

# Automatic Computer Reduction of Astronomical Television Images

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During the 15 months that we operated the Telescope experiment on the Orbiting Astronomical Observatory, we acquired 8700 television frames of star fields containing a total of approximately 10 000 stars.

Figure 1 shows an example of one of these frames. Note the target ring, an aluminum deposit on the target of the tube, in each corner of the picture; the shadow in the upper left corner; the calibration lamp just below the center of the picture; and its ghost slightly below and to the left. All other objects

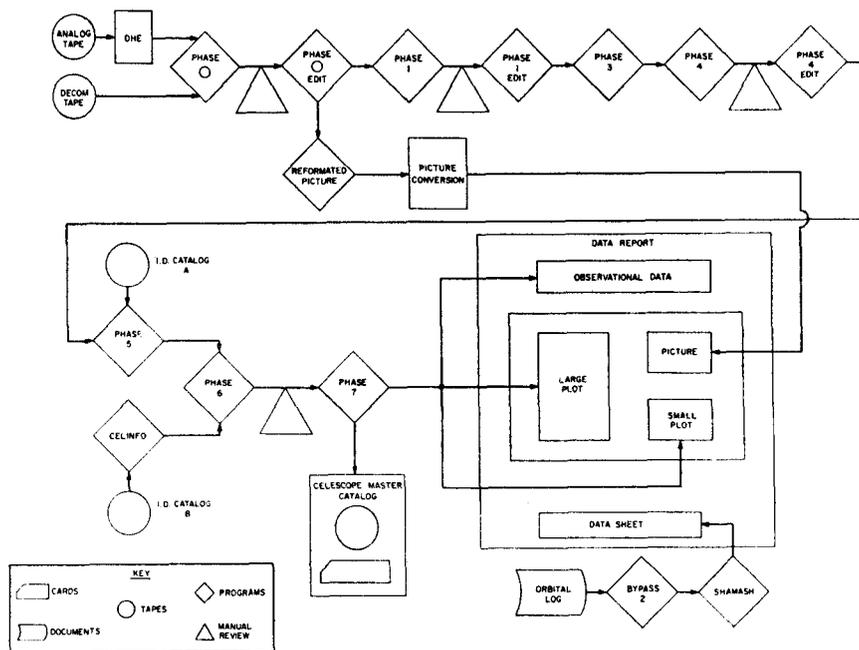


Fig. 2

A schematic representation of the Telescope data-reduction system.

are stars. Each frame consists of 256 scan lines designated by the number  $k$ , with each line containing 251 pixels (picture elements) designated by the number  $l$ , making a total of 65 000 intensity points  $I(k, l)$ . The frames are divided into two spectral regions by two filters—lines 1 to 128 have one spectral range, lines 129 to 256 have a different one. Hence, each frame is reduced as two half frames in the first portion of the reduction system.

Because of this volume of data, it was necessary to create an automatic reduction system that requires a minimum of manual intervention. Figure 2 shows a schematic diagram of this system. I will briefly describe each of its main parts and then return to Phase 1, the heart of the system.

Phase 0 is an editing and reformatting program that gathers the necessary data from the tapes supplied to us by the Goddard Space Flight Center Data-Processing Division and creates our master archive tape. Phase 1 separates the stars from the background and calculates the raw intensity of each star. Phase 3 uses the experiment calibration data to reduce the raw intensities to absolute units. Phase 4 identifies all the known engineering objects in the field, such as target blemishes, the calibration lamp, and its ghost. Phase 5 matches the positions of observed objects with catalog positions of known stars and computes the right ascension and declination of all stars in the frame. It also associates all the

astrophysical information about the star contained in the catalog with the observed data. Phase 6 provides an output that an astronomer can review and check for errors, and Phase 7 creates the final output format, ready to send to the presses for publication.

This entire system relies on Phase 1 to find all the stars in each frame and all the intensities  $I(k, l)$  associated with each star. We assume that the stars are relatively sharp spikes on a smooth background and that we can fit a general cubic equation,  $A + Bk^3 + Ck^2 + Dk + Ek^2l + Fkl + Gk^2l^2 + Hl + Il^2 + Jl^3$ , to the background. Any intensity points that are significantly above the fitted background are regarded as parts of stars.

The actual program has three distinct parts: the first section fits the background, the second decides which points are signal and to which star they belong, and the third prints the output of the stars for any necessary manual review and creates an output tape for the remaining stages of processing.

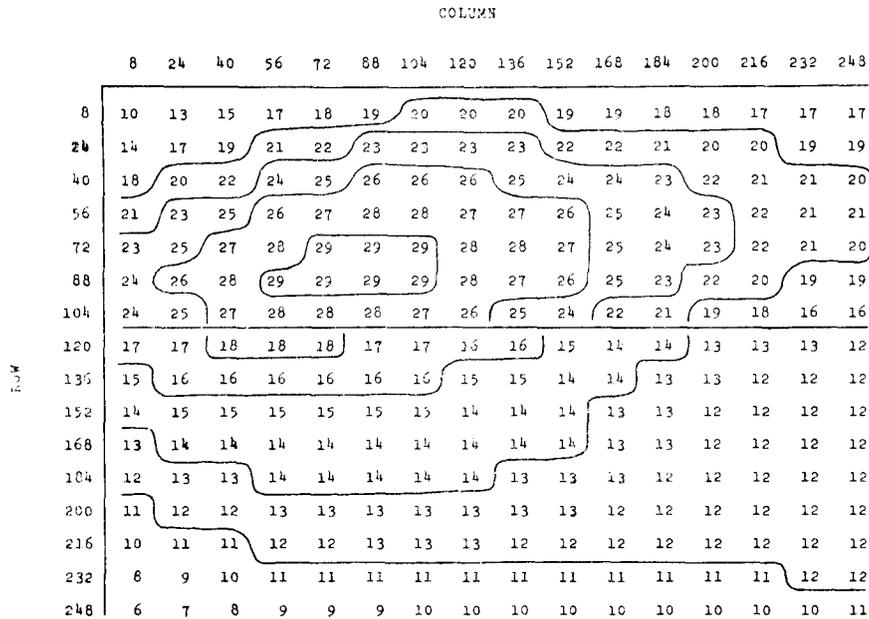


Fig. 3  
Significance level for camera 3, contact Rosman, orbit 413.

The first section of the program computes a significance level for each filter half of the frame by using a least-squares technique to fit the background equation to every fifth intensity point on every fifth line. It iterates this step at least two times, eliminating any points that are more than three standard deviations from the fit, because it assumes that these points are parts of stars unintentionally selected by the regular grid. The iteration continues three more times or until the standard deviation of the fit is changing by less than 0.2. This final equation is the background that the program uses for each half frame. Phase 1 then computes a significance level by adding 2.5 times the standard deviation of the fit to the background equation at each raster point. All intensities greater than or equal to the significance level are signal; all others are background noise. Figure 3 shows the significance level for every 16th point of the sample frame. Note the different levels for the upper and lower portions of the frame.

The second section of the Phase 1 groups all contiguous points greater than or equal to the significance level into objects. The program starts searching for objects in the upper left corner of the frame and works across and down until it finds a point above the significance level. A search is made to find all points above the significance level that are contiguous. When this occurs, the program searches for the next star.

The third portion of the program calculates the center of intensity of the star, subtracts the calculated background from the individual points, and adds them together. Based on its shape and the density of points in the object, the program then decides whether the object is a star, an object that may be either a star or noise, or just plain noise. If it is a star, the information is written on the output tape and printed. If it is a questionable object, Phase 1 only prints the output page and punches a card

with all the data so the object may easily be added to the output tape. If the object is noise, it is dropped. Figure 4 shows examples of the first two classes of objects, a star and a large spurious object. Note the message on the second object—THIS OBJECT IS NOT ON THE OUTPUT TAPE. The program then prints a computer picture of all points above the significance level and numbers each star at its center of intensity so that we can easily find the star in the printed output. Figure 5 shows an example of this printed picture for the sample frame.

This program has been used successfully on over 4000 frames of data and provides the automation necessary to reduce the data with a minimal amount of hand manipulation.

In closing, I wish to thank Mrs L. Kirschner and Mr N. Hall for their programming support and ideas that made Phase 1 work, and to acknowledge the support provided by the National Aeronautics and Space Administration via contract NAS 5-1535.

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OUTPUT FROM THE PROGRAM THAT SEPARATES THE STARS FROM THE BACKGROUND
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Tape  FM  UPPER LEFT CORNER(ROW, COL)  CENTER INTENSITY  N  LENGTH  FAC  SEQ.NUM
TEST   2           118 109             121 112           727   31   6   7  2.50   59

BACKGROUND AVERAGE=  11.23  K,L AND RAW INTENSITY OF THE PEAK ARE 121 113  73

  0  0 19 24 22  0  0
  0 20 36 42 33 24  0
17 24 42 68 64 40 19
  0 24 42 69 73 44 23
  0 17 35 58 63 33 18
  0  0 16 27 23 16  0

-----
Tape  FM  UPPER LEFT CORNER(ROW, COL)  CENTER INTENSITY  N  LENGTH  FAC  SEQ.NUM
TEST   2           121 55             123 56           31    5   4   3  2.50   61

BACKGROUND AVERAGE=  12.07  K,L AND RAW INTENSITY OF THE PEAK ARE 124 55  20

  0 18  0
  0  0 18
  0 17  0
 20  0 18

- THIS OBJECT IS NOT ON THE OUTPUT TAPE --
-----

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Fig. 4

Output from the program that separates the stars from the background.

## DISCUSSION

J. L. LOWRANCE: Why do you skip an odd number of lines when fitting the background?

W. A. DEUTSCHMAN: If every other scan line is different for some reason, then if you skip an even number you will always pick up the even or the odd lines, but if you skip an odd number you pick up alternately even and odd.

E. W. DENNISON: Does that mean you use an interlaced field scan?

W. A. DEUTSCHMAN: No, we use a straight scan, but for some reason the even lines do not give quite the same value as the odd lines.

C. L. STEPHENS: What computer do you use, and how long does it take to analyse a field containing, say, 100 stars?

W. A. DEUTSCHMAN: The computer is a CDC 6400. It doesn't really matter how many stars are in the field; that takes a very small part of the time. It takes about 60 sec of central processor time per frame.

C. L. STEPHENS: What is the magnitude of the possible faint star images that you are rejecting?

W. A. DEUTSCHMAN: Most of the objects we throw out are at the very bottom of our calibration range or below it. We could probably extend our calibration with them, but because of manpower and budgeting restrictions we've chosen to reduce the best of the data first. The limit depends on spectral type, but is 11th or 12th magnitude for A0 stars.

H. D. GREYBER: What percentage of objects found were identified with visible objects?

W. A. DEUTSCHMAN: Unfortunately so far we have not found anything that was not identified with a visible object. There are about three that have questionable identifications.



Fig. 5

Example of printed picture for sample frame.

H. D. GREYBER: Down near Lyman  $\alpha$  do you lose objects in fog?

W. A. DEUTSCHMAN: We haven't been able to reduce the Lyman  $\alpha$  filter data at all, because the Lyman  $\alpha$  background adds nonlinearly.

G. A. H. WALKER: Where multiple frames exist for a region, have you been able to add them?

W. A. DEUTSCHMAN: Yes, but the variation in gain across the face of the tube is large enough that we cannot add the raw signal but must convert it to a calibrated image before addition.

K. AA. STRAND: Have you repeated some of the same fields, and what were the percentages of recognizing the same objects?

W. A. DEUTSCHMAN: Over short periods we get 10 per cent repeatability; over long periods we have problems with filter degradation; but that's getting into the experiment rather than the data-processing system.