TITLE: A SEARCH FOR FAINT GALACTIC FEATURES

MASTER

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SUBMITTED TO: Conference on Applications of Digital Image
Processing to Astronomy, Pasadena, CA,
August 20-22, 1980

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A SEARCH FOR FAINT GALACTIC FEATURES

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Abstract

Trying to determine the size of galaxies and looking for tails and connections between galaxies can be intriguing. These very faint features are often buried in the film grain noise. Our study is of the NGC 3623, NGC 3627 and NGC 3628 region. The search for these faint features is complicated by film variation, sky background, microdensitometer drift and stars in the neighborhood of the galaxies. We address these questions and show that faint features can be found with the use of judicious data stretching and averaging along suspected features.

Introduction

In the constellation of Leo is a prominent, compact trio of spiral galaxies, NGC 3623, NGC 3627 and NGC 3628. Two of these galaxies, NGC 3627 and NGC 3628, show signs of an apparent tidal interaction which has been modeled for example by Rots [1]. Observations at 21 cm by Haynes, Giovanelli and Roberts [2] show that in general the tidal models seem to represent the observations rather well. As shown by Kormendy and Richell [3] and better illustrated in Haynes et al., there is a long plume-like structure associated with NGC 3628 which extends 45 arc min to the east northeast of the galaxy.

Photoelectric and photographic observations of the trio will be presented by Burkhead and Hutter [4], but due to excessive microdensitometer variations the very faint extensions of the galaxies and the plume could not be adequately studied. This paper is an attempt to show with re-digitized plates how we intend to proceed with the plate reduction to investigate the structure and extent of the plume, to determine if any luminous material exists between the galaxies, and to detect any faint outer structure of the individual galaxies.

The photographic material

The two plates selected for detailed investigation were Kodak 127-04, 10 x 10-inch plates baked at 65°C in K_2 for four hours. Exposures of 74 minutes were obtained with the 38-inch Schmidt on Palomar Mountain in January 1976. The galaxies were carefully positioned on the plate so that there were no "ghost" images from bright stars that might be reflected onto the galaxy field. Unfortunately we did not at the time realize the full extent of the plume structure and therefore the edge of the plate is uncomfortably near the end of the plume. Both plates were taken in good seeing but during a portion of one exposure light haze produced a large halo around the brighter stars. The plume is evident on both plates.

The granite-bed PPS microdensitometer at the Los Alamos Scientific Laboratory was used to digitize the plates. An array of 2048 x 2048 pixels was scanned using a 50- μ square spot. As an aid in detecting and correcting for any possible microdensitometer drifts, a small strip 10 x 2048 pixels perpendicular to the scan path was digitized before and after each complete plate scan. The microdensitometer showed much less variation in 1980 than in previous years.

Figures 1 and 2 show the two scanned images. The only enhancing done was a severe stretch. All pixels above a value near the mean were set to absolute black (since negatives are shown) and all values below were made white. The first thing one notices in these figures are the large light and dark areas. These are mostly due to plate variation. The three galaxies can best be identified in Fig. 1. Along with a large circular star image, they form a group near the center. The small vertical oval in the lower left is NGC 3623, the larger vertical oval in the lower right is NGC 3627, and the horizontal oval at the top right is NGC 3628. Part of the plume can be seen extending from the upper right corner of NGC 3628. The pictures are peppered with small stars which will be eliminated. Lastly, there are horizontal streaks due to drift in the microdensitometer. This variation in scan density will also be eliminated.

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Fig. 1. Computer displayed negative of Plate 1. Up is north, and right is east.

Fig. 2. Computer displayed negative of Plate 2. Note halos around bright stars.

Preliminary enhancement

The preliminary enhancement consists of removing the streaks resulting from microdensitometer drift and removing the small stars that pepper the entire image. As previously stated, a small strip of 10×2048 pixels perpendicular to the scan path was digitized before and after each complete plate scan to aid in correcting for microdensitometer drifts. The location of this strip was chosen such that it missed all galaxies and large stars, i.e., having as uniform density as possible. This is important since it appears that sudden changes in plate density is a possible source of the drift, and since we are going to normalize the total image to these two strips, we want the strips as free of error as possible.

The removal of microdensitometer drift is done in the following manner. The ten points of the first scan line of the total image, which corresponds in position to the two strips, are averaged. Then the corresponding 20 points from the two strips are averaged. The difference between these two averages is taken to be the microdensitometer drift error. All points on the first scan line of the total image are then adjusted by this difference. The process is repeated for all scan lines. A plot of this difference for 500 scan lines of Plate 2 is given in Fig. 3. The drift is evident, but not exactly determined as seen by the dispersion of points. Perhaps this is largely due to the accuracy of the averaging. There are a few points that deviate greatly from the rest. These occur when the microdensitometer encounters a star. Such spurious differences are detected and arbitrarily placed among the average. If left uncorrected, these spurious differences produce a thin, white or black line across the resulting image.

Stars are foreground objects and hence are of no interest in this study. Not only do they clutter the image, but their large density gradients can influence the results of enhancement techniques. The stars must be removed so that the resulting image approximates how the object of interest would look if the foreground stars did not exist.

There are other methods of star removal [5], but our method involves checking each pixel, P , in the image to see if it is greater than all of its eight neighbors. If P is a local maximum, it is checked further, otherwise we proceed to the next pixel since P cannot be a star. The further check involves averaging points that lie in circles of increasing size, all of which are centered at P . The circles considered have diameters of 5, 9, 13, 17, and 21 pixels, with A_n ($1 \leq n \leq 5$), being the values found by averaging the pixels on each of the circles, respectively. Obviously no set of pixels lie on a perfect circle, but we choose the pixels that best approximate circles of the various sizes. We assume that all circles larger than the star image have about the same average. Hence, for some small value ϵ , 0.01 is used here, we check $A_n \leq A_{n+1} + \epsilon$, for successively larger n , until the inequality is satisfied. When the inequality is satisfied, we assume the possible star to

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be within the n^{th} circle. If the inequality is never satisfied, it is assumed to be within the largest circle.

Next, for P to be a star center, it must be significantly greater than the surrounding area. Hence for P to be a star, it must also satisfy the inequality $P > A_n + d$, where the A_n was chosen above and d is specified. We used a d of 0.1. If P is a star, all the pixels within the n^{th} circle are replaced with a scattering of points that lie on the circle. For the larger circles, points must be used more than once to fill the entire area.

Figure 4 shows Fig. 2 with small stars and microdensitometer errors removed. This is a nicer picture to look at and is better suited for further reduction. Figure 4 is also lighter since it is displayed with a different density slice.

Fig. 3. A sample of the microdensitometer corrections applied to Plate 2.

Fig. 4. Plate 2 with microdensitometer drift and stars removed. Note oval southeast of NGC 3627.

Search for common features

One can easily see in both plates the long plume extending to the east northeast from NGC 3627. This raises the question whether some of the other bright areas in the two plates might also be real. The plume tells us that the same feature can appear differently on two plates since it looks much longer in Fig. 1, Plate 1, than it does in Figs. 2 and 4, Plate 2. The search for real features consists of first finding a feature on at least one display of one or more plates. We then check this feature with an averaging technique and compare the results from both plates. This averaging process, which will be described later, is useful for verification since it greatly reduces noise. However, the shape of the suspected feature must be known before the averaging process can be applied. Hence, we take several different looks at each plate, varying density levels, in an effort to locate features that might be real. These suspected features are then shown to be similar (real) or different (not real) with the averaging process. Obviously, the level of confidence that can be placed on the conclusions will increase with the number and quality of the plates used.

The easiest way we found to get several looks at a plate, and one which did bring out structure, was to simply slice an image such that all pixels above some specified density level were set to absolute black and all pixels below to absolute white. This method lets the eye integrate over a small area and assigns it a gray level. We took five looks at each plate at increments of 1.0% in density. Since there is a film variation background on both plates, this allowed us to bring out features in different regions of the plates. Figure 5 shows Plate 1 with a slice at a density of 1.63, which reveals the outer extent of the plume. Figure 6 shows a sampling of pixels in this outer plume region. The sampling is taken along vertical line 1540 between points 1000 and 1500. The point (0,0) is in the lower left hand corner. Note that the pixels have a spread of about 0.08 in density. This will be of interest later when the averaging technique is discussed.

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Fig. 5. Plate 1 with microdensitometer drift and stars removed. Density sliced to show faint end of plume.

Fig. 6. A sampling of pixels in a column of Plate 1. Compare this point dispersion with the line averages in Figs. 12 to 15.

Next, a modification of the simple slice was tried. Each pixel in turn was assumed to be the center of a circle containing 21 points. If 16 of these 21 pixels were greater than some specified density level, the central pixel was set to absolute black. Otherwise, the pixel was set to white. Then isolated points, points different from eight like neighbors, were set to the value of their neighbors.

Before applying this technique to each plate for different slices, all pixels above a specified density were set to a density slightly above the maximum background and a high pass Fourier filter applied [6]. This high pass filter flattens the background and allows one to see features over a larger area of the image. However, high pass Fourier filtering has two drawbacks. Large, faint features are also low frequency components whose density variation is reduced with a high pass Fourier filter, but to a lesser extent than the background variation. The Fourier filter also introduces an artificial drop in density (ringing) around bright objects such as galaxies. The magnitude of ringing is reduced with the previously mentioned cutoff. The ringing alters the faint outer extent of the galaxies, a region which is of interest.

The results of applying this technique to the digitized plate data are given in Figs. 7 and 8. The methods used here to bring out features are rather simple. We may apply more sophisticated techniques as our work progresses [7,8].

Inspecting the various images in Figs. 1, 2, 4, 5, 7, and 8, several features become apparent and are worth checking further. These features are marked on the image in Fig. 9 and labeled on the sketch in Fig. 10. Figure 9 was formed by averaging the two plates, flattening the background with a high pass Fourier filter and then applying a density slice.

Verification of common features

Now that we have identified several features we believe "could" be real, we use a line averaging technique in an attempt to verify that these suspected features exist on both plates. Line averaging cannot find features, but once one speculates at the shape of a feature, it greatly reduces the noise by averaging along the specified path. This way we see the average shape of a segment of the feature. This averaged data from one plate can then be compared with the averaged data from another plate to check for similarities. The reader should be warned that these comparisons are subject to interpretation and hence do not always lead to indisputable conclusions. This is due to plate variations and other seemingly random light and dark areas which by chance may align on a limited number of

Fig. 7. Plate 1 after high pass Fourier filter and 16 of 21 point counter.

Fig. 8. Plate 2 after high pass Fourier filter and 16 of 21 point counter.

Fig. 9. An average of Plates 1 and 2, high pass Fourier filtered and black/white density sliced. Paths of line averages are marked.

Fig. 10. A tracing of Fig. 9 labeling the galaxies and the line averaging paths.

plates. The obvious way to verify or disprove a feature is to examine more and better plates; however, for now we use two plates and state some probability, based on judgment, whether each feature is real.

Line averaging has been used previously [9], and was demonstrated to reduce noise. Considering its ability to lift details out of the noise, it may be interesting to apply this technique to other problems such as faint solar streamers in the outer corona [10] and the faint regions around NGC 111 and other galaxies where the question is not to show existence but extent of these structures.

Line averaging is applied here in the manner illustrated in Fig. 11. One starts with a feature which seems to have about the same cross-sectional structure along some curve. This curve is approximated with connected straight line segments (solid lines in Fig. 11). These

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line segments are defined with integer pixel locations, indicated with '+'s. The pixels nearest these straight line segments are averaged as are pixels along similar paths on either side. These paths are shown as dashed lines connecting pixels in Fig. 11. The average along each of these paths is a point in Figs. 12 to 15 below. The center paths we considered are marked with black/white line segments in Fig. 9. These central paths are called pixel number zero in Figs. 12 to 15. The length (number of pixels averaged) of each path considered is given in Table 1. The noise should be reduced by approximately the

Fig. 11. A sketch illustrating the line averaging process.

Table 1. Line average lengths

Curve	Length (pixels)
5	85
C	175
D	113
E	107

square root of the path length. Comparing the point distribution in Figs. 12 to 15 with a sampling of the unaveraged data in Fig. 6, this is seen to be true. No effort has been made to take the cross section perpendicular to the path. All cross sections are along either rows or columns of pixels. Curves referred to by numbers have their cross sections along rows as sketched in Fig. 11. All curves with cross sections along columns are referred to by letters. Negative pixel numbers are left for numbered curves and down for lettered curves.

The plate correlation of a rather bright section of the NGC 3628 plume, C (Fig. 10), is shown in Fig. 12. (The same portion of the plume is crossed by the scan in Fig. 6). The plume is easily visible on Plate 1 rising approximately 0.01 density units above the background variations. Although not so obvious on Plate 2 due to the rapidly changing background, the plume is certainly present. Similar results are obtained along the length of the plume from A through F. On very high contrast prints, there appears a faint feature along D and E. There is evidence for the feature on Plate 1 (Fig. 13), but the evidence is not overwhelming for its existence on Plate 2. M and N show a minimum along their path. Obviously it would be worthwhile to obtain better plates to see if the plume does turn back on itself toward NGC 3628.

To the southeast of NGC 3627, there is a small, nearly circular area that appears on both plates. Averages along 5 and 6 (Fig. 14) show the area to be common to both plates with a width in the east-west direction approximately 8.3 arcmin and 0.008 density units above the background. In the north-south direction, 7 and 8 (Fig. 15), the feature is also detected but with a length of 6.7 arcmin. Careful examination of a deep print of the 8.3 x 6.7 arcmin region reveals no faint cluster of stars or galaxies. The region is relatively "clean."

Fig. 12. Line average plots of C. The top graph is from Plate 1 and the bottom graph from Plate 2. The plume is the density spike centered near pixel number 0.

Fig. 13. Line average plots of D. A possible extension of the plume is the weak density spike centered near pixel number 25.

Fig. 14. Line average plots of E. The oval feature near NGC 2627 is the density hump between pixel number -25 and 200.

Fig. 15. Line average plots of G. The oval feature, averaged perpendicular to Fig. 14, is the density hump between pixel numbers -125 and 50.

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A bright region to the east of a line joining NGC 3628 and NGC 3627 is seen on both plates, but its nature is puzzling. The plate backgrounds are varying strongly and in an opposite sense so that verification is difficult. Averages along 7, 8, J and K do not show the required correlations, however they do show some tantalizing agreement.

Averages around NGC 3627 (3, 4, H and I) and NGC 3628 (L) reveal the same extended features shown in Burkhead and Hutter [4].

Conclusions

We have developed and applied the following techniques to search for very faint images on photographic plates:

1. By scanning a reference strip of the digitized portion of the plate immediately before and after measurement of the plate and comparing each line with the reference strip, we have greatly reduced the microdensitometer fluctuations.
2. A technique of linear averaging has been developed that greatly reduces plate noise and improves certain detection of faint features.
3. The technique of linear averaging was applied to various features of the galaxies demonstrating that features greater than 0.01 density units above background could be detected. Certain detection requires that a feature be seen on more than one plate. A very faint area southeast of NGC 3627 was detected and weak evidence for further structure in the NGC 3628 plume was presented. It is painfully obvious that only with plates of the very highest quality will we be able to detect and be certain of the detection of large, faint, diffuse structures.

Acknowledgements

Martin S. Burkhead would like to thank Dr. Charles F. Keller for the invitation to utilize the powerful reduction facilities at LASL. The authors also thank Ofelia M. Diaz for typing the paper, and H. Grady Hughes for helping with the computer graphics.

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