STIFF
$v1.12$
User's guide

E. BERTIN
Institut d'Astrophysique & Observatoire de Paris

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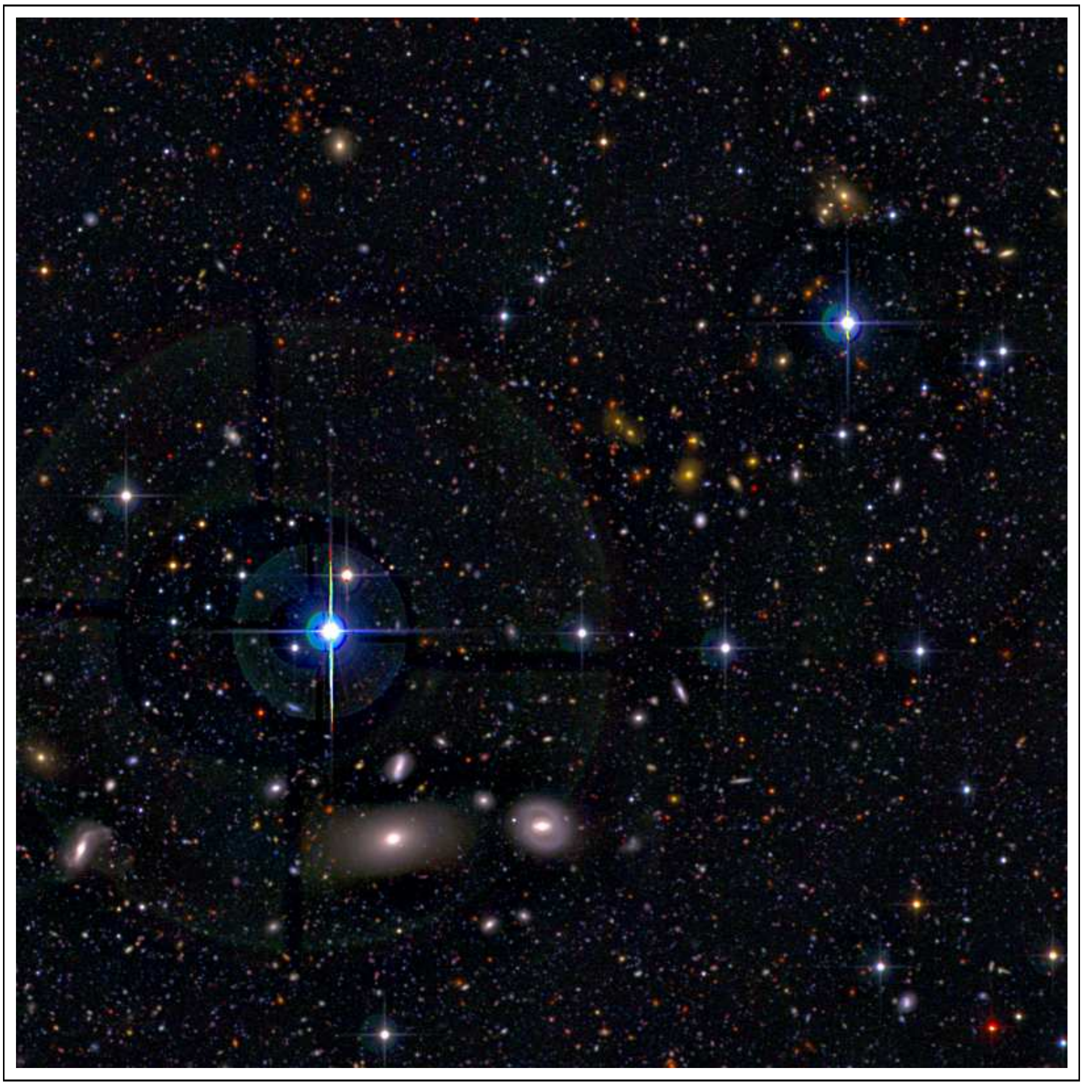

Contents

1 What is STIFF?

STIFF is a program that converts scientific FITS[1] images to the more popular TIFF[2] format for illustration purposes. The main features of STIFF are:

- one or three input channels: 8 (grayscale) or 24 (true colour) bits per pixel output
- Support for arbitrarily large input images on standard hardware (useful for posters!)
- Pixel rebinning
- Accurate reproduction of the original surface brightnesses and colours
- Automatic or manual contrast and brightness adjustments
- Automatic sky background intensity and colour balance
- Adjustable colour saturation
- Colour-friendly gamma correction capabilities

2 Skeptical Sam's questions

Skeptical Sam doesn't have time to test software extensively but is always keen on asking agressive questions to the author to find out if a program could fit his needs.

S.Sam: I don't understand the purpose of this software. There seem to be already a lot of convenient FITS readers and converters available out there.

Author: Yes, but most (if not all) of them do not do a proper job at converting FITS image data to 8 bits. It is often said that 8-bit images stored in JPEG, PNG or TIFF files are unable to cope with the high-dynamic range of 16 bits CCD images from the professional astronomy world. This is plain wrong (actually, perceptually, they even offer a larger contrast), because in these 8-bit file formats the intensities are implicitely stored in a non-linear way. But strangely, most current FITS image viewers and converters seem to ignore this fact and provide the user an incorrect translation of the FITS image content by simply rescaling linearly input pixel values. A first consequence is that the people working on astronomical images usually have to apply narrow intensity cuts or square-root or logarithmic intensity transformations to actually *see* something on their deep-sky images! A less obvious consequence is that colours obtained by combining images processed this way are not consistent across such a large range of surface-brightnesses. The picture below shows the same 3 FITS images passed through a standard FITS image converter ("FITS LIBERATOR"[3]) and STIFF. The same cuts in surface brightness were applied. If your display or printer is properly calibrated, you should be able to distinguish most of the faint details on the rightmost image. On the left image on the contrary, most of the faint stuff is missed. This is because the aforementioned standard software ignores the non-linear behaviour of your display.

S.Sam: Well within FITS LIBERATOR and the like you are generally afforded a choice of non-linear transformations to apply in order to make the faint stuff stand out more clearly in the images.

[1] `http://fits.gsfc.nasa.gov/`
[2] e.g. `http://home.earthlink.net/~ritter/tiff/`
[3] `http://www.spacetelescope.org/projects/fits_liberator/`

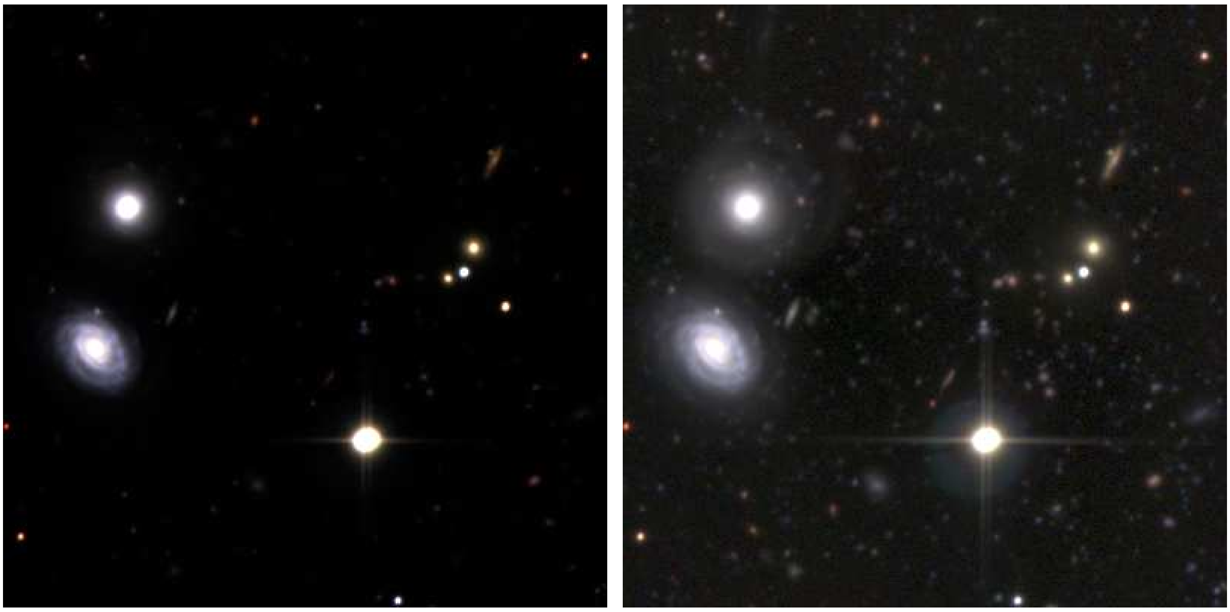

Figure 1: The same 3 R,G and B deep-sky images processed by FITS LIBERATOR (left) and STIFF (right), using the same intensity cuts.

Author: Sure, but with the limited selection of choices you are given colours will not be accurately rendered, and some manual tweaking will be necessary. The purpose of STIFF is to produce beautiful pictures in an automatic and consistent way.

3 Installing the software

3.1 Software and hardware requirements

STIFF has been developed on Unix machines (GNU/Linux), and should compile on any POSIX-compliant system. It does not depend on any specific library.

The software is run in (ANSI) text-mode from a shell. Memory requirements do not exceed a few megabytes at most. The program is not (yet) parallelized.

3.2 Obtaining STIFF

The easiest way to obtain STIFF is to download it from an internet site. The current official anonymous FTP site is `ftp://ftp.iap.fr/pub/from_users/bertin/stiff/`. There can be found the latest versions of the program as standard `.tar.gz` and RPM archives, including the documentation.

3.3 Installation

To install, you must first uncompress and unarchive the archive:

```
gzip -dc stiff-x.x.tar.gz | tar xvf -
```

A new directory called `stiff-x.x` should now appear at the current position on your disk. You should then just enter the directory and follow the instructions in the file called “`INSTALL`”.

4 Using STIFF

STIFF is run from the shell with the following syntax (single-channel mode):

% `stiff` *image* `-c` *configuration-file* `[-`*Parameter1 Value1*`]` `[-`*Parameter2 Value2 ...*`]`,

or in 3-channel mode:

% `stiff` *image_red image_green image_blue* `-c` *configuration-file* `[-`*Parameter1 Value1*`]` `[-`*Parameter2 Value2 ...*`]`.

The part enclosed within brackets is optional. Any "`-`*Parameter Value*" statement in the command-line overrides the corresponding definition in the configuration-file or any default value (see below).

4.1 The Configuration file

Each time STIFF is run, it looks for a configuration file. If no configuration file is specified in the command-line, it is assumed to be called "`stiff.conf`" and to reside in the current directory. If no configuration file is found, STIFF will use its own internal default configuration.

4.1.1 Creating a configuration file

STIFF can generate an ASCII dump of its internal default configuration, using the "`-d`" option. By redirecting the standard output of STIFF to a file, one creates a configuration file that can easily be modified afterward:

```
% stiff -d >stiff.conf
```

A more extensive dump with less commonly used parameters can be generated by using the "`-dd`" option.

4.1.2 Format of the configuration file

The format is ASCII. There must be only one parameter set per line, following the form:

Config-parameter *Value(s)*

Extra spaces or linefeeds are ignored. Comments must begin with a "#" and end with a linefeed. Values can be of different types: strings (can be enclosed between double quotes), floats, integers, keywords or Boolean (`Y/y` or `N/n`). Some parameters accept zero or several values, which must then be separated by commas. Integers can be given as decimals, in octal form (preceded by digit `0`), or in hexadecimal (preceded by `0x`). The hexadecimal format is particularly convenient for writing multiplexed bit values such as binary masks. Environment variables, written as `$HOME` or `${HOME}` are expanded.

4.1.3 Configuration parameter list

Here is a list of all the parameters known to STIFF. Please refer to next section for a detailed description of their meaning.

Parameter	default	type	Description
OUTFILE_NAME	stiff.tif	*string*	Output TIFF file name.
BINNING	1	*integer*	Pixel binning factor.
GAMMA	2.22	*float*	*gamma*: exponent of the display intensity transfer curve.
GAMMA_FAC	1.0	*float*	*gamma*-correction factor for the luminance.
COLOUR_SAT	1.0	*float*	Colour-saturation factor.
NEGATIVE	N	*boolean*	If true, produces a negative image.
SKY_TYPE	AUTO	*keyword list* ($n \leq n_{\rm ima}$)	Sky level determination mode for each input image.
		AUTO	– Sky level is automatically determined from the pixel data.
		MANUAL	– Sky level is taken from the SKY_LEVEL value.
SKY_LEVEL	0.0	*floats* ($n \leq n_{\rm ima}$)	User-specified sky level for the SKY_TYPE MANUAL mode.
MIN_TYPE	GREYLEVEL	*keyword list* ($n \leq n_{\rm ima}$)	Meaning of the MIN_LEVEL parameter.
		QUANTILE	– MIN_LEVEL is interpreted as the lower quantile of the pixel histogram.
		MANUAL	– MIN_LEVEL is directly interpreted as a pixel value.
		GREYLEVEL	– MIN_LEVEL is interpreted as a grey level in the output image, in fractions of a “pure white” (0.0 is pure black, 1.0 is pure white).
MIN_LEVEL	0.0	*floats* ($n \leq n_{\rm ima}$)	Lower cut of the image dynamic range (see MIN_TYPE).
MAX_TYPE	QUANTILE	*keyword list* ($n \leq n_{\rm ima}$)	Meaning of the MAX_LEVEL parameter.
		QUANTILE	– MAX_LEVEL is interpreted as the lower quantile of the pixel histogram.
		MANUAL	– MAX_LEVEL is directly interpreted as a pixel value.
MAX_LEVEL	0.0	*floats* ($n \leq n_{\rm ima}$)	Higher cut of the image dynamic range (see MAX_TYPE).
VERBOSE_TYPE	NORMAL	*keyword*	How much STIFF comments its operations:
		QUIET	– run silently,
		NORMAL	– display warnings and limited info concerning the work in progress,
		FULL	– display more complete information.

5 How STIFF works

5.1 Overview of the software

Basically, the action of STIFF can be summarized as reading one (monochromatic case), or three (colour case: one for each of the primary colours, respectively red, green, and blue) input FITS images, and saving a grayscale or colour TIFF image to disk. The work is done in two passes through the data:

1. Input images are examined, a histogram of pixel values is constructed, from which statistics are derived for the automatic determination of the low and high cuts in dynamic range.
2. The images are actually processed and converted to TIFF format.

The global layout of STIFF is presented in Fig. 2. Let us now describe in details the processing of STIFF, and how to control it.

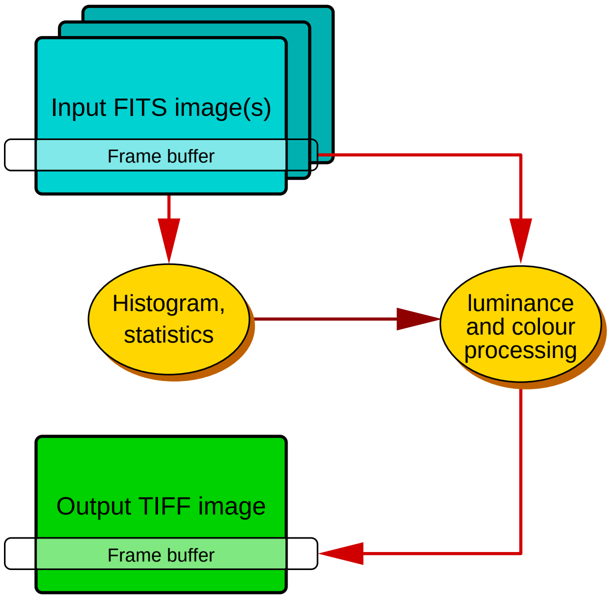

Figure 2: Global Layout of STIFF.

5.2 Gamma corrections

The pixel values f stored in GIF, JPEG, PNG and TIFF images are approximately related to the true flux intensities F (recorded or displayed on a properly adjusted device) through the power law

$$F = f^{\gamma}, \tag{1}$$

where γ is what we will call the "gamma". The display gamma is nowadays generally assumed to have a value of 2.22, although in practice it may roughly vary from 1.7 to 2.5. Actually this non-linear relation also applies to other electronic image and video storage formats, including analog ones like Laserdiscs and VHS video tapes. It even applies to the data stored in image frame-buffers and video cable signals. The reason behind this non-linear relation between light intensity and voltage comes from the times when Cathode-Ray Tubes (CRTs) were ruling the world of electronic imaging. CRT cameras would capture an electric signal $\propto F^{1/\gamma}$, which would be transmitted or stored, and displayed on CRT screens that would apply the reverse transformation from f to F. This non-linear transformation has many advantages[4] :

- the recordable intensity range between the darkest and the brightest parts of an image is effectively increased (from 48dB to $\approx$ 100dB with 8 bits per pixel),

[4]More information on issues related to gamma corrections can be found on the web; see, e.g. `http://www.cgsd.com/papers/gamma.html`, `http://www.normankoren.com/makingfineprints1A.html`, or `http://www.poynton.com/notes/colour_and_gamma/GammaFAQ.html`

- quantization effects are reduced perceptually: the perception of light intensities by the human eye is itself non-linear and differences as small as 1% can be detected. Storing light intensities linearly with only 256 shades of grey would bring visible *banding* in the darker parts of an image,

- the signal is often photon-noise-limited on astronomical images; the standard deviation around the mean is proportional to the square-root of the flux. Hence storing the signal at the power of 0.45 gives a noise level close to constant over the image, which is optimal for quantization,

- although CRT displays are now disappearing, being progressively replaced by Liquid-Crystal Displays (LCDs), the latters do also have a "native" γ close to 2 in the dark parts of images: $F \propto 1 - \cos(f/f_0)$ (however this is not the case for DLP, plasma and OLED devices).

STIFF applies automatically the gamma correction $f = F^{1/\gamma}$ to pixel values before storing the data to TIFF. The gamma γ can be modified using the `GAMMA` keyword. The defaut value is 2.22. It is not recommended to change this, especially for colour images (see below).

In some cases, one may want to enhance or reduce the contribution of low surface brightnesses to the final image, without saturating brighter regions. For this a non-linear transformation has to be applied, and modifying the gamma γ is the easiest way to achieve this. Increasing or decreasing γ will compress or expand the contrast scale, respectively. Although this works fine with monochromatic images, it affects colours on multi-channel images. Fig. 3 shows using a simulation the effect of increasing γ to enhance the extended wings of a galaxy profile: here as no background light is present the consequence is only a desaturation of the colours. When several components of various colours are superimposed, significant shifts in colour can occur.

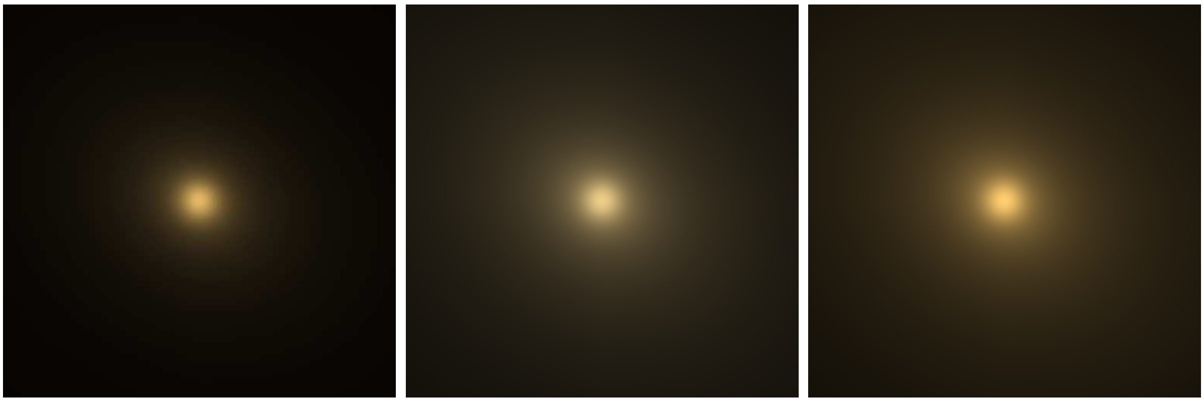

Figure 3: A simulated colour image of an early-type galaxy converted in TIFF by STIFF. *Left*: original gamma of 2.2. *Middle*: using a gamma of 3.3 affects the colour saturation. *Right*: applying a gamma correction factor of 1.5, to luminance only, preserves colour rendition.

As Lupton et al. (2004) remind us, such problems can be circumvented by applying the additional non-linear corrections only to the *luminance* part of the Red,Green,Blue (RGB) signal. We simply define[5] the luminance as

$$Y = \frac{R + G + B}{3}, \tag{2}$$

[5]This definition is somewhat different from the one generally used in video when green is given much more weight.

where R, G, and B are the red, green and blue component values at a given pixel before any non-linear transform is made to the signal. By applying a gamma correction factor γ_Y to the luminance only, one will store in the output TIFF file the r,g,b values

$$r \propto \left(\frac{R}{Y}\,Y^{1/\gamma_Y}\right)^{1/\gamma}, \tag{3}$$

$$g \propto \left(\frac{G}{Y}\,Y^{1/\gamma_Y}\right)^{1/\gamma}, \tag{4}$$

$$b \propto \left(\frac{B}{Y}\,Y^{1/\gamma_Y}\right)^{1/\gamma}. \tag{5}$$

In STIFF, γ_Y is represented by the configuration parameter `GAMMA_FAC`, which defaults to 1.0. By increasing `GAMMA_FAC`, one can enhance low-surface brightness features in the image without affecting the colours.

5.3 Controlling the image dynamic range

Despite the fact that, as we have seen, 8-bit images with a non-linear intensity scale can record surface brightnesses with a dynamic range as high as 100dB, it is generally preferable to restrict the intensity range in input by imposing a low and a high cut for pixel values. STIFF can set these cuts semi-automatically or manually for each channel (colour component). If one chooses manual mode (`MIN_TYPE MANUAL` and `MAX_TYPE MANUAL`), the low $F_{\rm min}$ and high $F_{\rm max}$ cuts are directly set by the values of `MIN_LEVEL` and `MAX_LEVEL`, respectively. If `MIN_TYPE` and/or `MAX_TYPE` are set to `QUANTILE`, `MIN_LEVEL` and/or `MAX_LEVEL` are interpreted as quantiles (between 0.0 and 1.0) of the histogram of pixel values. This is the default for `MAX_TYPE`.

There is a third mode specific to `MIN_TYPE` called `GREYLEVEL`. In that mode, the lower cut $F_{\rm min}$ is automatically adjusted to have the sky background reach a given apparent grey level $\rho_{\rm grey}$ (specified by `MIN_LEVEL`) as a fraction of full white in the TIFF image. This is the default mode for `MIN_TYPE`, with a default `MIN_LEVEL` of $\rho_{\rm grey} = 0.005$ (a very dark grey). The gamma correction factor is taken into account:

$$\rho_{\rm grey} = \left(\frac{F_{\rm sky} - F_{\rm min}}{F_{\rm max} - F_{\rm min}}\right)^{1/\gamma_Y}. \tag{6}$$

Hence

$$F_{\rm min} = \frac{F_{\rm sky} - \rho_{\rm grey}^{\gamma_Y}\,F_{\rm max}}{1 - \rho_{\rm grey}^{\gamma_Y}}. \tag{7}$$

The sky background intensity $F_{\rm sky}$ is estimated automatically from the input image(s) by STIFF when `SKY_TYPE` is set to `AUTO`, which is the default. Note that this estimation is rather crude (it is the median of the histogram of pixel values). Therefore it is sometimes better to switch to manual grey-level mode (`SKY_TYPE MANUAL`), for which the sky background level is directly read from `SKY_LEVEL`.

5.4 Creating colour images

STIFF can generate a composite RGB TIFF image from 3 co-aligned FITS images obtained in different channels. The 3 images must have the same number of pixels in each dimension. If the data are properly astrometered but not aligned, you might want to pass them through SWarp[6] first.

[6] `http://terapix.iap.fr/soft/swarp/`

Without further processing, the colours obtained from images observed with broadband optical filters often look dull and disappointing. STIFF offers the possibility to increase the colour saturation of images, while maintaining their luminance and global white balance. To this aim we introduce an additional α parameter that linearly replaces each R, G, B input triplet with R', G', B' such that:

$$
\begin{aligned}
R' - G' &= \alpha\,(R - G), && (8)\\
G' - B' &= \alpha\,(G - B), && (9)\\
(R' + G' + B') &= R + G + B, && (10)
\end{aligned}
$$

from which we obtain

$$
\begin{aligned}
R' &= Y + \alpha\,\frac{2R - G - B}{3}, && (11)\\
G' &= Y + \alpha\,\frac{2G - R - B}{3}, && (12)\\
B' &= Y + \alpha\,\frac{2B - R - G}{3}. && (13)\\
& && (14)
\end{aligned}
$$

α is represented in STIFF by the `COLOUR_SAT` configuration parameter. `COLOUR_SAT` acts exactly like the saturation knob of a colour TV: if `COLOUR_SAT` is set to 0, the 3 channels are combined to form a black-and-white (greyscale) image; a `COLOUR_SAT` of 1.0 (the default) lets the input colour saturation unaffected, while a `COLOUR_SAT` above 1.0 exaggerates the colours. Fig. 4 shows the impact of various `COLOUR_SAT` settings on a deep-sky colour image. For images observed in contiguous channels, a `COLOUR_SAT` of 2.0 generally gives best results. To avoid funny-looking artifacts showing up with high `COLOUR_SAT`s for very bright objets, a per-channel clipping is applied to saturated pixels prior to exaggerating the colours. Note that this does not prevent pixels with values exceeding $F_{\rm max}$ in one channel or more to appear shifted in colour in the output image; for instance, the core of some bright, orange star may appear slightly yellowish.

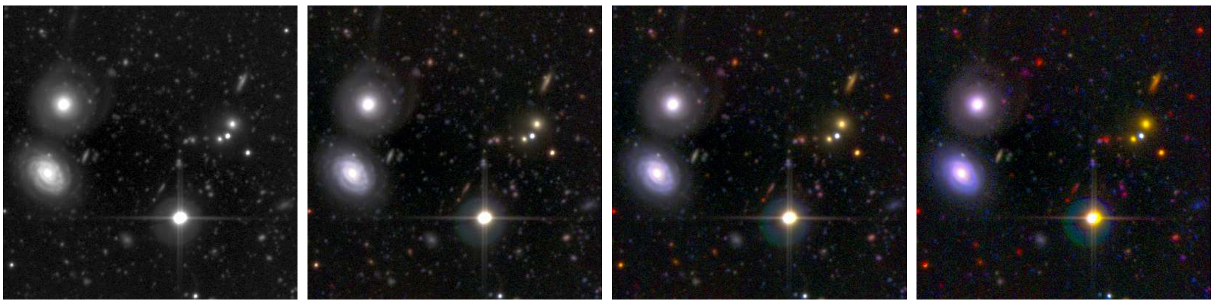

Figure 4: A three-channel deep-sky image converted to TIFF RGB by STIFF with 4 different values of `COLOUR_SAT`. From *left* to *right*: 0.0, 1.0, 2.0 and 4.0. Note the CCD saturation artifacts on top of bright stars.

6 Hints for creating "realistic" deep-sky colour images

The main motivation for writing STIFF was to create vivid yet realistic images of the sky. In the following we will leave aside purely aesthetic considerations to insist on a few simple basic principles that might help us reach that goal.

The first problem is obviously that, even in the optical domain, it is difficult to actually *see* the colours of resolved deep-sky astronomical objects. The colours of many HII regions and planetary nebulae can be seen through the eyepiece of large telescopes, but for galaxies it is another story. Their surface brightnesses are one to two orders of magnitude lower and remain mostly in the scotopic regime of the human vision.

The second difficulty is that the spectral response curves of astronomical imagers rarely match those of our cones.

Fortunately, the colours of astronomical sources result essentially from a handful of well known physical phenomena: the slope of a thermal or non-thermal emission continuum, emission/absorption lines, reddening and diffusion by molecules, and cosmological redshift, that will guide us on our way to represent multi-channel data.

Ordering of channels A first rule to make the physical interpretation of colours easier and consistent from a case to another will obviously be to let the red component represent the largest effective wavelengths and the blue one the shortest wavelengths.

Colour balance Away from nebular and HII regions, the light from point-sources and galaxies is largely dominated by continuum emission in the near-optical domain. Despite the fact that the spectral responses of the observation filters do not match those of our cones, we might want at least to have the colours of regular, unreddened stars to fall roughly on the blackbody track in a CIE diagram (Fig. 5). That is, from red-orange to white-blue (in particular, green stars or galaxies are seldom observed!). Experience shows that this is quite easy to achieve for contiguous broadband filters in the optical/near-IR, after adjusting 2 of the 3 `MAX_LEVEL`s.

The sky background Although this is not realistic, it is strongly advised to use a dark, neutral grey colour for the sky background (actually the real night sky, from the ground or in orbit around the earth, is redder than the sun in the visible, see Leinert et al. 1998). This is what automatically done with the `MIN_TYPE GREYLEVEL` option (the default). A dark grey sky does not affect too much the perception of object colours, and prevents the faintest objets from disappearing in a completely black background. The intensity of the dark grey is set by default to `MIN_LEVEL` 0.005, that is 0.5% of full white, a good value for properly-calibrated display screens. For print-outs, one may prefer a slightly higher value, since many printers have a tendancy to "bury" low surface brightnesses in dark backgrounds.

7 Troubleshooting

I have trouble to properly adjust the contrast and brightness of large mosaic images in `MIN_TYPE QUANTILE` mode.

Because of memory constraints, for large frames the quantile is not computed on all the pixels at once. The quantile algorithm in STIFF may be confused if, in addition, a large fraction of pixels is set to constant values (because of gaps, image margins or overscans). Currently the best solution is then to return to `MIN_TYPE MANUAL` mode.

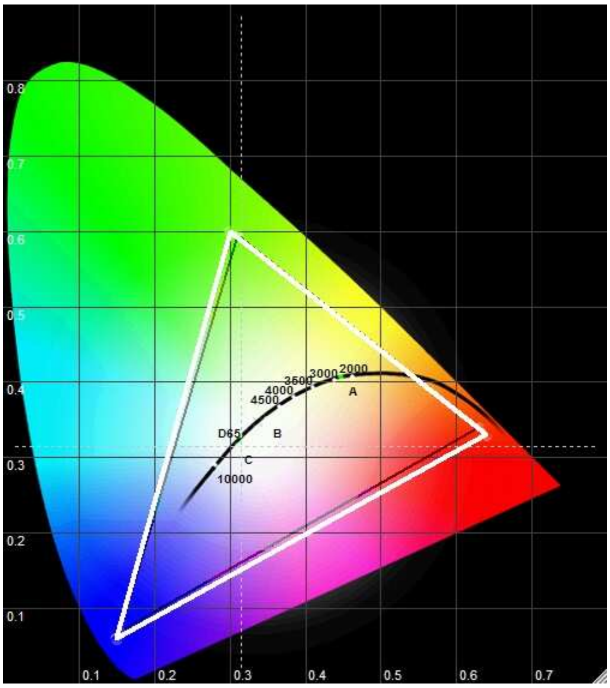

Figure 5: CIE chromaticity diagram (from `http://home.earthlink.net/~tlhuffman/`). The dark line is the track followed by a blackbody with increasing temperature (from the right to the left). Triangles enclose the range of colours ("gamut") that can be reproduced with two typical display devices (for information on chromaticity diagrams and gamuts, see e.g. `http://www.normankoren.com/color_management.html`).

8 Acknowledgements

Many thanks to the TERAPIX crew for testing and support; especially to Henry Joy McCracken for proof-reading the manuscript of this documentation.

References

[1] Bertin E., 1999, *SExtractor 2.1, User's manual*, IAP

[2] Leinert C. et al. 1998, *A&ApS* **127**, 1

[3] Lupton R., et al. 2004, *PASP* **116**, 133