EXPLORING METHODS OF EFFECTIVE DATA DISPLAY IN AN INTERACTIVE ASTRONOMICAL DATA-PROCESSING ENVIRONMENT

(Invited paper)

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1. INTRODUCTION

Many of the image restoration algorithms discussed during these past days work best on fields which are virtually empty except for a few discrete sources. But the sky also has faint regions of extended emission; these regions invariably turn out to be of great astrophysical interest and must be represented as accurately as possible in the maps. The methods chosen to present the data in pictorial form can have an important effect on the speed and efficacity with which the astronomer can extract the useful information. I would be afraid of boring all of you with this discussion of display methods if I did not know that, besides being well versed in subjects of probability, statistics, and applied mathematics (and in some cases philosophics and polemics), you are also astronomers with a strong motivation to sift out of your data the useful information on the physics of cosmic radio sources, and to do it in the most efficient way possible.

I should say at the start that I shall not discuss either the structure or the implementation of interactive computer image-processing systems, nor shall I describe the various enhancement and processing algorithms applied to images. My concern here is restricted simply to the problems of displaying the images. Although I am convinced that careful attention should be paid to displaying the data at every step of the reduction, most of my own experience has been with maps of the radio sky at the latest stages of the data reduction process.

2. DISPLAYING SINGLE-IMAGE DATA SETS

When the area to be displayed contains only a modest number of telescope beams (10^1-10^3), the traditional representations as contour and ruled surface maps are generally adequate (e.g. Fig. 1). Indeed, the addition of shades of grey or colour to the contours in this case is usually viewed as unnecessary embellishment, of use possibly only for public relations purposes. Contour diagrams have the great advantage of providing a

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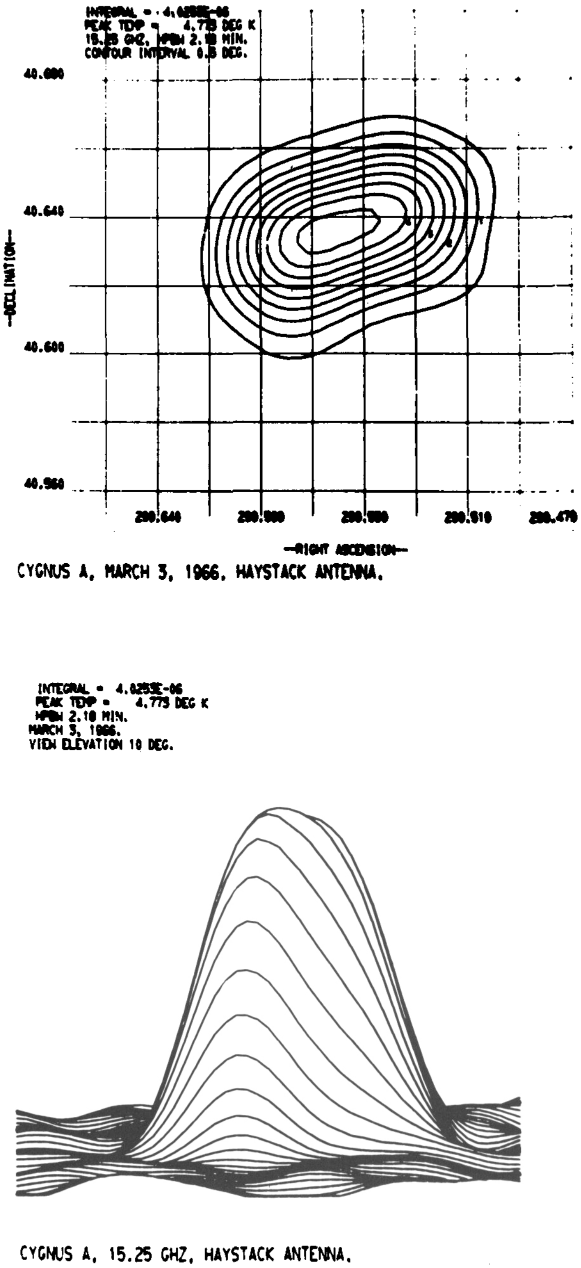

Figure 1. Contour (upper) and ruled-surface (lower) representations of a radio image of Cygnus A. This is a familiar way of displaying fields which contain only a modest number of beam areas.

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method for quantitative display, in particular for negative intensities if some means of flagging negative contours is used.

Difficulties with contour and ruled-surface displays begin to appear when the area to be represented covers very many telescope beams (10^3 or more). In this case, grey shading and the use of colour can indeed be useful and may even be essential.

a) Contour Display

Although retaining the important advantage of being reasonably quantitative, contour plots of high-resolution images give a poor visual impression; gradients are emphasized rather than intensities (e.g. Fig. 2), and if the S/N ratio is furthermore not very high the particular choice of contours and contour interval has a great effect on the appearance of the picture (e.g. Fig. 3). Reducing the number and choosing the level placement of contours in order to improve the visual impression inevitably results in a loss of information which can severely limit the utility of the display.

b) Ruled Surface Display

This type of display provides a reasonable visual impression for high-contrast features (e.g. Fig. 4) such as discrete sources and bright ($S/N > 10$) extended regions. It is essential that the "hidden lines" be deleted from the display; otherwise the impression of viewing a solid surface disappears and the picture dissolves into a jumble of wiggly lines. An important shortcoming is that weaker features of objects can literally be hidden behind stronger ones.

If the S/N ratio per beam area is only of order unity, extended sources remain invisible to the eye on ruled surface plots. Grey-scale displays are better for detecting such features.

c) Grey Display

The right panel of Figure 5 is a high-contrast grey display of the same image from which the ruled surface display of Fig. 4 was made. The existence of faint extended emission from the disk of the galaxy (left panel of Fig. 5) is unequivocal even though the S/N per beam area is only about 0.5. This type of display presents a more familiar kind of picture to the viewer, and the highly-developed pattern-recognition capacity of the eye and the brain is more readily utilized.

Grey displays are, however, generally not very quantitative; they also require arbitrary zero level shifts in order to represent negative intensities. The available dynamic range of the final display is an important limitation; representing an intensity range more than about 30 on photographic printing paper is hardly feasible. Transparent film is better ($\sim$300) in this respect. For a given level of background illumination the range of intensity discernable to the average human eye is of the order of 1000.

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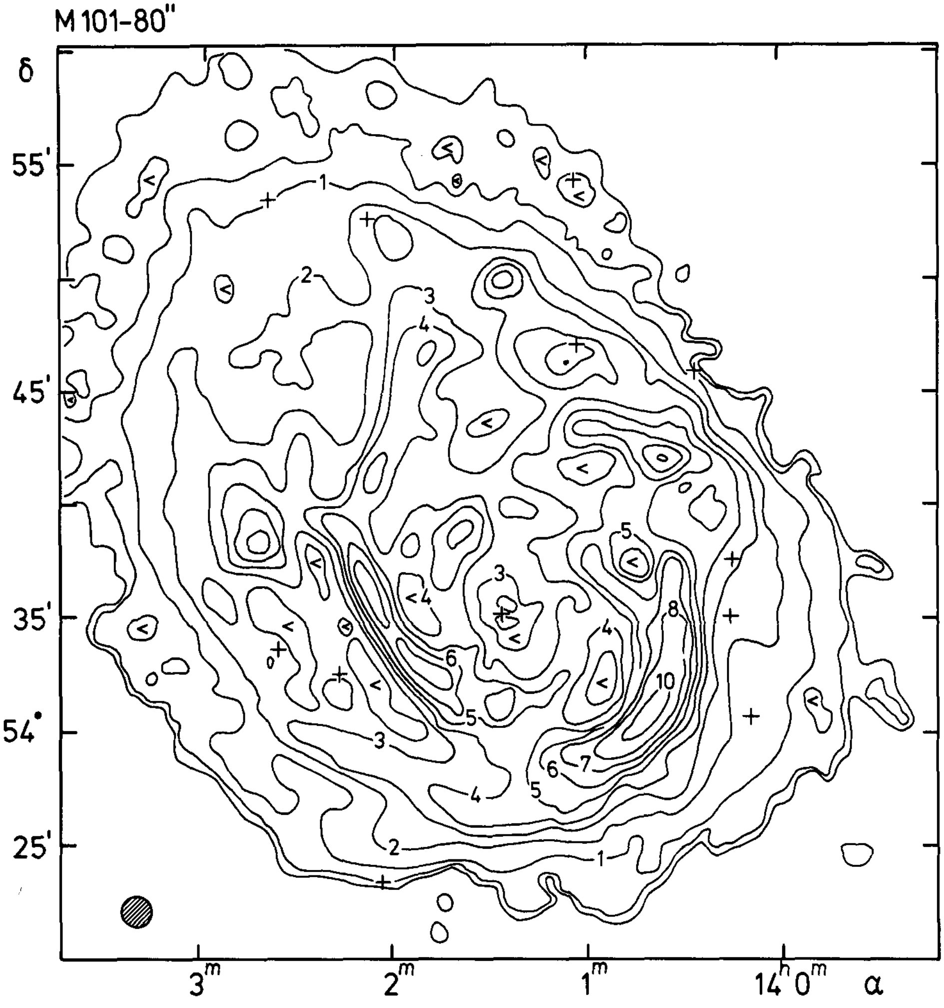

Figure 2. Contour display of the total HI in M101. A selection of contour levels to display has been made; for example there are no negative contours, the zero contour is omitted, and the contour intervals are not equal. Although the visual presentation is thereby improved somewhat, the overall impression is still confusing, and gradients are emphasized rather than intensities. The region of interest contains about 500 beam areas.

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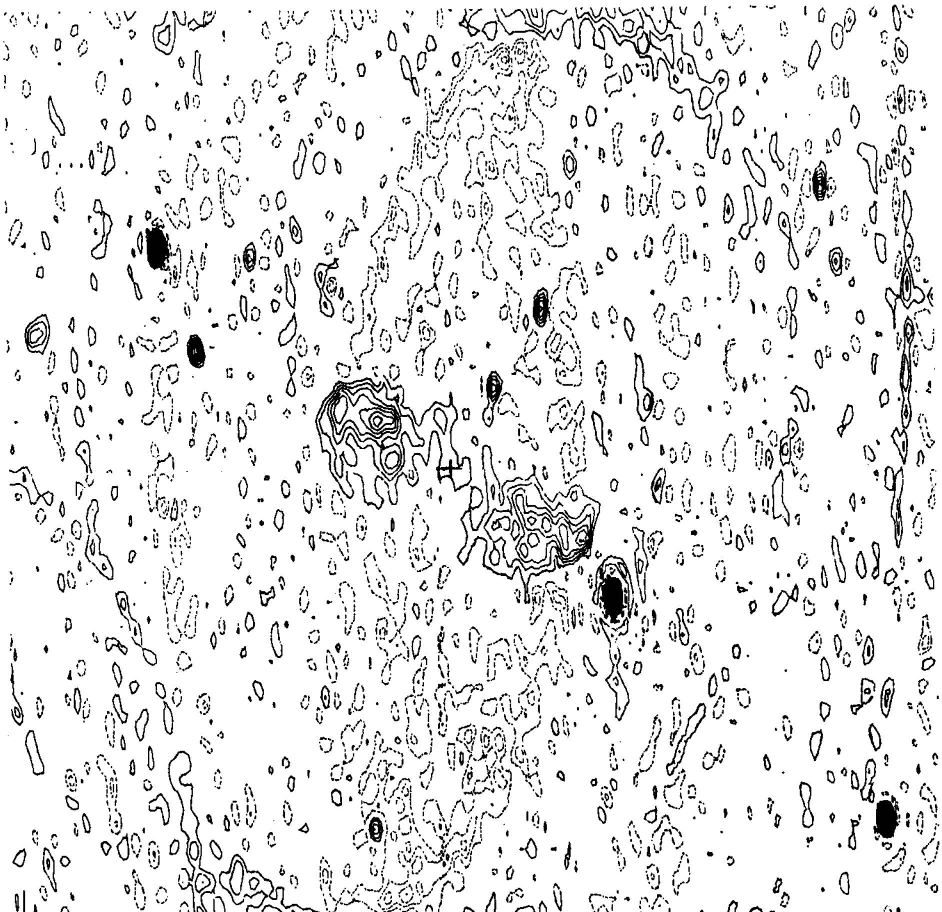

Figure 3. Contour display of a region containing about 5000 beam areas. The general first impression is one of confusion, even though the zero contour has been omitted to improve the presentation. Negative contours are dashed.

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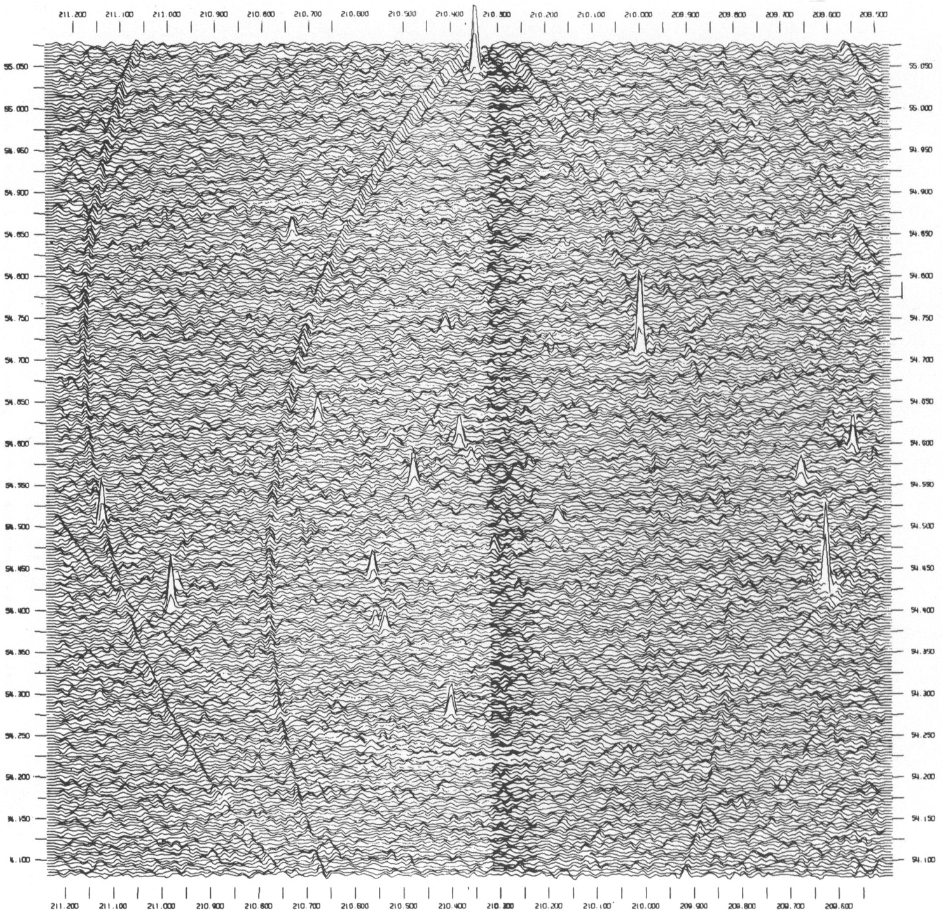

Figure 4. Ruled surface display of a region containing about 11,000 beam areas. High-contrast features stand out here, such as the discrete sources and their associated grating rings. Faint extended regions of low surface brightness remain invisible (cf. Fig. 5).

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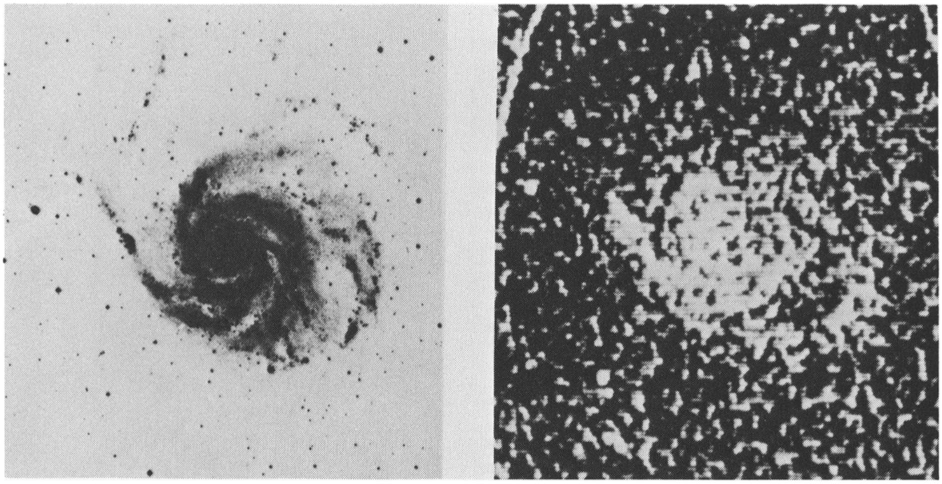

Figure 5. The right panel is a high-contrast representation of the central regions from Fig. 4; all positive areas are simply set white. The faint (S/N ≈ 0.5 or less) extended continuum emission from the disk of the galaxy is clearly recognized here, although it remains invisible in Fig. 4 even if one knowns exactly where to look. The optical image of the galaxy is shown in the left panel.

d) Pseudo-Colour Display (colour contouring)

For this type of display each data value is used to determine the colour (lightness L, hue H, saturation S) of the image at that point. Usually a small range of data values are all assigned the same colour; the effect is the same as when one colours the areas between two contours on a contour plot drawing. Besides the pattern-recognition capabilities of the eye we can here make use of the capacity to detect small changes in hue.

Pseudo-colour displays also offer a method for obtaining higher dynamic range in the final representation than is possible with grey displays. Successive contours can be assigned colours which cycle through the spectrum, effectively providing a high-contrast display at every contour level. Furthermore, negative intensities can also be easily distinguished by making a judicious choice of intensity level colour coding around the zero level. Most important is that colour printing methods can preserve the integrity of a pseudo-colour image in a final publication.

One difficulty is that the visual impression created by a pseudo-colour image may sometimes be too strong, such as when large areas of the picture are filled with bright saturated colours or when the colours for successive contours are chosen at random. Even more serious is that the visual impression may also be incorrect if unimportant features are inadvertently over-emphasized. It would seem that there is room here for some controlled and systematic experimentation in order to arrive at an effective presentation.

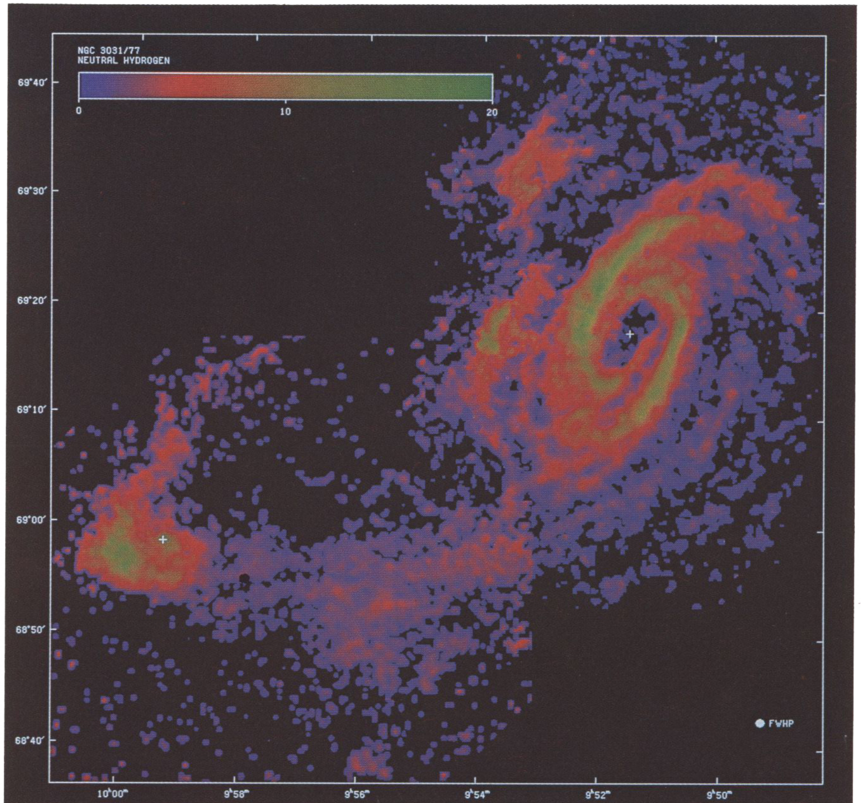

Figure 6. A pseudo-colour (colour-contour) display of the HI distribution in the region of M81 and NGC 3077. Care has been taken to represent contours covering larger areas of the display in more subdued tones.

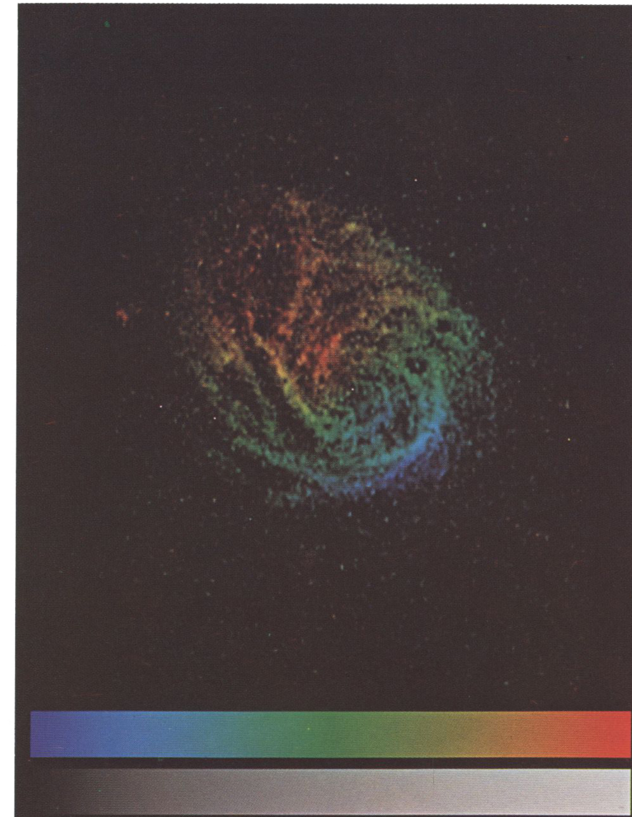

Figure 10. False colour image of the HI distribution and kinematics of M101. There are more than 100,000 independent data values represented in this picture.

Figure 6 shows an example of colour contouring in which a useful choice of colours has been made.

3. DISPLAYING MULTIPLE-IMAGE DATA SETS

Two methods have been explored for representing a third independent variable such as polarization or frequency in an image data set; these are "false" colour and cinematography. Before describing an example of a false colour display it may be useful to examine Table 1, in which the different kinds of colour displays are described in the terms commonly used in the electronic-image-display industry.

a) False-Colour Display

If the data set contains only 3 images, a one-for-one assignment of L,H, S may be tried; two examples are for radio polarization (e.g. Intensity = L, Position angle = H, Percent polarization = S) and for the first three moments of spectral line profile images (e.g. Profile integral = L, Mean frequency = H, Profile width = S). As with the pseudo-colour display, some systematic experimentation is needed here.

If the data set contains $N > 3$ images, some $N \times 3$ matrix transformation can be tried. Figure 7 shows a grey display of two images from a set of 12 single-channel HI maps of a nearby galaxy. A possible matrix transformation on this set is shown diagrammatically in Figure 8 superposed over the total integrated HI profile of the galaxy. The three R,G, B output images are shown in Figure 9, and the final colour composite in Figure 10. The features best illustrated by this type of display are the overall rotation of the galaxy (i.e. the gradient of colour from blue on the lower right to red on the upper left), and the large-scale deviations from circular motion. Here too it is clear that further experimentation is necessary; one could, for example, try to enhance the smaller-scale velocity anomalies by first subtracting off a model of the circular rotation.

b) Cinematographic Display

This type of display seems especially useful for detecting correlations among the different images of the data set. It makes use of the highly-developed capacity of the eye and the brain for detecting motion. An experiment has been made by time-sequencing a set of spectrometer maps along the frequency axis and recording the sequence on video tape. A number of new phenomena could be seen in the data (the video tape was demonstrated at the meeting).

Another possibility would be to time-sequence the remaining spatial dimension in a data set organized as position-velocity images. There is here also much room for further experimentation. The cinematographic display probably is especially useful in the initial phases of reconnaissance of the data set.

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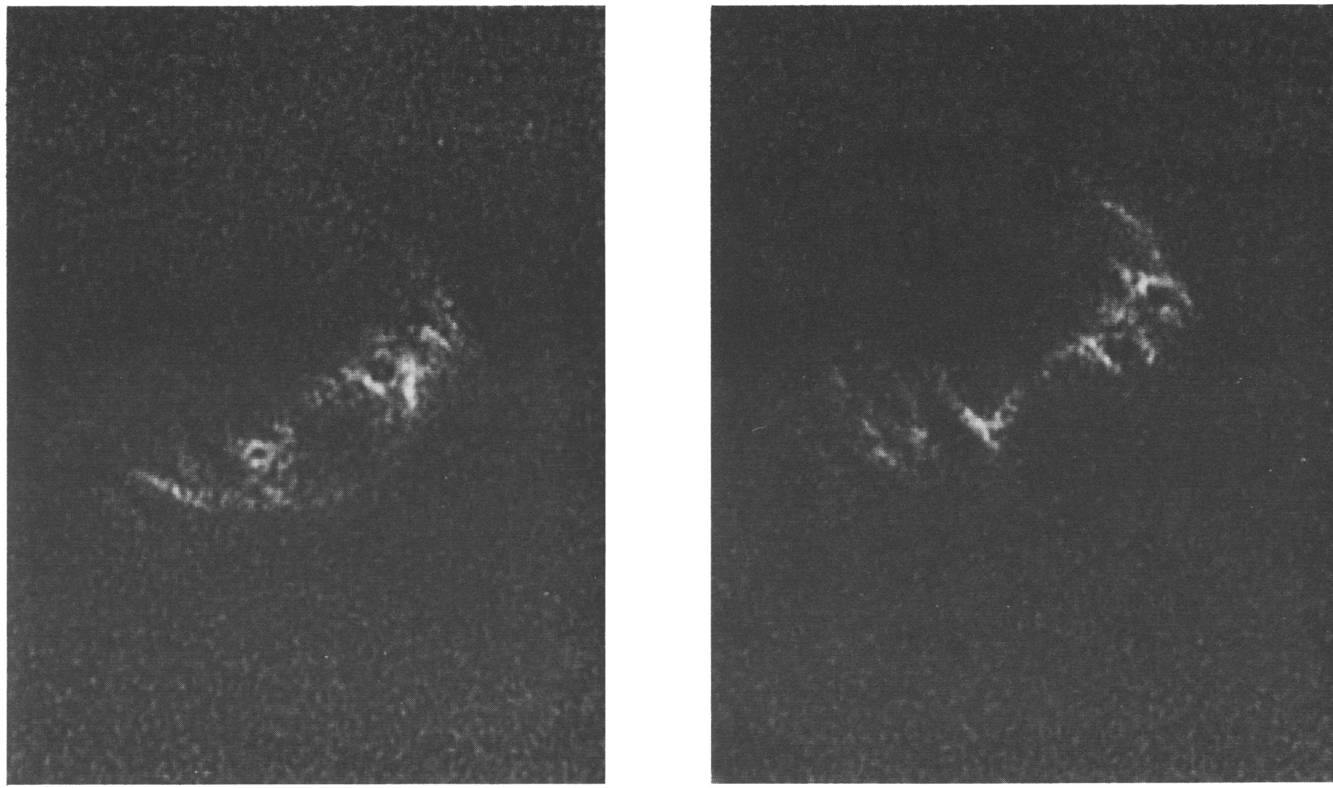

Figure 7. Two neighbouring channels (at velocities of 220 and 240 km s^{-1}) from a spectrometer synthesis survey of a large nearby galaxy are shown here as a grey display. The set of 12 such images was used as input to the "3-filter" matrix transformation shown in Fig. 8.

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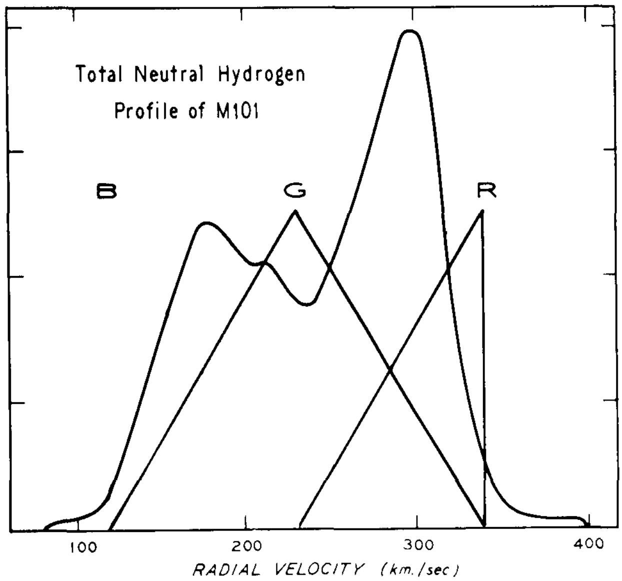

Figure 8.

Graphical representation of the R,G,B filters used to transform the 12-map set of images (cf. Fig. 7) to the 3-map set of Fig. 9.

1. Pseudo-Colour (colour contouring)

Use the numerical value of a pixel at a given point of a single image to compute an assignment of displayed R,G,B intensities at that point. The computation may pass through an intermediate step of choosing the lightness, hue, and saturation (L,H,S) which are then transformed to R,G,B intensities and additively displayed.

2. "True" Colour

Photograph a given real scene three times onto black-and-white film through R, G, and B filters successively. These three colour separation images are then projected by the same R,G,B filters onto a single screen to produce a "true" colour display.

3. "False" Colour

Subject a set of $N \geqslant 3$ two-dimensional images to some computational procedure which produces 3 secondary R,G,B images; these 3 intensities are then additively displayed. As with the pseudo-colour display an intermediate step through L,H,S may be made.

TABLE 1. Operational definitions of the different types of colour displays as understood by the image display industry.

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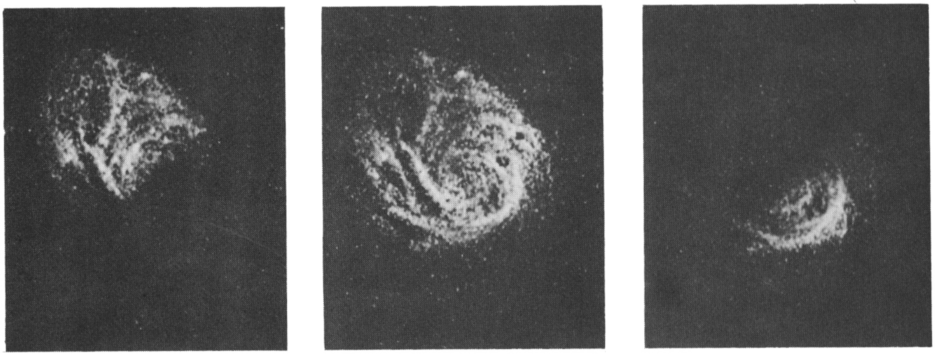

Figure 9. The R,G,B colour separation images produced by a 12×3 matrix transformation in the spectral dimension on the data set of Fig. 7.

4. POSSIBLE DIRECTIONS FOR FUTURE DEVELOPMENT

The need for experimentation in methods of effectively displaying astronomical data has been repeatedly mentioned in the previous discussion. In order to carry out such experiments it is necessary to have the hardware at hand. It would seem therefore profitable to set up a data analysis and display system which makes grey, colour, and cinematographic displays easily and conveniently available to the astronomer at the earliest stages of his image-processing effort; these facilities should be provided as an integral part of an interactive computer data reduction system. A means would then be available for:

- examining all the data taken;
- early detection of residual instrumental problems;
- rapid access to the astrophysically interesting parts of the data set (often only a very small fraction of the total);
- recognition of unexpected results.

A second area still to be explored is to try to bring the model-building phase of the analysis as much as possible into the same interactive picture-processing system. This makes available all the display facilities in order to compare models and observations in a similar way, and should provide the possibility for a rapid parameterization of the astrophysically interesting results in the data in terms of the models.

ACKNOWLEDGEMENTS

I am grateful for the collaboration of R.D. Ekers on several of the experiments described in this talk. J.M. van der Hulst and A.H. Rots kindly provided me with the pseudo-colour picture shown in Figure 5. R. Sancisi and U.J. Schwarz gave helpful comments on an earlier version of the manuscript.

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DISCUSSION

Comment R.H.T. BATES

Have you attempted to use histrogram equalisation, which is now standard practice in remote sensing? Histogram equalisation significantly increases the visually apparent details in an image.

Reply R.J. ALLEN

No, I have not tried to do this on radio astronomical images, although I have observed the technique being applied to satellite photographs.

Comment D.C. BACKER

I have worked with false color displays of pulsar polarization observations and I have encountered a problem with color blindness: two of the pulsar experts involved were color blind. I would like to test the statement that a large fraction of the males in the audience is color blind. Could we have a show of hands of those who are partially color blind?

Reply by AUDIENCE

Less than a few percent of the 100 attendants indicated color blindness.

Comment B.F. BURKE

Color displays of data have absorbed large amounts of money and talent, with almost no results so far. Grey-scale representations seem to be adequate. I suggest that there is a psychological basis for the lack of usefulness of color displays. Perhaps black and white are good enough for the "gestalt", while color involves the emotions.

Reply R.J. ALLEN

You may very well be right. However, I think that far too little systematic experimentation with the color display of astronomical data has been done, perhaps because the presently available techniques are rather clumsy and time-consuming. I would prefer to regard your comment as a hypothesis to be tested.

Comment R. GORDON

As an application of appropriate interactive or automatic image processing, it should be possible to guide telescopes according to the maps gathered so far. This could substantially reduce the observing time.

Reply D.B. SHAFFER

There is an on-line example of imaging at the NRAO single dishes. Line and continuum observers can get a quick look at their spectra and maps, and decide on their next move. This ability has proved to be efficient in terms of telescope time.

Reply R.J. ALLEN

Yes. I'm sorry to have let my personal bias come through; I was not thinking primarily of single-dish spectral line data for this presentation, although it is clear that more space should have been devoted to it.