1

VISUALIZATION OF THE COSMOS

From time immorial the starry sky has appeared in the human eyes as a vast dome of darkness speckled with tiny spots of lights. With the sun rise all those speckle of lights disappear. As the hours of the day increase the sky becomes blue until the fall of night when it sinks into darkness ushering in the candles of the Heaven. In clear nights, when the moon does not shine, one can see a faint band of illumination passing across this heavenly dome. It is known as the Milky Way, because it looks like a path where a milkman in the Heaven has spilled on the way.

In the ancient world the moving objects in the sky, which are known as the planets today, were considered to be the manifestations of different gods. Among them the Sun is the most blazing and powerful one. Knowledge about these gods got a radically new perspective when Galileo brought the Heaven closer with the telescopes.This resulted in dethroning the gods from the Heaven.

With the help of the invention of better and better telescopes the human vision expanded further and further beyond the moving planets. Soon human beings found themselves being surrounded by millions and millions of stars. It was first believed that the universe was an infinite sphere filled with stars. Even better quality of telescopes revealed that all the heavenly objects were not similar. Some of them were fuzzy and nebulous. Inmvention of even larger telescopes showed the details of the fuzzy objects , which, in fact, were island universes containing millions of stars.

The nature of these stars remained unknown until the last part of the twentieth century, when the physics of the burning of nuclear fuel inside the stars was understood. This started changing our view of the cosmos in an accelerated pace. The major contributor to this change has been the theory of light. Newton had found out that the white light was composed of different wavelengths corresponding to different colors. It breaks into a spectrum of a rainbow when it passes through a prism. When the spectra emitted by different incandescent objects were analyzed, some wavelengths were found missing from an otherwise continuos spectrum. By the second half of the nineteenth century it was realized that this absorption of wavelengths from the spectrum was caused by chemicals present in the burning object. As different elements absorbed different wavelengths, knowing the missing lines in the spectra, one could find out which chemical elements were present in the object. This gave us the understanding about the chemical nature of the stars, which were found to be composed of the same elements observed on Earth.

Then the advancement of research on nuclear reactions brought an understanding about the real nature of the stars. The universe contained millions and millions of burning gas balls of huge dimensions, possessing temperatures of tens and hundreds of million degrees, which were held together by the forces of gravity.The Milky Way was nothing but an arm of a galaxy, which contained millions and millions of stars. Sitting at the edge of an outer arm inside this galaxy we have been watching the island of stars as the Milky Way.

In the sky some stars appear brighter than the others to eyes. The Sun is the brightest of them; then comes Sirius, which is several billion times less brighter than the sun. The stars, which are a few hundred times less brighter than Sirius, are not visible to naked eyes. These invisible stars are, in fact, most numerous. The faintest star is about 100 million times fainter than Sirius. They look so faint because they are very far away from us. Sirius, which appears faint compared to the Sun is, in fact, 5 times more blazing than the Sun. However, it is nearly nine light-years away, while the Sun is only 8 light-minutes from Earth.

The developments of satellite technology during the last few decades of the twentieth century have added newer perspective to this human adventure to see deeper into the cosmos. With launching of satellites Astrophysics can now survey the sky in x-rays and gamma-rays.

Limitation of human vision

Normally our eyes can only see in a restricted band of wavelengths ranging from 700 nm to 400 nm. The sensors in the retina, that are about 100 millions in number, possess different sensitivities to different wavelengths. Moreover, the sensitivities of the eyes to colors do not have any linear relation with the wavelengths. There exists three different types of sensors in the eyes, that have different absorption characteristics as a function of wavelengths. One type shows peak absorption in the blue region, the second in the green, and the third in the region bordering red. The physical attributes of the sensors on the retina create our perception of colored vision. Therefore we see some colors better than the others, though their intensities could be the same. Not only that, the perception of different intensities of the same color do not follow linear relation too. When the intensity detected by the sensor is only 18% of the original intensity, our eyes perceive this as half as bright. So the theory of human vision is highly complex, and not understood yet.

Computer vision

By using the knowledge of the color theory, and the human perceptions of vision, the eyes can be aided to see beyond the range of wavelengths, that they can normally visualize. This belongs to the subject of color mapping and image enhancement.

The visualization with digital camera is achieved by building sensors that are sensitive to the wavelengths in which one wants to see. They detect intensities of radiations and make a digital map of the data in a given frame. The values of the data points have no colour at this stage. However, one is free to assign a colur to a particular intensity value, and make appropriate transformations to the rest of the points. This distribution of the colour values depends on the color pallette one works with. If one uses a pallette of 256 colors, only 256 different groups of points corresponding to different intensity values can be generated. If one uses a palette of millions of colours, then one can explore much finer details of intensity variations detected by the sensors. By this way computer gives a tremendous boost to our power of seeing.

Moreover, bringing computers one can enhance intensities according to one's desire, and assign a histogram of colors to the data set suitable for the purpose of observation. So the ways of seeing depend on the ways of manipulating the data. As such, there exists no such thing as a real way of seeing the data set, which is nothing but a set of numerical values. All seeing become dependent on the purpose of seeing, and the information one is interested to extract from the data.

Most usual way of interpreting data in science is the rainbow color map. In this representation the lowest value of intensities are mapped as blue, while the highest values are mapped to red. The intermediate values are mapped continuously onto values interpreted between these two colors in the red-green-blue color space. Information reproduced by such mapping is an artifact of the mapping and may not reveal the underlying characteristics that may be present in the data. To make a meaningful extraction of information one also needs to take into account the theory of color perception because, as mentioned before, the signal information received through our perceptual apparatus to the brain do not carry one-to-one linear relationship with the data.

In fact, every color we view possess three perceptual dimensions: First is the luminance dimension, which creates the perception of brightness of the source; second is the saturation dimension, that implies the purity of the color under view; the third is the hue dimension defined by the wavelength of the color seen. Human visual perception also depends on how the intensities vary in space. In situations of high frequency variation one can see more structures by manipulating the luminance values, while saturation variation can be a better tool for the low-frequency regions. So the content of the color vision fully depends on how one interprets the data set.

Image acquisition, processing and display

To see the cosmos beyond the wavelengths that eyes can see, one needs instruments for data acquisition, interpret the information contained in the data, and then display the interpreted data for viewing. So information coming to the viewers pass through several non-linear transformation on the way from the sources to the eyes.

The milestone in the digital image acquisition is the invention of semi-conductor based photo-detector arrays. When radiation fall on the sensors, they absorb the photons and release electrical charges varying with the intensities impinging on the sensors. These charges are then converted into electric voltages. High sensitive instruments used in Astronomical studies in the visual range contain several million sensors, that possess high efficiencies to convert photons to charges. In some of them, the fraction of charges produced per photon can be close to one. The silicon imagers can also be made sensitive well into the x-ray wavelengths.

The electric voltages are then converted into digital signals to be used with the computers. Advanced image processing software then provide tools to manipulate and extract information from the digital data. The availability of hardware and software that can handle image processing with millions of colors with fast processors, together with millions of sensitive sensors for detecting the invisible signals from the cosmos have totally revolutionized our ways of visualizing the universe during the last few years.

Scalar and vector quantization of images

A digital image consists of an array of NxM cells, where N and M are the number of cells in each row and column respectively. In each cell a value of intensity is assigned. Each of these cells are called a picture element, or pixel. The visualization of the picture depends on how many color levels can be assigned to the pixels forming the image. So each picture is quantized by the spatial resolution and the color values. High spatial resolution and a large range of color values will generate a very rich information about the structure of the imaged object.

In the scalar quantization, the color value assigned to an intensity value is decided through a set of decision levels. If the intensity falls between two decision levels, it is quantized by a fixed reconstruction level. So the quantization problem in the digital images involve a set of decision levels and a set of reconstruction levels. The decision and reconstruction levels can be chosen to minimize the quantization error. In vector quantization the picture is described by vectors pointing to the intensity value in the image space. Vector quantization involves the subdivision of the image space into J decision regions D_j , each of which encloses one of the J reconstruction values. The signal vector is quantized to reconstruction vector r_j. So, the scaling of the image size will not affect the structure of the reconstruction vectors.

Image processing in false colors

In pseudo color, any color can be assigned to any intensity value and all pixels with the same intensity will possess the same color. Colors only highlight the differences among the intensity values in the data. So, the computers can provide enormous flexibility in analyzing the information contained in an image by using different color maps and techniques of image enhancements. Thus computer image analysis provides the possibility to visualize images, that could be useful in revealing details of the structure that are suitable for specific scientific or engineering needs.

Intensity transformations

Negative image

Negative of a digital image can be generated by assigning decreasing values to the reconstructed image points as the intensity value increases, which means the least luminous points will be represented as the most luminous points in the reconstructed image, while the most luminous values will appear dark in the gray scale.

Contrast manipulation

A computer can display 2^8(=256) different shades of grey, and most computers in the market these days can produce 256 brightness values for each of the three primary colors. Therefore computer can produce 2^{24} (= 16 million) different color values. This is extremely large variation, compared to the capacity of the human eyes to distinguish between colors. Normally we can only distinguish a few hundreds of colors. Assigning such a spectrum of colors to the intensity values will create a representation where much of the information of the image will remain hidden from our eyes. In this situation one can compress some region of the intensity values and expand another region to spread the values that can reveal information in the domain that otherwise remains invisible. Computers can generate highly nonlinear and arbitrary transfer functions for achieving results that can enhance image information immensely.

Histogram equalization

Let us say there are n pixels in an image to be processed, out of which n_k number of pixels are assigned the grey level r_k, then $p(r_k)=n_k/n$ can be interpreted as the probability of occurrence of the grey scale r_k .A plot of these function for all values of k will represent the histogram of the image.

Histogram of a typical natural scene, that has been linearly quantized, often shows that majority of the pixels possess a luminance less than the average. In these kinds of pictures the details that fall in the darker regions are not discernible. By modifying the histogram of the image it is possible to enhance the details in the darker parts. Histogram equalization is based on the idea that equal number of pixels have each possible brightness value. Thus it reassigns the brightness values of pixels, while individual pixels retain their brightness order , i.e. they remain darker or brighter than other pixels. This equalization can make it possible to see minor variations within regions, that appeared uniform and without structure before the modifications were made.

Edge enhancement

To use edge enhancing filters in modifying images can be very useful for astronomical purposes. In images, where extremely bright and dark areas cover the intensity range, by compressing the range nonlinearly making use of logarithmic transfer function, it can be possible to see structures from both ends of the extreme scale at the same time. There exists several methods of edge extractions, known as edge operators - among them Sobel operator, Kirsch operator, Marr-Hildreth operator etc. are often used.

Filterings

There are different kinds of filters. Image sharpening filters can be useful in discovering details in an image. These are highpass filters that eliminate or attenuate low frequency variations. As the low frequency components cause slowly varying characteristics of an image, the high-pass filter causes apparent sharpening of the edges, and produces other sharp details. The role of the low-pass filter is just the opposite.

Interdependent operations in image processing

Gamma modification, contrast stretching, hue and saturation adjustments, histogram equalization, filtering, edge detections all can be combined to reveal interesting information about the objects under study. What do not change in such manipulation is the relative intensity differences among the pixels, while all values can be stretched, compressed, reassigned to different colors, rearranged etc. However, it will be extremely difficult to produce a step-wise algorithm to extract exact set of information by combining all, or some of the operations mentioned above unless one has a clear knowledge of the human visual perception, which is highly nonlinear. For a particular object, certain combination of hue, saturation, contrast, gamma value, filters etc. can bring forth in details a marvelous hidden structure that one can not see in the standard methods of viewing by processing the data in rainbow colors.

SEEING THE COSMOS DIGITALLY

There are several good computer software available these days, that can handle the processing and visualization in false colors very well. Among the pixel oriented software Micrografix Picture Publisher, Adobe Photo Shop, and Paint Shop Pro by JASC are some of the software, which are found to be good for the purpose. However, different programs have different advantages and qualities as regards manipulation of different aspects of the digital images and color mapping. By making use of the best aspects of the software together, it is possible to reveal unprecedented information from the digital data of the cosmic objects. The analysis of the images have also been combined with vector graphic software like Macromedia Freehand, which is a resolution independent program, and handles the tracing of edges well. It can transform the pixel-based images into mathematical objects involving curves, as well as can transform a vector-image into a pixel-based raxtor-image efficiently. Macromedia Freehand has been an essential tool in studying the details of the images in small scales.

Image processing example: Cartwheel galaxy

The ways different image manipulation tools work are shown below by using the above mentioned software to the images of Cartwheel galaxy, that are taken by the Hubble Space Telescope.

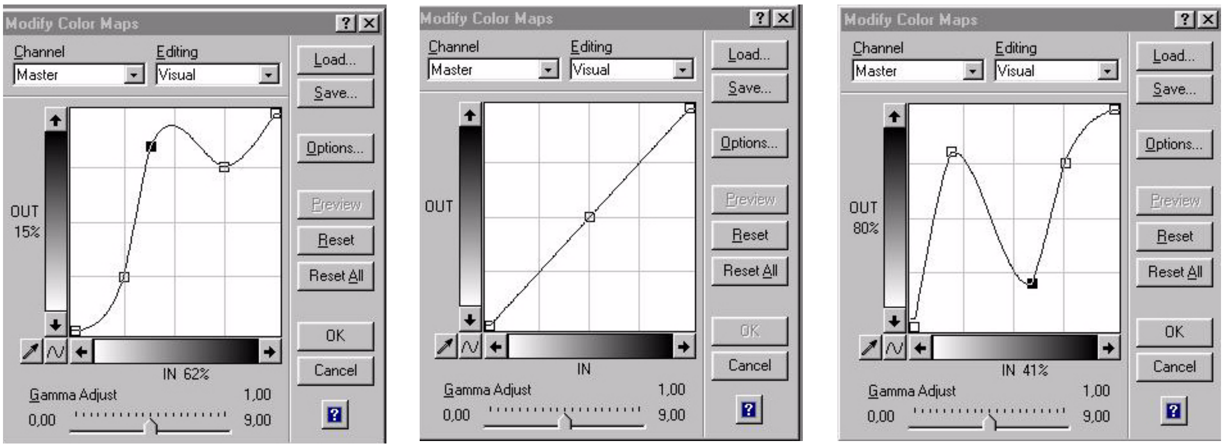
Intensity corrections: Gamma

Where the general intensity level is too low or too high, gamma transformation are used to map the intensities to a different sets of values as follows

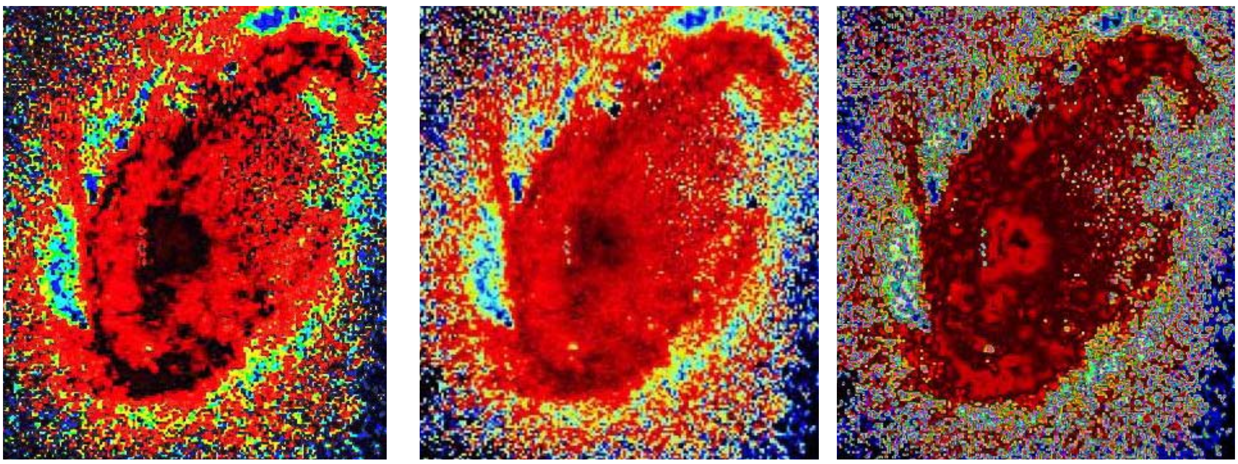
$$g(I) = I^{\left(\frac{1}{\gamma}\right)}$$

where I is the original intensity value and g(I) is the gamma transformed value. In this operation the highest and the lowest intensity values are kept unchanged.

Example of gamma corrected Cartwheel nucleus
(Original is by Hubble Space Telescope)



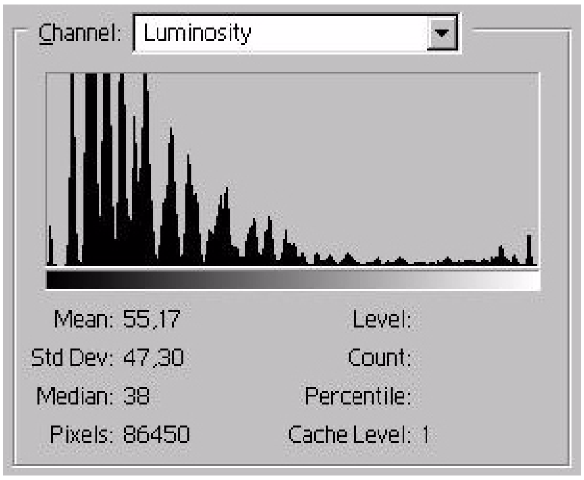
Gamma corrected | **Original** | **Gamma corrected**



Histogram equalization

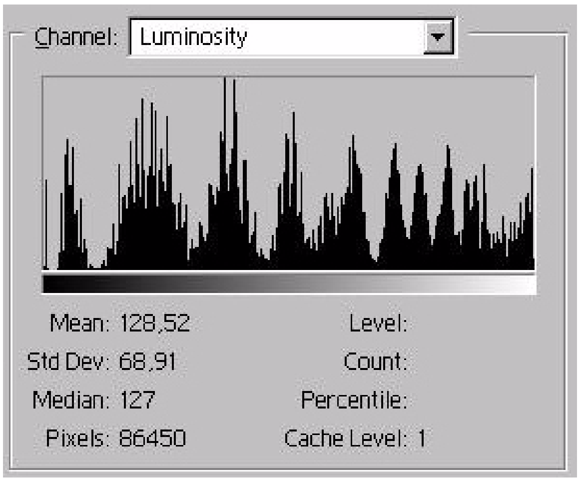
It increases the steepness of the intensity by making the shadows darker and changing the highlights to lighter values.

Example of Cartwheel
(Photograph by Hubble Telescope)



Histogram of the image to the right

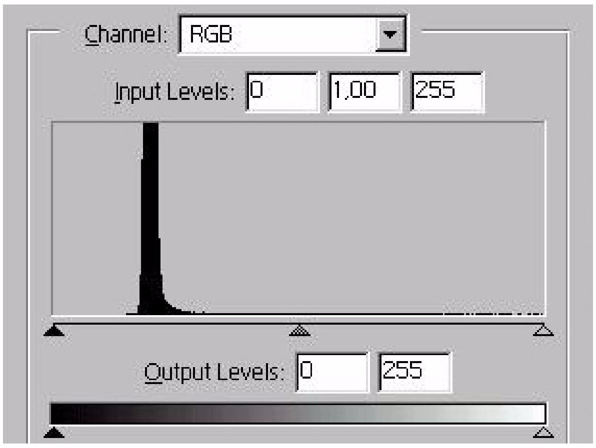
Histogram equalized image

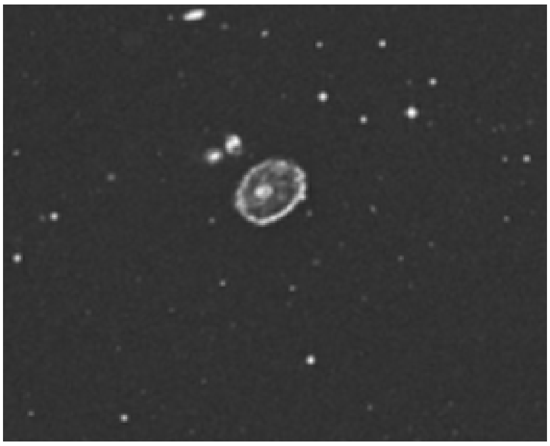


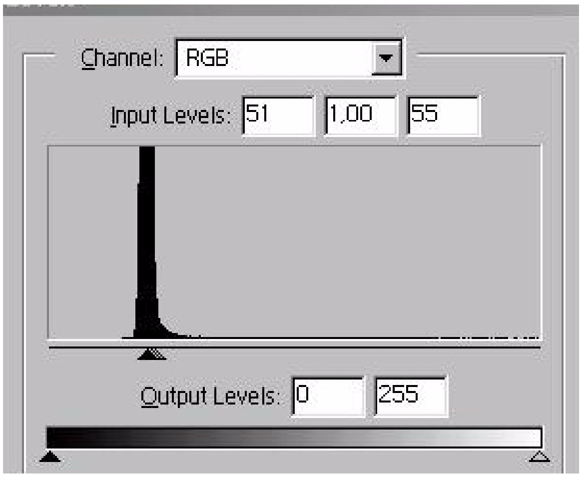
The histogram of the image shown to the left

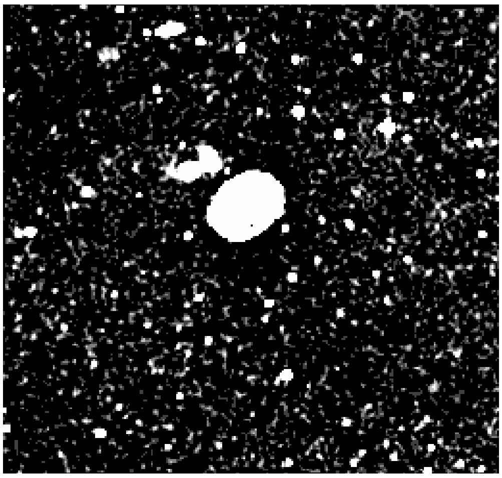
Segmentation and thresholding

Segmentation is used when an image contains not so different intensity values grouped in different regions. By choosing pixels with intensities above a threshold value one can extract greater information from different regions involved.





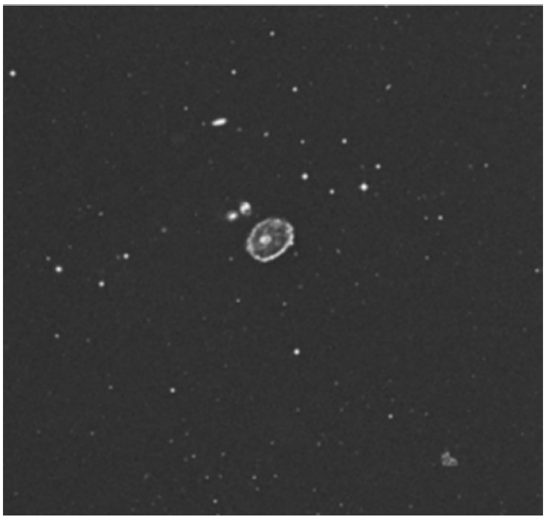




Threshold values in the range 51-55

Contrast enhancements: Picking Intensity of Interest

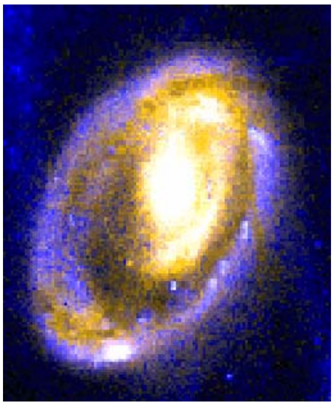
It is used when one wants to pick information from the features that involve intensities with low contrasts.



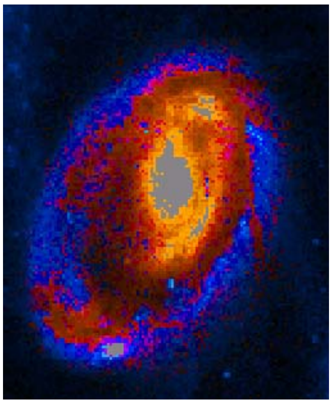
Original image

Image with contrast modified

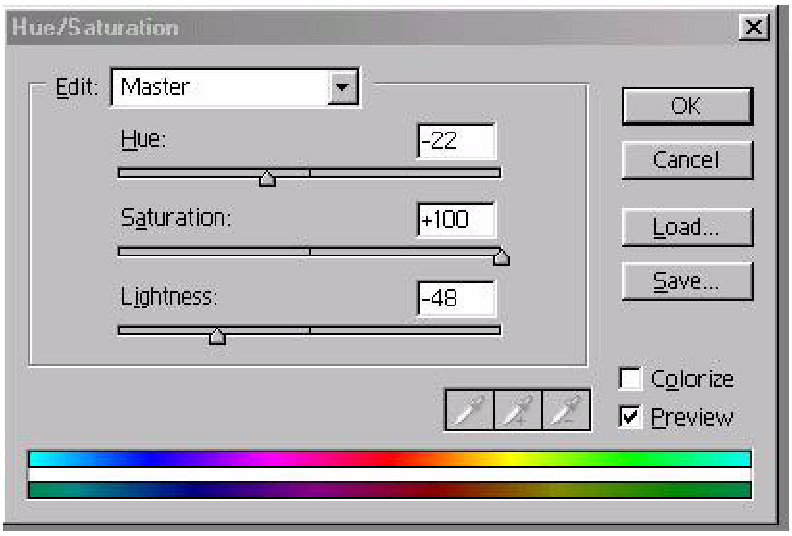
Saturation and hue modification



original



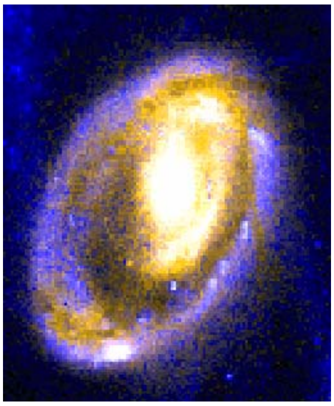
modified



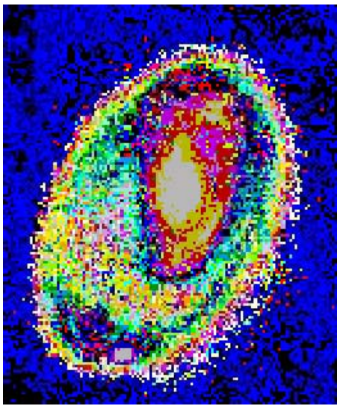
The changes in hue, saturation and lightness in the modified image

Mapping in pseudo colors

Different intensities can be assigned different color values and images can be mapped in pseudo colors to bring forth different details that can not be seen in normal imaging method, that uses standard rainbow colors, where blue and red are respectively assigned to the lower and higher intensity values.



Cartwheel nucleus: original from NASA



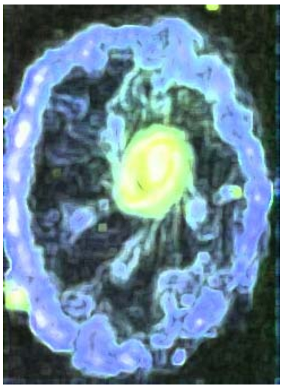
The same image after color mapping

Filters

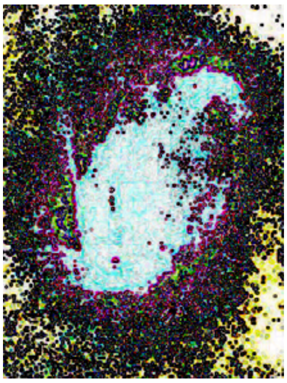
Filters are used to enhance appearance of raw images. However, information is lost in the process. Filters include low pass filtering for softening of images and high pass filtering for sharpening the images. Other very useful filters are the edge detection filters.

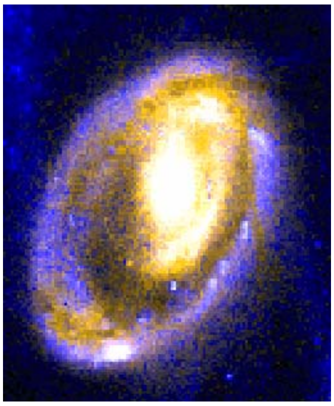
Low-pass filtering of Cartwheel galaxy

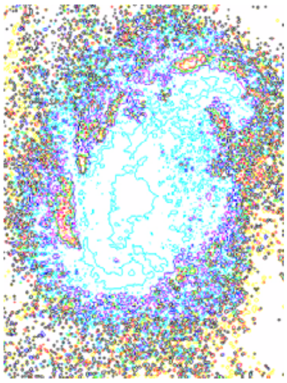
High-pass filtering of Cartwheel galaxy



Edge detection examples (Cartwheel nucleus)

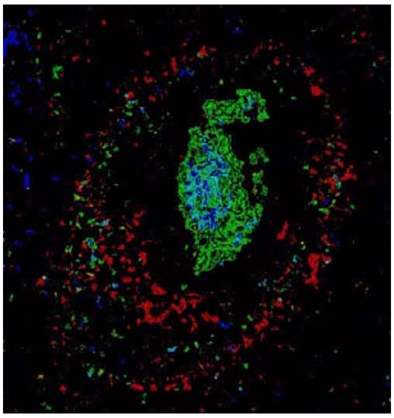






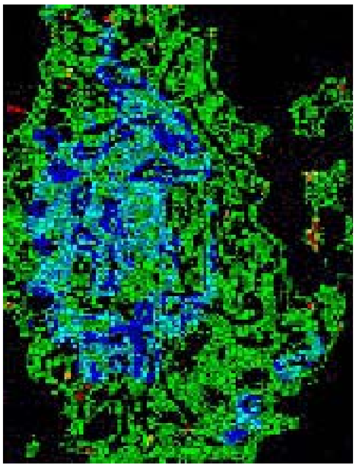
Tracing and vectorization of raxtor graphics

Example

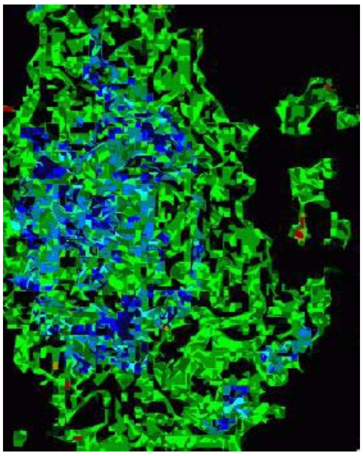


Heart of the Cartwheel nucleus

The central green part is shown on the right hand side images.



Raxtor image

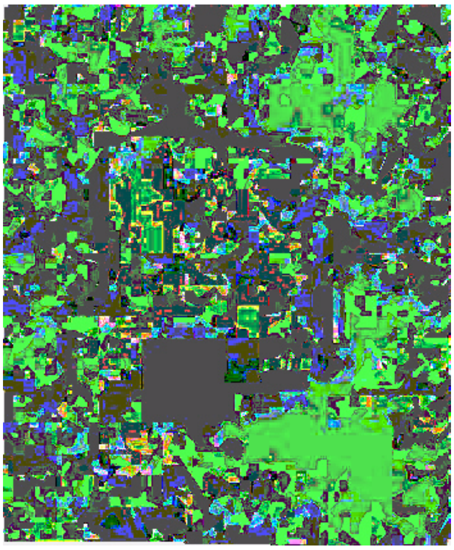


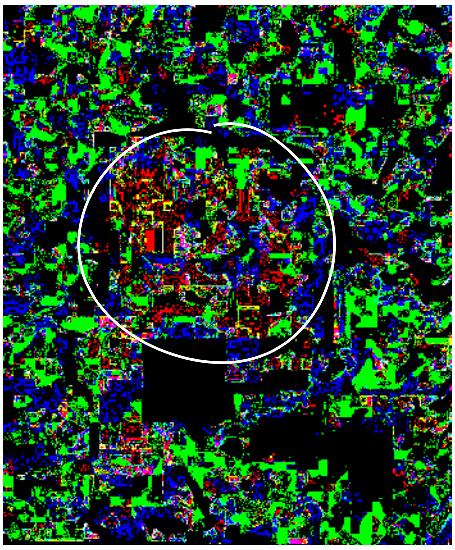
Vector image

Raxtorization of the vector graphics

Example

•





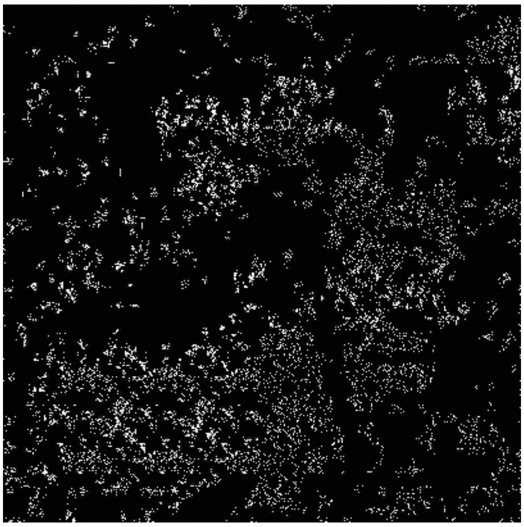
Deep inside the Carthweel nucleus **Another color map**

Image processing involving several of the above operations together

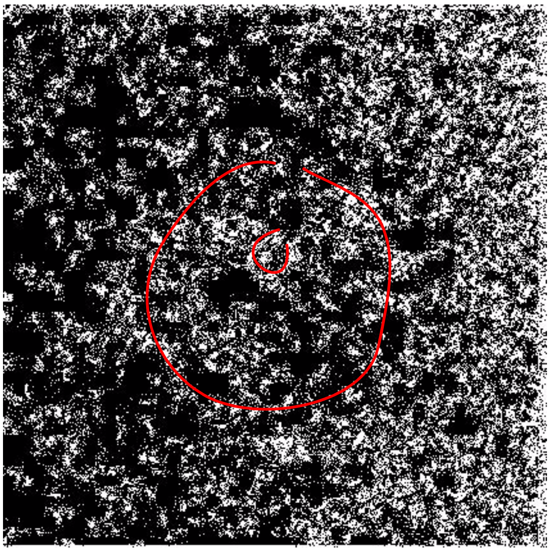
By analyzing the area marked by the white circle, which lies deep inside the Cartwheel nucleus, while applying several of the image enhancement techniques discussed above, and making transformations from vector graphics to raxtor graphic and raxtor to vector graphics several time, a hierarchically embedded design can be seen inside the Cartwheel nucleus.

The design consists of two complementary structures, that are entwined together forming the whole. It hierarchically embodies itself in smaller and smaller scales and remains the same when the scales are changed in discrete steps. The same appears to be true when one analyzes the large field of the sky where the Cartwheel galaxy roams.

Similar hierarchy is seen in other cosmic objects of all scales from clouds where single stars are born, to dimensions of galaxies, clusters of galaxies, superclusters of clusters and so on.



Design deep inside the heart of the Cartwheel nuclues



The large cartwheel structure around Cartwheel galaxy, which is marked by a small ring at the centre.

VISUALIZATION OF THE COSMOS

Seeing the cosmos Digitally