Processing astro-photographs using Retinex based methods

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Abstract

Stars, galaxies and some nebulae emit light, differently from solar system planets and satellites that mainly reflect Sun's light or nebulae that also partly reflect nearby stars light. Light emission is concentrated on specific wavelengths corresponding to transition states of atoms that compose the object. Professional photographers and astronomers use special narrow band filters to detect spectral light emission. Using monochromatic CCD cameras a multi filter photograph can be taken, producing at least long, middle and short wavelength snapshots that can be processed to give full color pictures. Amateurs can use wide-band filters or even color cameras. Colors in astrophotography do not correspond to perceivable colors by human vision system (HVS) and our visual system did not evolve to perceive these kinds of images. Any way we still have to consider our perception when creating pictures to observe cosmic objects photos, that have been rendered using the so called representative colors, selected to show the captured wavelength bands with the purpose to make visible what is scientifically relevant. The typical application field of the Retinex based algorithms is that of natural images, since their purpose is to simulate some behaviors of the human visual system. However we can use HVS properties to enhance astro-photographs and increase local contrast, thus allowing researchers to detect non-visible structures and lay people to be fascinated by richness of cosmic objects. We will present the results of applications of some Retinex based algorithms to astro-photographs. We will discuss their efficacy, compared to traditional methods and discuss possible developments.

Introduction

Since the launch of Hubble telescope (1990), the first out of atmosphere orbiting telescope, a large amount of new photographs of deep sky objects have been acquired for scientific research purpose and public distribution. A famous picture that contributed to diffuse discoveries of the structure of the universe is the so-called Pillars of Creation in the Eagle nebula Messier 16 (see figure 1 – downloaded from [1]).

Let's explain this image. The staircase structure is due to the structure of Hubble telescope camera system, WFPC-2 (Wide Field/Planet Camera-2 *wiffpick*) [2], composed of 4 cameras, the top right one having double resolution to observe details of planets, to be down scaled to compose the large field picture. The second observation is the peculiar color channels distribution. The image has been captured through three narrow band filters centered around the emission lines of specific atoms of gas molecules of nebulae: O III (Oxygen III, 501.2 nm $\Delta\lambda$ 2.7 nm), Hα (Hydrogen alpha, 656.4 nm $\Delta\lambda$ 3.5 nm) and SII (Sulfur II, 673.2 nm $\Delta\lambda$ 4.72nm). If we interpret these wavelengths as color bands we see that there is no blue component: OIII is around green and SII, Hα are in the orange-red interval. To explore this color rendering we have downloaded the three band pictures from Hubble Telescope repository [3] and processed for color display creating what in astronomer jargon is a "representative color", not to be confused with the arbitrary "false color" [4]. The three sub-images in figure 2 have been obtained by assigning channels as Sulfur to red, Hydrogen to green and Oxygen to blue (S=R, H=G, O=B). The second sub-image has been obtained exchanging Hydrogen with Sulfur (H=R, S=G, O=B) and the third sub-image is the assignment O=R, S=G and H=B. Color rendering vary largely among the three distributions and with respect to figure1.

We note that the left sub-image of figure 2 (where the color distribution among channels is the common one) is quite different from the one published in hubblesite.org (figure 1). First of all, the mosaic of the four tiles must be aligned, secondly, the colors have been corrected and third the contrast improved. Color correction and contrast improvement are necessary to increase the display of information for the scientist, rather than to obtain beautiful or natural images. They are necessary not to make the pictures more beauty, rather to empower the efficacy of information display for scientist to better understand the nature and structure of the cosmic object and get all the subtleties of the gas distribution.

Normally astronomers use GIMP, Photoshop or similar programs for these operations and sometime they use the "false colors" in order to show structures that would be otherwise invisible, thus exploiting different contrast adjustments at different wavelengths.

The issues we are facing here, concern the display of complex information, rather than the perception of natural scene (even if astronomical). Our aim is therefore to apply concept of color vision to these kinds of images and to verify if the adoption of algorithms derived from the Retinex theory can provide better results, with less lengthy trial and error work. The same problem applies also to astro-photographs taken with amateur telescopes using color camera rather than monochromatic camera with filters.

Retinex algorithms are spatial color algorithms (SCA) [5] inspired by the HVS behavior. They attempt to extract the maximum visual information from images, whose acquisition process and context are unknown. Research has shown that SC algorithms generate the final appearance of an image starting from very poor images in terms of dynamic range, contrast and chromatic content. Mimicking HVS, whose retina has a large overlap between long and medium wavelengths (causing a low L/M ratio), SC algorithms are able to perform an unsupervised enhancement that recovers important visual information from poor input, processing independently the three channels.

In some astronomical photographs information about the incoming radiance could be available or approximated from known characteristics of the emitting source (radiance, chromaticity) and the imaging system, but in most cases photographs are not calibrated in the sense that to each digit does not correspond a known invertible function of the radiance. This could be achievable with radiometric measurements, but radiometry is not used for viewing astronomic images.

When cosmic object visual rendering is required the purpose of the astronomer is to display some relevant information making it clearly distinguishable. In this case HVS/SCA contrast enhancement has been proved to be effective [6]. Moreover we note that processing color channels independently increases the possibility to maximize the visual information in each channel without adding any cross correlation during processing.

The idea of applying HVS inspired method to process astro-photographs is not new, but at our knowledge very few experiences have been presented. The Retinex method proposed in [7] has been applied to natural photographs, a single example of a photo of the Moon is presented in this site:

http://dragon.larc.nasa.gov/retinex/Lunar_Orbiter/.

Based on the same algorithms as in [7], F. Weinhaus has implemented a Retinex tool into ImageMagick processing function library [8]. Similar tools like e.g. STRESS [9] are also included in the GIMP program and sometimes used for processing astro-photographs. The use of Retinex is also discussed in forums about the image-processing program StarTools by Ivo Jager, who claims to be using Retinex: "The Dynamic range optimization in StarTools is based on a Retinex & Local Histogram Stretching hybrid algorithm" [10]. Gupta and Mandal in [11] consider Retinex as a processing technique to enhance histograms in astro-photographs but we could not find any effective example. A method to estimate fractional gradient to stretch the histogram has been proposed by Sparavigna et al. [12] and tested on some astronomic photographs. To conclude this short review we note that no specific research on HVS inspired methods for processing astro-photographs seems to have been published.

In the section Instruments and Methods we will briefly describe the selected algorithms, details are left to the literature, we also identify three kinds of astronomical photographs that show different features relevant for the SCA processing. Moreover we recall the main steps from the astro photo to the SCA processing.

In section Experiment Results we present and discuss the results obtained for the chosen astro-photographs and algorithms.

In Conclusions we will discuss the results and we will outline possible future developments for making practical SCA processing for astro imaging.

Instruments and Methods

First of all it is worth to note the characteristics of astronomical images.

In natural images we can have extended areas of constant or slowly varying color and contrast, we can have a relationship between a background and a foreground with out of focus regions. Edges in natural images correspond to different objects with some regular on at least known shape.

In astro photography we have a huge amount of point sources (the stars). Stars can appear as standalone high luminous points or dense or sparse cluster; they can be aggregated around galaxies or be surrounded by gas nebulae. Galaxies have an irregular light distribution, while nebulae can show more slow varying contrast and luminosity in the different spectral bands. There is no foreground-background relationship and the image field is at the same focus. Most galaxy and nebulae images frequently do not have clear edges.

These characteristics of astro images are important to understand how critical is the problem of noise, of contrast and of color rendering to make visible important information. In other words: to prepare the image for the further task of recognition and interpretation.

The first step in our work has been therefore to select representative images of the different kinds of deep sky objects and, second, to compare the efficacy of the chosen Retinex algorithms.

Image Selection

The images selection has been driven by the necessity to consider different kinds of sky objects as well as different kind of astro photographs. Narrow band photographs can be downloaded from astronomical data repositories, while wide band photographs have been created by one of the author of this paper using a DSLR camera. We can divide the selected images in three main categories, each of which with its own characteristics, as explained in the following.

Stars image

Any image shot by space telescopes have a huge amount of stars. So we decided to consider a region around a star in the Andromeda constellation, HIP2942 (coordinates R.A. 00:38:12 Dec. 35:29:11, extended 120x120 arc-minutes) [1], whose spectral class is G5III. The knowledge of the spectral class is important to refine the color of the rendered final image. Class G5III is close to the spectral class of our Sun, so the color temperature is in the range 5200-5900 K. Image data are available as Second Digital Sky Survey (DSS-2) for the three wavebands: blue (around OIII), red and infrared, from this site [3]. Each image is 1188x1190 16bit/pixel.

Galaxy Images

The subject Galaxy Messier 31 Andromeda has been processed as a narrow band image downloaded from [13] and as a DSLR photograph from amateur telescope.

The Palomar Observatory [2] image is the color composition of three images scanned from photographic plates taken with infrared (≈ 800 nm), red (≈650 nm) and blue (≈450 nm) filters. The red image had to be scaled 1.07 to align with the other two.

The DSLR image has ben captured with 150/750 f/5 reflector telescope with a Fujifilm X-E2 mirror-less camera, with different exposure times: 120", 240" and 360", ISO 1600. The photographs are saved in raw format, 4936x3296 32bit/pixel.

Nebula image

The selected nebula is Eagle Nebula Messier 16, "Pillars of Creation" downloaded from [14]. The original single channels photographs are 1600x1600 32bit/pixel, shot by Hubble orbiting Telescope with WFPC-2 camera. Three shots have been downloaded, corresponding to the wavebands 502, 656 and 673 nm.

Selected Retinex algorithms

We have decided to work with a family of algorithms derived from the Retinex theory, developed by our research group and in collaborations with other groups. As already mentioned these Spatial Color Algorithms re-compute every pixel of the image according to the spatial distribution of the other pixels, imitating the local behavior of the HVS. They work separately on the three RGB channels. In the following we briefly describe their main features, leaving details in the references.

ACE

ACE (Automatic Color Equalization) [15][16][17] is a two-step algorithm. In the first stage, it re-computes each pixel as a function of differences with the other pixels present in the image. The resulting image is remapped maximizing the output dynamic range. There are two parameters to be tuned: the first is *slope* that has influence on the non-linearity of the contrast; the second is

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[1] Copyright (c) 1994, AURA

[2] Copyright (c) 1992-2000, Caltech and AURA

alpha that controls the local/global effect. There are versions of ACE implemented in Matlab and in C++ written by C. Gatta that runs in Windows OS. We have used this version.

ACE-fast (web)

A fast approximation to ACE has been developed by P.Getreuer[18], and it is available on the web [19] for testing. The web implementation has various parameters that can be tuned. We have chosen to study the effect the *alpha* parameter that has the same effect as slope in ACE.

RSR

RSR (Random Spray Retinex) [20] generates a cloud of points (called random spray) around the target pixel. This spray is calculated to be denser near the target pixel, enclosing the idea of locality. The maximum value of the spray is considered as the local white for the normalization. This procedure is repeated for all the pixels in the image. Two parameters are important: the number of points within the spray (m), and the number of iteration (n). The first controls the locality of the algorithm, the second affects the noise: higher the value is, less the noise (but with the drawback of having high computational time)

STRESS

Spatial-Temporal Retinex Inspired Envelope with Stochastic Sampling algorithm [9] works similarly to RSR, with the difference that it calculates for each pixel also the local minima to compute the normalization to white and black, for each channel. Also in STRESS the parameters m and n are present.

Processing

Before processing the images with the chosen Retinex algorithms we had to compose the color images, particularly the narrow waveband ones. To this aim each band has been converted from fits to tiff format while stretching the histogram with the inverse function of hyperbolic sine (arcsinh), which is the most used stretching function. Once adequately stretched the three band images can be packed into a color picture using Photoshop; frequently they have to be aligned, in particular images from the DSS-2 archive (that have been scanned from photographic plates), while space telescope images are normally aligned. At this point the colors can be adjusted to improve the detectability of the different regions. In the case of the star image no color correction is necessary, since the most relevant information is the color of single stars that is associated to the respective spectral class and we are more interested on the noise generated by SC algorithms. In the case of galaxies and nebulae a color correction could be important for rendering purposes. In the case of star image the contrast is mainly global: each star is in good contrast to the background (assumed good viewing conditions) that can be considered as black. This problem can easily be solved still in the context of Photoshop like programs. In the case of galaxy and nebula the problem is much more complex, and the use of Retinex algorithms is helpful. Professional astro photographers use a variety of Photoshop tools to improve local contrast by using local mask levels, a time-consuming trial and error work. All pictures have been processed with the selected algorithms. Since all of them depend on a parameters choice, we have explored the effect of each parameter and their interaction. This has produced a large amount of data, and in this paper we only present what we have considered the best result.

Experiment results

Stars image HIP2942

The selected color image (figure 3) has been created by associating the infrared band to the red channel, the red band to the green channel and the OIII band to blue channel. In this case we did not expect particularly interesting results. We first observe that RSR and STRESS produce the same result (figure 4), has no effect on the colors of the stars, while the global contrast is increased and noise is introduced in the image. Indeed RSR and STRESS tend in general to add noise especially when the number of iterations is low, to save computational time. On the contrary ACE does not add noise artifacts, while it emphasizes the circular diffraction around the bright bottom right star (figure 5). Moreover the global contrast is increased while the noise is increased only in the optical diffraction area around the star. This effect is also present in the image processed with ACE-fast (figure 6) when parameter alpha > 2. Increasing alpha amplifies the existing noise.

The computation time of the four algorithms and some quantitative measures of the best images are shown in next table 1. The measures adopted are the average μ and the standard deviation σ as statistical descriptor of the value of the three channels. Moreover we compute a visual local multi-level contrast measure C as described in [21] [22]. The evaluation of the noise induced by SC algorithms is very important. To this aim we have estimated the PSNR between the processed image and the reference image that is the original image considered as noise-free. We recall that to higher PSNR values correspond lower noise. In Table 1 the measures for the different algorithms of the images that we consider best from a visual observation.

Table 1. Computation times and quantitative measures of the algorithms on region around HIP2942 size 700x700 8bit/channel

Alg.	t “	μ	σ	C	PSNR dB
ACE	5	5.86	25.02	2.30	27.71
ACE-fast	0.4	18.42	29.77	2,81	21.97
RSR/STRESS	250	15.71	17.56	5,56	20.41
Original	-	5.53	23.19	2.09	

Visual observation and measures can confirm that the best image has been obtained by ACE algorithm, keeping at minimum the noise and improving the contrast up to showing optical artifact. Ace-fast has a similar contrast increase, while RSR/STRESS produce an excessive contrast with added noise. We note that the statistical moments and contrast of the original image and ACE are very close. We recall that these are not true colors, even if the resulting colors are a fair representation of the spectral emission of star types.

Galaxy Image M31 Palomar

In figure 7 we can see the original image, as assembled from the three bands scan of the deep sky survey. Defects, scratches and the reddish background on the right have not been removed. They are due to aging of the photographic plate.

Quantitative results for the same images are shown in table 2.

We note that again ACE is much more effective than other algorithms. The contrast improvement is particularly evident in the background-foreground relationship, the emphasis on the galaxy arms and in the details of the galaxy nucleus, making small details evident. It is also worth to note the color correction that strongly reduces the reddish background in the right part of the image.

Table 2 – Measures of quantitative parameters of M31-Palomar, size 1697x1774 8bit/channel

Alg.	μ	σ	C	PSNR dB
ACE	77.38	52.80	48.65	17.74
ACE-fast	115.98	52.59	46.28	17.53
RSR/STRESS	150.30	41.67	31.08	11.53
Original	83.65	47.78	43.11	

Galaxy Image M31 DSLR

As already said, this image has been created using amateur equipment. Acquisition parameters are bounded to limits of the equipment. Exposure time is rather short given the telescope mount quality: after 5-6 minutes earth rotation compensation is defective showing star trails. Moreover the coma aberration in the off-center area is a consequence of the optical aberration of the telescope.

The camera used has the sensor X-Trans by Fujifilm with a non-Bayern pattern mosaic [23]. Astro-photographs rendering follows a standard pipeline [24] that includes a specific calibration stage. Raw images must be de-mosaicked. It is worth to note that images are 4936x3296 32bit/pixel, with a pixel size of 4.8 μ. This value is below the diffraction limit of the telescope, producing large stars that should be in general 3-4 square pixels. Therefore the images have been downsized by a factor 4 before any calibration processing. Calibration aims at removing electronic noise (bias), sensor noise (dark current, hot pixels), and no-uniformity of image area (optical vignette, sensor inhomogeneity). In amateur photography it is normal to shot multiple photos of the subject to compensate seeing limit like air turbulence or passage of aircraft or satellites. Averaging or summing criteria are selected to process a stack of multi-shots. We have calibrated 5x360" exposures with 5x dark field shots, 10x bias shots and 10x flat field shots. The stack of five calibrated pictures has been averaged and the resulting image has been histogram stretched with arcsinh function and color corrected to remove excess of red color.

The resulting pre-SCA filtering image is shown in figure 11. ACE is again the best algorithm as can be seen in figure 12. ACE-Fast (figure 13) improves the local contrast, making visible the spiral arms, but leave less contrast in the background. For this kind of image RSR and STRESS do not behave the same as in image of the stars. The result is not too noisy and the major effect is a better color rendering, that can be observed in the extreme arms of the galaxy NW and SE, making evident a blue component. In table 3 we show quantitative results.

In general the major effect of SC algorithms is to improve the contrast, making more evident the spiral arms, darkening the background and at the same time increasing the evidence of the extension of the galaxy toward the other small galaxy and the bright star. Considering the origin of the photograph, the amount of information made visible with SC algorithms is impressive.

Table 3 – Measures of quantitative parameters of M31-DSLR, size 1234x824 8bit/channel

Alg.	μ	σ	C	PSNR dB
ACE	32,43	38,64	25.42	21.04
ACE-fast	56,79	38,22	27.35	20.36
RSR	105,64	35,45	22.05	11.24
STRESS	104,73	35,73	22.23	11.34
Original	37,04	30,68	21.47	

Nebula image M16 Pillars of Creation

In the introduction we already described the structure of this photograph. The issue now is to understand what are the critical aspects that SCA processing can contribute to tackle. The reference image has been displayed in figure 1 and we can assume that professional experts have rendered it. We simply stretched the histogram of the three band downloaded photos and we packed them into the color picture. No alignment has been performed. Processed with ACE we found that a better contrast rendering of the lower region of the image can be obtained making visible subtle structures, almost hidden in figure 1, as shown in figure 15. The same effect is produced by ACE-Fast (figure 16) that also improves the luminosity of the image similar to an exposure correction. Indeed ACE keeps the image dark while ACE-Fast renders very well the fluffy red area in the top of the center pillar. RSR and STRESS behave almost the same (figure 17 and 18), with low noise and better contrast, but less effective than ACE and ACE-Fast. In table 4 we present the measurements. We note that ACE and ACE-Fast increase the contrast about the same amount.

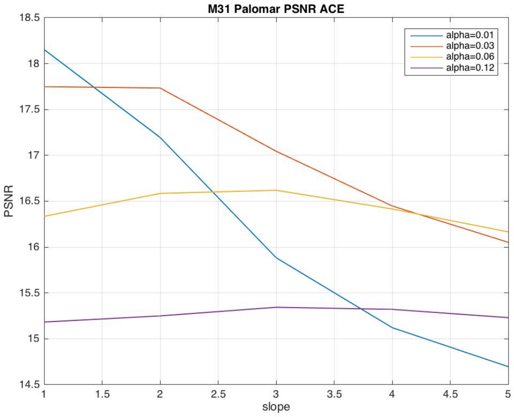
Table 4 – Measures of quantitative parameters of M16, size 1518x1497 8bit/channel

Alg.	μ	σ	C	PSNR dB
ACE	90.85	41.77	26.26	15.23
ACE-fast	113.62	56.74	26.21	18.84
RSR/STRESS	141.57	77.87	30.47	12.96
Original	91.39	63.61	12.57	

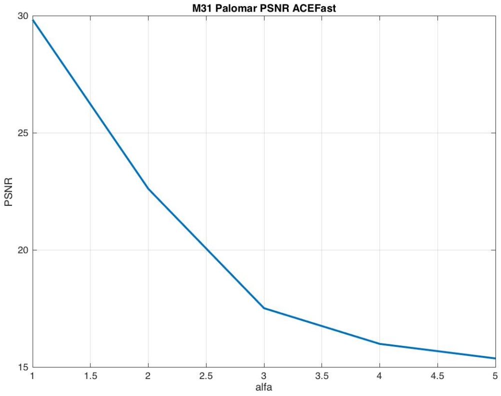
The lower value of PSNR in this case is probably due to the characteristics of the original image, that has a lower contrast than the other chosen images, and the increase in contrast ratio $C_{processed}/C_{original}$ for all SC algorithms is ranging in the interval 2.08-2.42. In the other images we have for the best PSNR an increase of the ratio ranging in the interval 1.10 – 1.18.

PSNR and ACE parameters

The relationship of noise with the parameters of the algorithms is particularly interesting. We have computed the PSNR of the image processed with ACE and ACE-fast as the control parameters vary. For sake of brevity we limit to show the analysis of the M31 Palomar image.
In the diagram below we see how PSNR changes with parameters *slope* and *alpha* of ACE:



In the next diagram we see the PSNR evolution of ACE-fast with parameter alpha. We recall that parameter alpha in ACE-fast corresponds to the slope of the ACE basic algorithm.



As a final note, we observe that a PSNR in the range 20-25 dB is considered acceptable in the field of image compression.

Conclusions

We have applied some Spatial Contrast Algorithms to astronomic photographs. We have selected three kinds of subjects that represent different kinds of cosmic objects, whose differences are relevant to the HVS based processing algorithms. The photographs chosen have been downloaded from astronomic photos repositories, one is the scanned digital version of photographic plates taken from Palomar observatory two others have been taken from the Hubble telescope. One photo has been taken with amateur equipment.
We have selected four spatial contrast algorithms developed by our research group in collaboration with other researchers. The first algorithm is ACE the second is an approximation to ACE implemented to get fast processing and is available to test on the web. The third algorithm is RSR and the fourth is STRESS, a variant of RSR. The results of astro photographs processing have been evaluated visually and some measures have also been computed. The visual evaluation has taken into account the effect on noise, the effect on local and global contrast, the effect on color. Color is not relevant in astronomic photographs, since they are a rendering of data coming from narrow band filters, with limited relation to perceivable colors. The role of colors in this rendering is to convey information related to color temperature or to the spectral nature of the subject. The role of contrast is more important to discriminate visually subtle structures of the subject. In this case local contrast can strongly improve the visual appreciation of the structure and morphology of a cosmic object. Global contrast is relevant to provide a sensation of depth in cosmic object, in particular rendering the background color. We have also evaluated how the different algorithms induce noise in the processed image, by estimating PSNR with respect to the original image, taken as the reference noise-free image.
Our conclusion is that ACE and the accelerated version ACE-Fast are promising algorithms, while RSR and STRESS tend to increase too much (or even introduce) the noise of the picture.
The advantage of using an SCA processing to render astro photographs is to avoid lengthy trial and error approach with common programs like Photoshop or GIMP. SC algorithms do not substitute other image processing programs regularly used by astronomers and amateurs; it is a post-processing aimed at a final rendering with improved color and contrast.
Further research is necessary to better characterize from a quantitative viewpoint the SC algorithms, by considering in more detail the behavior of noise and contrast as parameters vary and with a larger number of images that represent the selected kinds of cosmic objects.
We will also consider astro photographs in HDR format, and explore the possibility to process this kind of images with suitable methods. This could be particularly interesting to cope with halo artifacts induced by optical and photographic equipment.

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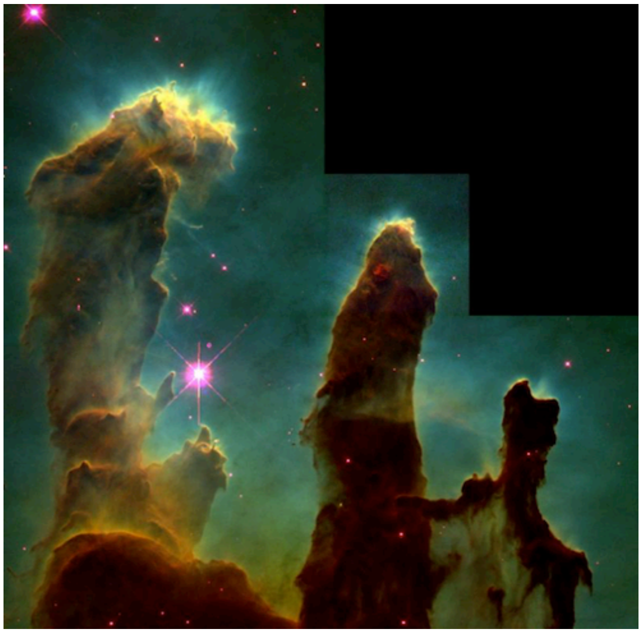

Figure 1. Pillars of Creation – 1995

Figure 2. Left S=R,H=G,O=B, middle H=R,S=G,O=B right O=R,S=G,H=B

Figure 3. Original image of region around HIP2492

Figure 5 – ACE

Figure 4 RSR / STRESS

Figure 6 – ACE-Fast

Figure 7 M31 Andromeda galaxy – Digital Sky Survey Palomar Observatory

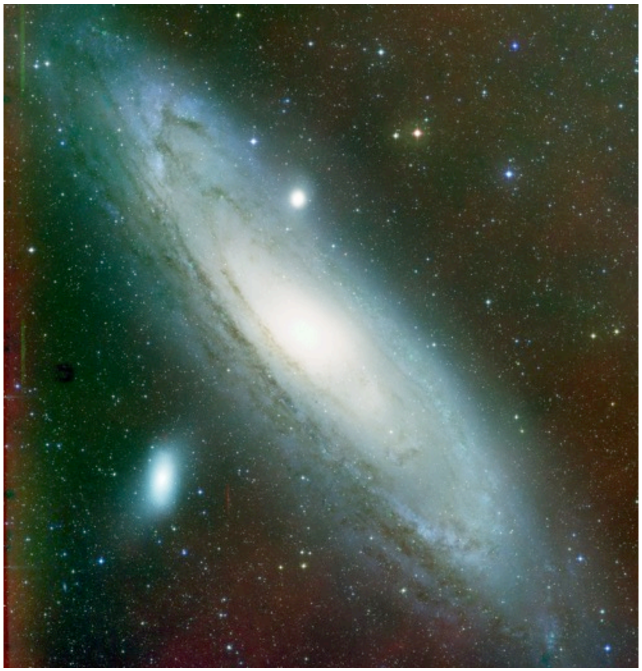

Figure 8 – ACE

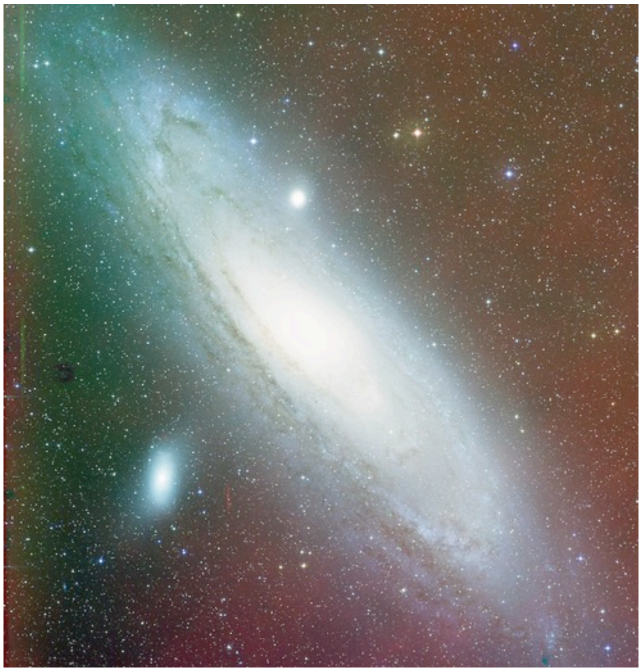

Figure 9 – ACE-fast

Figure 10 – RSR/STRESS

Figure 11 – M31 Andromeda with DSLR camera. Pre-SCA filtering

Figure 12 – ACE

Figure 13 – ACE-fast result

Figure 14 – RSR (top) and STRESS (bottom)

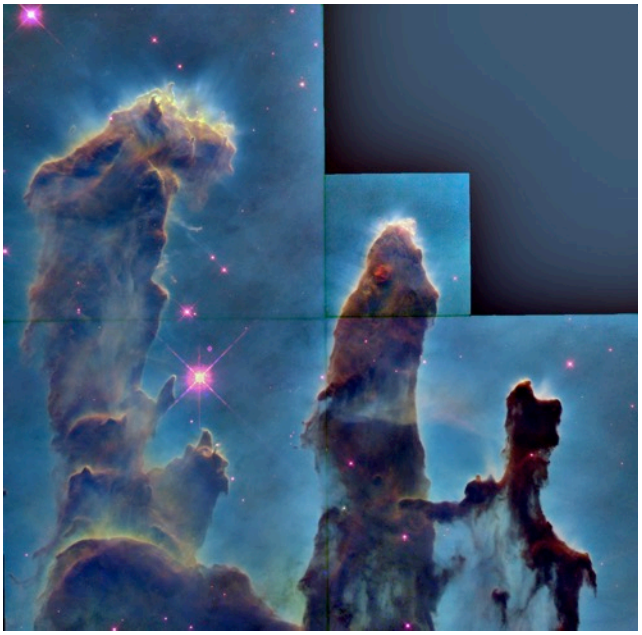

Figure 15 – ACE

Figure 16 – ACE-Fast

Figure 18 – STRESS

Figure 17 – RSR