A REEXAMINATION OF THE “PLANETARY” LENSING EVENTS IN M22

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ABSTRACT

We have carried out a further analysis of the tentative, short-term brightenings reported by Sahu and coworkers, which were suggested to be possible lensing of Galactic bulge stars by free-floating planets in the globular cluster M22. Closer examination shows that—unlikely as it may seem—small, pointlike cosmic rays had hit very close to the same star in both of a pair of cosmic-ray split images, and this caused the apparent brightenings of stars at the times and locations reported. We show that the observed number of double hits is consistent with the frequency of cosmic rays in WFPC2 images, given the number of stars and epochs observed. Finally, we point to ways in which cosmic rays can be more directly distinguished.

Subject headings: Galaxy: bulge — globular clusters: individual (M22, NGC 6656) — gravitational lensing — instrumentation: detectors — planetary systems

1. BACKGROUND

Sahu et al. (2001) have recently reported observations of the microlensing of stars in the Galactic bulge by stars of the globular cluster M22. They report one major event, with a characteristic time of ~18 days and a brightening by 3 mag, and six brightenings of 0.3–0.8 mag, each seen as similar brightenings in both images of a pair of images taken 6 minutes apart. We discuss here only the short-term events. We demonstrate that each pair of brightenings is caused by two separate cosmic-ray (CR) hits, one in each image of the CR split, that happen to occur near the same star. In § 2, we describe the observations and our reanalysis; in § 3, we present the evidence that the short-term events are caused by CRs; in § 4, we discuss the prevalence of CRs; and in § 5, we suggest effective ways of reliably avoiding CR contamination.

Since there are already at least five papers (Gaudi 2002; de la Fuente Marcos & de la Fuente Marcos 2001; Hurley & Shara 2002; Fregeau et al. 2001; Soker, Rappaport, & Fregeau 2001) that discuss the short-term events, we feel that it is urgent to report our new finding, based on further analysis.

2. THE DATA AND INITIAL ANALYSIS

The observations of Sahu et al. (2001) were made with the WFPC2 of the Hubble Space Telescope (HST) between 1999 February 22 and June 15 (GO 7615), to determine the frequency and nature of the lensing of bulge stars by those of M22, the details of which are given by Sahu et al. (2001). Upon seeing the results of Sahu et al., the two of us who had not been part of the original team (J. A. and I. R. K.) were eager to apply our astrometric techniques (Anderson & King 2000; King et al. 1998; Bedin et al. 2001) for the measurement of proper motions, to determine whether the lensed stars were in fact bulge members or whether they were cluster members, which would imply a different lensing object, somewhere between the cluster and us. There exist in the HST archive images taken in 1994 and 1995, which provided an excellent baseline for such a separation.

Close examination of the images for the purpose of identifying the “brightened” stars, however, raised questions. In each pair of CR-split images, the brightness pattern of the pixels around the brightened star differed between the two images, much more than did the pixels around other stars of comparable magnitude, which made a convenient reference standard. This called for further investigation. J. A. and I. R. K. immediately contacted the PI of the original paper, and the present Letter is the result. (We regret that it has been delayed by trips for observing and summer meetings.)

3. DETAILED ANALYSIS OF THE SHORT-TERM EVENTS

In Table 1, we give for each of the events the name, right ascension, declination, and date of brightening, from Sahu et al. (2001), along with the date, data set name of the image (in brackets, the number of the chip in which the event occurred), and the pixel coordinates of the star that was affected. (In two cases, the indicated region appeared in more than one pointing, as is evident in Table 1. The second pair was taken about 9 minutes after the first pair.) We then compared the images in question with images taken before and after, in order to identify easily the star that had changed. Note that there was a transcription error in the position and date of event B as given by Sahu et al.; it has been corrected here. To explain that the “brightenings” were caused by pointlike CR hits close to the same star in both images, we now show two of the events in detail, as images and in numerical form.

Figure 1 shows event D, reproducing a small section of the images at a large enough scale to allow examination of individual pixels. The top two panels show the two images of the CR split in which the event occurred; the bottom panels show the image pair at another time when the placement with respect to pixel boundaries happened to be nearly the same but there was no brightening. The white dots identify the pixel within which the centroid of the star should fall, as transformed from other images that show no brightening.

We have chosen this case for illustration because the two
Table 1

| Name  | R.A. (2000) | Decl. (2000) | Date    | DOY   | Data Set  | Pixel Coordinates |
|-------|-------------|--------------|---------|-------|-----------|-------------------|
| A     | 18 36 28.63 | −23 53 55.6  | Apr 01  | 91    | u5331901r | (359, 225)        |
| B     | 18 36 26.08 | −23 53 36.6  | Mar 14  | 73    | u5331001r | (629, 235)        |
| C     | 18 36 31.24 | −23 53 12.5  | Jun 06  | 65    | u5332405r  | (415, 350)        |
| D     | 18 36 28.14 | −23 52 57.5  | Apr 30  | 107   | u5332901r | (170, 245)        |
| E     | 18 36 24.09 | −23 55 51.9  | Apr 16  | 107   | u5332405r | (140, 434)        |
| F     | 18 36 26.07 | −23 53 36.6  | Mar 14  | 73    | u5331003r | (625, 226)        |

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

* The day of year is given for the purpose of coordination with the times in Fig. 2 of Sahu et al. 2001.

Brightened images of star D do indeed resemble each other and appear to be centered the same; on the basis of such a visual inspection, an observer might be inclined to accept them. Despite these similarities, both brightenings are best explained by CRs.

Table 2 shows, in its upper half, a comparison of pixel values between the two images of the star. Each array gives the inner $5 \times 5$ pixels of the star, in each of the two CR-split images, and then the difference between them. The lower set of arrays shows the corresponding numbers for a star of similar brightness, in the same two images. In all cases, pixels are labeled by row and column numbers.

The arrays labeled "Difference" are quite revealing. The comparison star has very small differences, but the brightened star shows large differences between the two images, something that would not be the case for real star images.

Furthermore, a careful measurement of the centroids of the star in the two brightened images shows that they too differ by an amount that is much larger than the centroid shifts exhibited by other stars. We will demonstrate this in detail in § 5.

In Figure 2, we show event E, which is more typical of the other events. Here the resemblance of the two images to each other is much less. As would be expected, the numbers in Table 3 look worse, and, as we shall see, the positional discrepancies are larger. Nevertheless, even in this case, each of the individual images looks like that of a star. It is only when we compare them with each other, and with other pairs of star images, and make the additional tests that we describe that it becomes clear that the event is not a real brightening. The other events are qualitatively similar to event E, and we omit displaying them here.

One might conceivably imagine other effects—all of them extremely unlikely—that could cause positional shifts or differences in image shape. But even though we are convinced that the brightenings are caused by CRs, in a sense it is not essential to know whether it was that or some more esoteric cause; what really matters is that these differences and shifts exclude microlensing as the cause. It is conceivable, for example, that the source is blended (either because it is part of a binary or because another star happens to lie very close to the same location); microlensing could then cause a shift in the centroid (Dominik & Sahu 2000). However, apart from the fact that two such blended components would most likely be resolved in our case, the blending cannot explain the relative
centroid shift between the two CR-split images. An additional argument against microlensing as the cause of the apparent brightening is the fact that for event B and for event F, there was a second pair of exposures taken only 9 minutes later, which do not show any brightening.

For all the reasons that we have explained, we believe that microlensing is excluded as a possible cause of the brightenings. Of the other possible causes, CRs seem the only likely one—especially since we are about to show that it is statistically probable that this many paired CR hits would occur.

4. THE LIKELIHOOD OF A DOUBLE CR EVENT

At first, it might seem extremely unlikely that in a CR-split pair, both images of the same star would be affected by CRs in a similar way. We have noted from direct examination, however, that this set of images has a CR hit of about the strength observed (20–75 DN) in about 1 pixel out of every 2000. Since a hit by a pointlike CR in any one of a half-dozen pixels around the center of the star will produce the effect that we are discussing, both images of a pair will be hit about one time in 10^5. If we note that there were dozens of observations, with (conservatively) 30,000 stars in each, this makes more than a million pairs of star images. Thus, 10 or so double hits are to be expected, so that six is not a surprising number after all.

The above is a very approximate calculation, especially in the visual-inspection criteria described by Sahu et al. (2001), but it does make the point that an appreciable number of double hits is not unlikely.

5. RELIABLE REJECTION OF CRs

There is a lesson to be learned from our unhappy experience. CRs are everywhere and can indeed “strike twice in the same place,” in a way that can pass visual comparisons. How then are we to avoid them? We recommend both of the tests that we have applied here. Differencing entire images can be cumbersome, however—not in taking the differences but in interpreting them. Bright stars generate large Poisson fluctuations in their differences, so that a difference map has to be compared with the original image in order to interpret it. The power of the differencing method is in testing individual objects, as we have shown here.

For general screening against CRs, we recommend careful measurement and comparison of positions. Our measurements of stellar flux, for example, involve a simultaneous measurement of position (Anderson & King 2000). We can compare this with the star’s average position (from all the observations), transformed into the coordinate frame of this image.

Figure 3 shows the position residuals of the 2 × 31 F814W observations of each of the six stars involved in these events. (In the case of events B and F, each of which fell in two pointings, we used only the PC, which was the chip in which...
the events were seen.) The 3 \( \sigma \) error circle is shown in each case. Any observation whose measured position falls outside of this circle is unlikely—for some reason, possibly a CR or a bad pixel—to have an accurately measured flux. We note that many of these particular stars are faint and superposed on a mottled background because of the halos of bright stars, so that it is natural to have some unusually large position errors. Star E, as seen in Figure 2, is a good example; the size of its error circle in Figure 3 is a good indication too. Note also that the asymmetries that we noted earlier in Figure 2 correspond to large position discrepancies.

As just explained, “outlier” measurements are not uncommon, particularly for stars as faint as these. In calculating mean positions, we therefore used what can be called “iterative sigma-clipping.” First we calculate a mean and a sigma from all the observations (the latter from a percentile-based algorithm, so as to avoid giving undue influence to the outliers). Then we reject all measurements that are outside a circle whose radius is 3 times the single-coordinate sigma. This process is iterated until it converges (usually after no more than one or two iterations). Thus, the circle symbols in Figure 3 denote points that were not used in calculating the means and sigmas.

6. CONCLUSION

We conclude that the six minor events found in the GO 7615 observations of M22 can best be explained by coincident CRs rather than by gravitational lensing. Indeed, Sahu et al. (2001) stated that “The interpretation of these events as microlensing is necessarily tentative.” That caution was even more appropriate than it seemed at the time. Although these apparent brightenings are not caused by microlensing, we should note that microlensing remains a sensitive technique to detect the presence of small-mass objects in a globular cluster.

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