time covered. Excluding the two novae that erupted before the start of the survey (Nova 1 and Nova 3) gives

\[ R = \frac{10}{0.43 \text{ yr}} = 30 \text{ yr}^{-1} \]

This rate also requires no correction for partial spatial coverage since we are covering the entire galaxy. For comparison, Shafter, Ciardullo, & Pritchet (2000) report a nova rate for M81 of

\[ R = 24 \pm 8 \text{ yr}^{-1} \]

based on 15 novae discovered over a 3 year period, and refer to an unpublished study whose preliminary results indicate that the nova rate in M81 may be somewhat lower than this.

We can adjust our raw rate by the completenesses shown in Table 5. Since the novae in fields 2N and 5S were distributed closer to the nucleus of M81, we must account for the lower completenesses found. For field 2N we use a completeness that is the average of the two positions measured, or 64%. For field 5S we also average the completeness measurements to get an 82% average completeness. Dividing the number of novae that erupted in each field by the appropriate completeness fraction and adding, we derive a completeness-corrected number of novae during our 5 month survey of 13. Using this corrected number of novae, we find a global M81 nova rate of

\[ R = 3.5 \pm 0.46 \text{ yr}^{-1} \]

This is still a conservative lower limit, because by averaging the completenesses in the two bulge fields, we are assuming that the number of novae at each measurement location is the same. Figure 1 shows that the novae are more likely to come from the regions of lower completeness nearer to the nucleus of M81, and hence the true completeness correction is probably larger than what we have used here.

8.1. The Monte Carlo Approach

Shafter & Irby (2001) describe a Monte Carlo technique that uses the maximum magnitudes and decline rates of the novae in their Table 11 and their survey faint limit to find the

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**Table 6:** Completeness of Representative Novae

| Nova* | Max \(m_{H\alpha}\) | Completeness (%) | Decline Rate \(m_{H\alpha} \text{ day}^{-1}\) |
|-------|------------------|----------------|------------------|
| 5...... | 18.2             | 79             | 0.031            |
| 7...... | 17.0             | 80             | 0.078            |
| 12..... | 17.9             | 74             | 0.087            |
| CFNJS 6... | 18.2             | 65             | 0.080            |
| CFNJS 20... | 19.8             | 54             | 0.0044           |
| CFNJS 26... | 17.6             | 82             | 0.029            |
| CFNJS 31... | 18.5             | 80             | 0.013            |
| N1992-07... | 19.0             | 71             | 0.0070           |
| N1995-06... | 18.9             | 78             | 0.015            |
| N1995-07... | 19.4             | 71             | 0.0090           |
| N1995-09... | 21.2             | 3.5            | 0.046            |

* Novae from this work are identified with a number, while novae from Shafter & Irby 2001 have the identifications from their Table 11. The magnitudes from Shafter & Irby 2001 have been corrected by +2.48 mag to account for the difference in \(H\alpha\) filter widths and the different distances of M31 and M81.
most probable nova rate in their survey region. We used the 11 representative nova light curves described above, combined with our frame limits, in a similar Monte Carlo experiment to derive nova rates for each of our fields.

This technique makes many independent estimates of the observed nova rate in the given field as a function of the true nova rate \( N_{\text{obs}}(N_{\text{true}}) \). For a given trial estimate of \( N_{\text{true}} \), the true rate, we choose a random set of light curves and outburst times and use the frame limits to calculate the number of observed novae, using the candidate criteria described above. We repeat this \( 10^5 \) times and record how many times we recover the number of nova candidates actually observed for that field. The estimate of the true nova rate \( N_{\text{true}} \) is then incremented and the process is repeated. This produces a probability distribution for \( N_{\text{true}} \) in the given field. The best estimate for \( N_{\text{true}} \) is that which corresponds to the peak of this distribution.

Figure 9 shows the probability distributions for an interesting subset of fields. The two distributions at the top of the figure, for field 1S and field 4S, show the difference between two disk fields with no observed novae, but very different time coverage and depth. This is reflected in the widths of the distributions and consequently the errors on the estimated true nova rate. The middle two distributions are for fields 3N and 6S, having one nova observed in each. The bottom two distributions are for the two fields that had the bulk of the observed novae with three for field 2N and seven for field 5S.

Table 7 presents the results of the simulations for each of 15 sets of frame limits. To derive a global nova rate from these data, we add up the nova rates in all the fields. Without accounting for the incompleteness near the center of M81, i.e., using the frame limit sets derived at the field centers of the two bulge fields, we find a global nova rate of \( 28^{+6}_{-4} \) yr\(^{-1} \), which is in good agreement with our corrected nova rate of \( 30 \) yr\(^{-1} \). If we include the rates from the frame limit sets closer to the nucleus of M81, as we did for the completeness, we get a higher nova rate. Averaging the two rates for field 2N, we get a rate of \( 11^{+5}_{-3} \) yr\(^{-1} \). Averaging the three rates for field 5S, we get \( 18^{+7}_{-6} \) yr\(^{-1} \). Adding these rates to the nova rates for the other fields, we derive a Monte Carlo, completeness-corrected nova rate for M81 of \( 33^{+13}_{-7} \) yr\(^{-1} \). We point out again that this is a conservative estimate, because we have not accounted for the distribution of novae in our simplistic averaging of nova rates for fields 2N and 5S.

### 8.2. The Luminosity Specific Nova Rate

The Two Micron All Sky Survey (2MASS) offers a uniform infrared photometric system for normalizing nova rates from different galaxies to their underlying stellar luminosity. This will remove one of the major uncertainties in the study of how the luminosity-specific nova rate in a galaxy varies with Hubble type. The Large Galaxy Atlas of the 2MASS (Jarrett et al. 2003) gives a \( K \)-band integrated magnitude for M81 of \( 3.831 \pm 0.018 \). Using this we derive a \( K \)-band luminosity for M81 of \( L_K = 8.34 \pm 0.14 \times 10^{10} \text{L}_\odot \). We derive a LSNR of \( \rho_K = 3.96^{+1.8}_{-1.1} \text{yr}^{-1}(10^{10} \text{L}_\odot)^{-1} \) from our nova rate of \( 33^{+13}_{-7} \) yr\(^{-1} \), from the Monte Carlo experiment.

This LSNR moves the position of the data point for M81 in Figure 6 from Shafer, Ciardullo, & Pritchet (2000) up from \( \rho_K = 1.80 \pm 0.71 \). This does not change the conclusion they drew from it, namely, that no correlation exists between \( \rho_K \) and galaxy \( B-K \) color. There are many systematic and random errors that could mask such a correlation. The normalization of nova rate to infrared luminosity using 2MASS should reduce the scatter in this diagram caused by nonuniform infrared galaxy magnitudes. We maintain that the biggest source of error in this diagram is that nova rates are systematically underestimated for the inner regions of galaxies where most of the novae may well occur. This figure could change substantially as global nova rates are improved and normalized to a uniform measurement of stellar luminosity for these galaxies. We now show that novae probably do appear preferentially in the bulge of M81.

### 9. THE SPATIAL DISTRIBUTION

We do not yet have enough novae in M81 to perform a reliable maximum likelihood decomposition of bulge and disk novae, as did Ciardullo et al. (1987) for M31. We can, however, do a simple test comparing the distribution of light and novae. We used the bulge/disk decomposition of Simien & de Vaucouleurs (1986, Table 4) to calculate the cumulative radial distributions of the bulge, the disk, and the total light of M81. We then compared these with the cumulative radial distribution of the novae. We used the Kolmogorov-Smirnov (K-S) test to determine at what confidence level we can rule out the hypotheses that the nova distribution is identical to the three different light distributions. Figure 10 shows the results of this comparison.

The “best match” with the nova distribution of the three is the bulge light distribution that can only be ruled out at the 21% confidence level. The total light fares considerably worse by over a factor of 2 and can be ruled out at the 57% confidence level. The disk light distribution is the worst match and can be ruled out at the 99% confidence level. Even though the bulge light does the best, the confidence level of 21% is still high. This is most likely due to the incompleteness in the central regions of the galaxy (see Fig. 7).

Another diagnostic for the bulge-to-disk ratio of novae was described in Hatano et al. (1997). They used a model for dust in M31 and predicted its effect on the distribution of novae in the bulge region. They state that if novae arise primarily in the bulge, a large asymmetry in their distribution would be apparent because the dust in the disk obscures the bulge novae behind the disk. In this case there would be fewer novae seen on one side of the bulge than on the other. They use the major axis of M31 as the dividing line between novae on top of the disk and novae on the bottom and compared the number of novae below the disk, on the bottom of the bulge, with the number of novae in the bulge above the disk. This ratio is called the bottom-to-top ratio (BTR). If disk novae predominate, the asymmetry is much less pronounced across this line since the fraction of novae obscured by the disk is the same on each side of the major axis. Using their dust model, Hatano et al. (1997) calculated the BTR for two different scenarios for M31: one with a bulge-to-disk nova ratio of 9, which produced a BTR of 0.33, and one with a bulge-to-disk nova ratio of \( \frac{1}{3} \) which produced a BTR of 0.63.

If we look at our sample of novae in M81, we can calculate the same BTR diagnostic. M81 clearly has dust in the disk that extends into the bulge (Jacoby et al. 1989). Its inclination of 60°4 (Shara, Sandage, & Zurek 1999) is not that different from the inclination of 77°0 for M31 (Ciardullo et al. 1987). By examining the image of M81 from the Hubble Atlas (Sandage 1961), one can see that the top of the bulge is on the northeast side of the major-axis line. If we say that the 10 novae within 2.5 of the nucleus of M81 are the apparent bulge...
novae, we see that two of these novae are south of the major-axis line (on the bottom) and eight of these novae are north of it (on the top) giving a BTR of 2/8 = 0.25. This BTR is much closer to the model for M31 from Hatano et al. (1997) with a bulge-to-disk nova ratio of 9 and clearly rules out the scenario with a bulge-to-disk nova ratio of $\frac{1}{2}$. One thing we must consider is that our novae were discovered using Hα light, while the models of Hatano et al. (1997) were based on novae in M31 discovered in the B band. Using the redder Hα light should reduce the effect of dust on the discovery rate of novae in the bulge. One would expect for the same bulge-to-disk nova ratio that the distribution in Hα light would be more

![Field 1S](image1)
![Field 2N](image2)
![Field 3N](image3)
![Field 4S](image4)
![Field 5S](image5)
![Field 6S](image6)

**Fig. 9.**—Monte Carlo probability distributions of the true nova rate, $N_t$, for six of the 12 M81 fields. The dashed vertical lines show the locations of the most probable $N_t$. The solid horizontal lines show the limits encompassing half the probability and define the errors for each estimate of $N_t$. 

```latex
\text{Field 1S} & 0^{+1.6}_{-0.0} \text{ yr}^{-1} \\
\text{Field 2N} & 8^{+3.2}_{-2.3} \text{ yr}^{-1} \\
\text{Field 3N} & 2^{+2.6}_{-0.9} \text{ yr}^{-1} \\
\text{Field 4S} & 0^{+4.9}_{-0.0} \text{ yr}^{-1} \\
\text{Field 5S} & 16^{+3.6}_{-2.9} \text{ yr}^{-1} \\
\text{Field 6S} & 2^{+2.6}_{-0.9} \text{ yr}^{-1}
```
symmetric, not less, than the distribution in the $B$ band. In addition, the fact that M81 is slightly more face-on than M31 should also reduce the asymmetry, since a face-on galaxy would show no asymmetry regardless of the bulge-to-disk nova ratio. The fact that our distribution is even more asymmetric than their M31 scenario with a bulge-to-disk nova ratio of 9 argues for an even higher bulge-to-disk nova ratio in M81.

Unless the disk of M81 has a vastly different distribution of dust than the disk of M31, one must ask why Hatano et al. (1997) conclude that M31 has a bulge-to-disk nova ratio close to 1, while using the same assumptions, we conclude that M81 has a bulge-to-disk nova ratio greater than 9. One possibility is that Hatano et al. (1997) used data from photographic surveys that have been shown to be incomplete in the inner regions of M31 (Ciardullo et al. 1987). Another problem, compared with our survey, is that M31 has never been surveyed comprehensively. Thus, calculations of the ratio of disk to bulge novae must account for differences in disk and bulge discovery rates from fundamentally different surveys, adding large uncertainties to the calculation. A uniform, comprehensive survey, such as presented here, removes these uncertainties.

The spatial distribution of the novae in M81 adds more weight to the idea that novae are associated with older stellar populations. It is important to continue to test this idea because, if verified beyond a doubt, it would strongly constrain the theory of how these objects form and evolve. We would have to consider that novae take much longer to form than previously thought and may not appear at all in young stellar populations.

10. BULGE VERSUS DISK NOVAE

We can examine our novae sample in M81 to test the idea that bulge novae are preferentially fainter and slower than disk novae. Della Valle & Livio (1998) found that for novae in the Milky Way, the bulge novae were spectroscopically distinct, having Fe II lines in the early emission spectrum, slower expansion velocities, and slower decline rates, while the disk novae had He and N lines, larger expansion velocities, and faster decline rates. Unfortunately, the two unambiguous disk novae reported here, novae 3 and 10, were not covered well.

![Fig. 10.—Cumulative radial distribution of novae compared with the bulge/disk decomposition of Simien & de Vaucouleurs (1986) in $B$-band light. Using their parameters we calculated the K-S statistic to test how well we can rule out the hypotheses that the radial distribution of the novae, indicated by the solid thin line, differ from the radial distributions of the various components of M81. The bold solid line represents the bulge light and can be ruled out at only the 21% confidence level. The total light shown by the bold dotted line can be ruled out at the 57% confidence level. The exponential disk, shown by the bold dotted line can be excluded with a confidence of 99%. While the bulge of M81 does the best, its high K-S statistic may be due to incompleteness of nova detection in the inner part of the galaxy.](image-url)
enough to determine their maximum magnitudes, although their decline rates are toward the slow end of the distribution (see Table 4). The presence of Fe II lines in the spectrum of nova 6 (Filippenko & Chornock 2003) implies that it could be one of the slow bulge novae. The decline rate for this nova is, however, the fastest one observed in M81 and argues that it may be one of the hybrid objects that evolve from showing Fe II lines to the faster He/N class and more properly be a member of the fast/bright novae class (della Valle & Livio 1998). Nova 6 is 1.6 from the nucleus of M81 and could be either a disk or a bulge nova. These facts are suggestive and illustrate the difficulty in testing this idea conclusively. Clearly, we need more comprehensive light curves for both bulge and disk novae to provide a more definitive test.

11. FUTURE WORK

Adding to the database of complete Hα nova light curves will improve the accuracy of the nova rates derived with Monte Carlo simulations as the parent population becomes better sampled. Once we accumulate enough nova in both the bulge and the disk of M81, we will be able to perform a decomposition and derive an accurate bulge-to-disk nova ratio. If we have enough complete light curves, we should begin to detect the differences in the bulge and disk novae one would expect from the results of della Valle & Livio (1998). We will see whether the asymmetry in the bulge novae across the major-axis line persists. Adding continuum observations for the novae in the database will allow us to directly compare the maximum magnitude decline rate (MMDR) relation in M81 with the MMDR relation for M31 and determine a nova distance to M81. We will also be able to directly compare continuum and Hα rise times.

We are currently upgrading the Calypso Telescope WFCAM 2048×2048 pixel CCD to a 4096×4096 pixel CCD, which will quadruple the coverage area (from 5′ to 10′ on a side). The filter used for this study was clearly too narrow and we have ordered a 75 Å FWHM Hα filter to allow us to compare our nova brightness distribution with that in M31. The maximum transmission of the new filter will be greater than 80% as compared with 55% for the 30 Å wide filter. The improved throughput combined with the high resolution afforded by the Calypso Telescope will provide a substantial improvement in the completeness close to the nucleus of M81.

Using this upgraded equipment, we will conduct an 8 month survey of M81 in 2003–2004 and include either B- or V-band observations of the novae we discover. Now that our data reduction pipeline is in place, we will notify the IAU Circulars when each new nova is discovered and hopefully obtain independent spectroscopic confirmation of each nova candidate. This will allow us to produce the most accurate nova rate for any galaxy known. We hope to extend this survey to include other members of the M81 group and members of the Local Group as well.

12. CONCLUSIONS

1. The raw nova rate for M81 provides a hard lower limit at 23 yr⁻¹. Using a set of representative nova Hα light curves in random outburst simulations we derive a completeness-corrected nova rate of 30 yr⁻¹. Monte Carlo simulations using the same set of light curves provide our most reliable nova rate for M81 of 33⁺¹⁻¹ yr⁻¹. The high nova rate found here for M81, with a survey technique that uses comprehensive time and spatial coverage, implies that the nova rates for other galaxies derived from surveys with incomplete spatial coverage and widely spaced epochs are at best rough values and may be serious underestimates. 2. The LSNR for M81 is $\rho_k = 3.96^{+1.8}_{-1.1} \text{ yr}^{-1} \left(10^{10} L_{\odot, K}\right)^{-1}$ using our best nova rate and the 2MASS K-band photometry for M81. This raises the LSNR for M81 up by a factor of 2 from that published by Shafter, Ciardullo, & Pritchet (2000) and implies that the LSNR for other galaxies could be systematically low by similar or greater amounts. A definitive comparison between galaxies of different Hubble type must await the results of comprehensive nova surveys, such as the one presented here.

3. The cumulative radial distribution of the novae matches the bulge light distribution significantly better than either the total or the disk light distribution, which is ruled out at a 99% confidence level. The BTR value for M81 of 0.25 derived from the asymmetry in the spatial distribution of the apparent bulge novae across the major-axis line, implies a bulge-to-disk nova ratio for M81 of greater than 9, according to the models of Hatano et al. (1997) for novae in M31. Both these facts lead to an association of the novae in M81 with the older bulge stellar population. 4. The disk novae reported here, novae 3 and 10, have decline rates that place them in the slow class of novae, but their maximum magnitudes were not determined. Nova 6 is most likely a fast hybrid nova, is 1/6 from the nucleus of M81 but cannot be unambiguously assigned to either the bulge or the disk. More comprehensive light curves of both bulge and disk novae are required to test for differences in their average maximum magnitudes and decline rates.

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