

Visualizing Hubble Data

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Astronomical color images intended for presentation are a fortunate byproduct of science data: separate black and white (grayscale) images made through different filters. Professional astronomical imaging instruments such as those aboard HST use grayscale detectors, unlike consumer digital camera sensors, which directly read out a multi-channel color image. Usually, multiple exposures have been produced and combined to produce each filter exposure. Exposures may have been made at multiple pointings, which may be stitched together to build a wider field of view. Standard reduction and calibration is applied, as for science analysis.

The main steps in producing color images are as follows. The first steps are applied to each color band separately.

- Reduce data
- Register frames, stitch mosaics
- Scale data to optimize tonality
- Apply color

Subsequent steps are applied to the composited image:

- Composite
- Adjust brightness, contrast, tonality color to maximize visible detail (information)
- Retouch artifacts

Initial processing depends on the nature of the data and images. Generally, routine, pipeline processing of raw data suffices to produce calibrated, geometrically corrected images as a starting point for assembling an outreach image. In most cases, three images are required, from different spectral bands to reconstruct a color image.

A dataset may represent an image mosaic to produce a wider-field panorama, in which case the individual frames would be stitched into the mosaic filter by filter. In any case the separate grayscale frames are registered before compositing.

Intensity Scaling

The first step is to scale the data from the original (usually floating-point) in the FITS transforming into something usable for further processing. For this step we

use FITS Liberator¹, free, special-purpose software developed by ESA and NASA, primarily at ESA/Hubble. Originally developed as a plug-in for Adobe Photoshop, in its latest version (3.0) it is stand-alone software that outputs a standard TIFF image file. FITS Liberator allows significant flexibility in the transformation, including several transform functions (linear, log, asinh, etc.), in addition to black and white clipping and other scaling parameters. A GUI and visual display previews the effect of adjusting the parameters before saving a TIFF and optionally opening in the image editor.

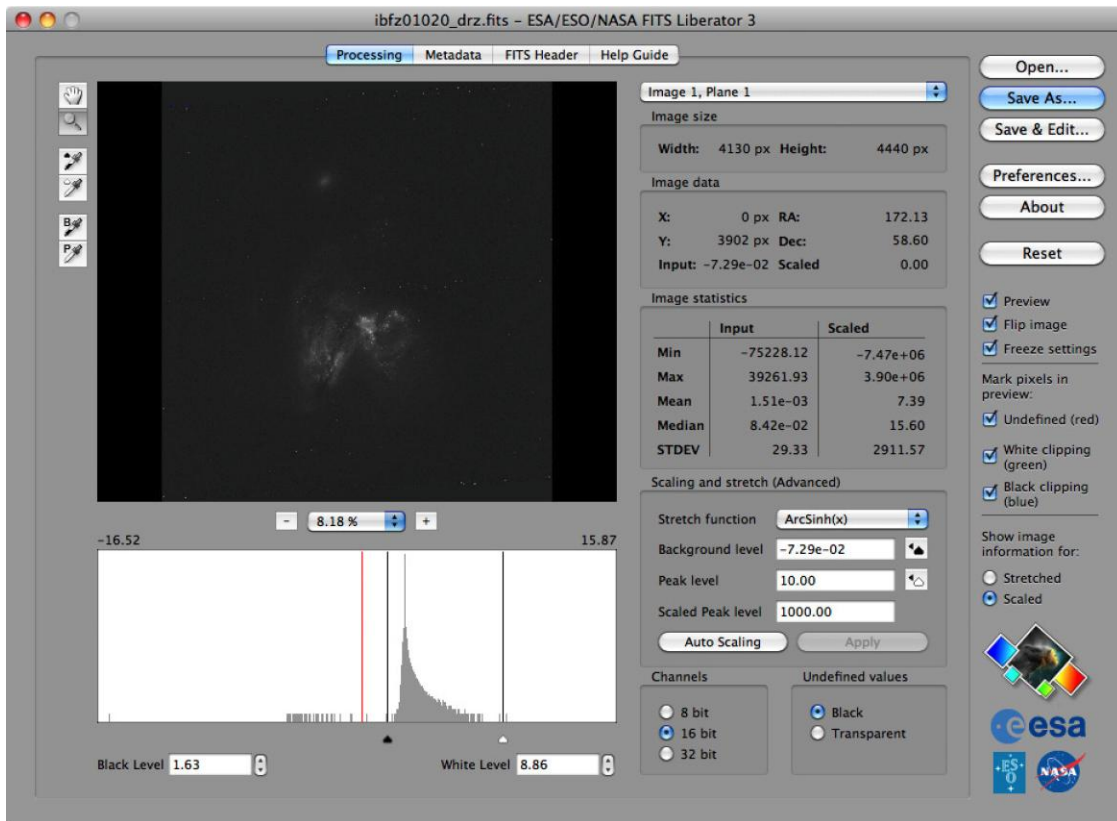


Figure 1. Screen image of the FITS Liberator GUI.

Specific FITS Liberator steps and guidelines

- Check important options: Preview (displays and updates the image view), Flip image (FITS y-axis opposite in sense to Ps), Freeze settings (remembers last settings on reopening the app), White clipping (shows saturated pixels as green), Black clipping (shows under-saturated pixels as blue), 16 bit Channels (higher dynamic-range output for more flexibility in further adjustments in Ps, but output files 2x the byte size. In practice there may be no noticeable difference in image quality between 8 and 16 bit. 32 bit allows using high dynamic range capabilities of downstream SW.)

¹ http://www.spacetelescope.org/projects/fits_liberator/

- Depending on the FITS file structure, it may be necessary to select the desired Image/Plane with the pull-down menu, but usually the FITS contains only one image/plane.
- Use Reset to restore default parameter values (useful if the image is very different from the last one processed, and parameters were saved via Freeze settings).
- The FITS Header tab shows the header parameters, It's sometimes useful to check for instrument/filter, exposure, etc. The Metadata tab shows what information has been retrieved from the header and will be written to the AVM tags in the output TIFF.
- Select the Stretch function. Most commonly ArcSinh(x) works well and is similar to Log(x). These functions brighten and increase contrast of fainter values, while compressing dynamic range and decreasing the contrast of brighter values, which is desirable for many astronomical images. For low dynamic range images such as many nebulae, sometimes linear or $x^{1/2}$, etc. works better.
- Auto Scaling button can help to get near the appropriate parameter values.
- Establish Background level and Peak level via eyedropper tools: select B eyedropper button and click in the image for a representative background value, select P eyedropper button and click in the image on a representative peak value, generally the brightest non-stellar area). May need to zoom (magnifying glass button or %/+/- buttons) and pan (hand button) around the image to find the most likely background and peak regions.
- Adjust black point and white point (usually using histogram display, but also can use the black and white eyedropper buttons) to get close to but not over saturate white level and under-saturate black level.
- Adjust Scaled Peak level to establish optimal mid-tone values, aiming for reasonably even distribution of tones (ignoring cores of stellar PSFs which can saturate for the brighter stars). Ratio of Peak/Scaled Peak values adjusts image brightness/contrast (higher Scaled Peak = brighter image). Note that you can zoom the histogram display by selecting the magnifier button and dragging horizontally across the histogram plot across the smaller area to expand.
- Watch background noise, too much "shadow" contrast can dramatically enhance noise. Adjustments to Background and Scaled Peak levels can sometimes be helpful. Watch "highlight" contrast and clipping. Keeping

white level clipping above the value of the brightest relevant image areas allows preservation/enhancement of highlight detail.

- May need to iterate on several parameters to improve the tonality, but as long as it's close, and important detail areas are not under- or over-saturated (at low or high values), other adjustments will be applied in post-processing in Photoshop. There is usually plenty of dynamic range available with 16 bit depth to apply rather aggressive adjustments without introducing artifacts such as banding or posterization, but need to be careful not to over-enhance noise.
- Save As... to selected TIFF, or Save & Edit... to save and open TIFF in Photoshop.
- Keeping Freeze settings selected saves the parameters; most often the next image a similar dataset.

Subsequent processing is accomplished using image-editing software such as Adobe Photoshop². The three images are scaled separately to optimize the tonal range in each image. This means setting white and black clipping points, and scaling to optimize visible structure throughout the gray levels in the image.

While much additional processing can recover structure and detail in the images, it is important to achieve a good tonal balance in the images initially, trying to reduce the noise levels, and certainly to avoid clipping the important bright areas in the image. For example, it is important to avoid clipping to white the brighter regions of nebulae or the cores of galaxies, but to achieve the brightest values in these areas while preserving “highlight” detail, and at the same time to maximize the brightness and contrast in the lowest values (“shadow” details) without overly enhancing the noise. By the same token, there is no reason to avoid clipping star images quite deeply, as there is generally no important inherent structure in the stellar PSF for a presentation image.

Composite Color

To reconstruct color, different hues are applied to each image and the images composited together using the “Screen” layer blend mode. In general, the lowest energy (reddest) image is assigned red, the highest energy (bluest) image is

² Photoshop is part of the industry-standard Creative Suite software developed by Adobe Systems, Inc. Photoshop includes extensive, powerful tools for editing digital images. Descriptions of using the software here should not be construed as an endorsement of a specific commercial product by STScI or NASA. Much of this sort of image processing can be accomplished in other tools, including open-source software such as The GIMP. The terminology and paradigms embodied in Photoshop are useful for discussing these concepts.

assigned blue, and the intermediate energy is assigned green. Any hue may be applied in principle, but the three additive primary colors: red, green and blue maximize the color gamut in the reconstructed image. Variation may be applied for aesthetic reasons to shift colors or to enhance particular features.

This technique permits combining multiple images in different layers with more flexibility than staying limited to the three primary color channels. It allows including more than three filters/layers. One advantage of this technique is the opportunity to apply hues to the filter images that vary from the additive primaries, which may not necessarily have a close relationship to the color response of the filters and detectors used to make the observations but may provide a more pleasing color palette, but also more importantly may allow seeing and separating features inherent in the data. It is also possible to easily apply non-destructive adjustments to the separate images. Adjustments can be applied selectively to different spatial locations in the image or to selected ranges of tonal values, using selections, masks, and other techniques.

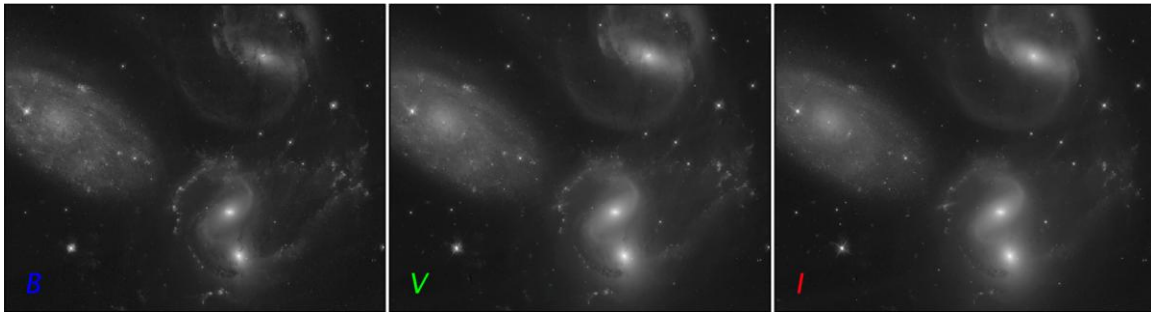


Figure 2. HST WFC3/UVIS images of the galaxy group Stephan's Quintet in three broad-band visible-light filters; left: F439W (*B*), center: F555W (*V*) and right: F814W (*I*).

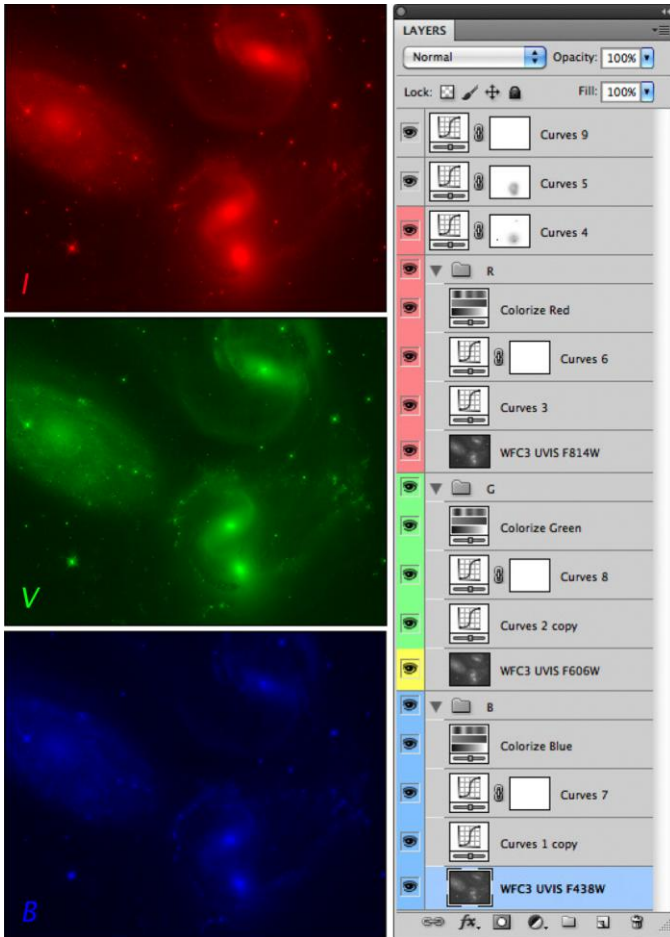


Figure 3 Left panels: The same images as in figure 2, with a different additive primary hue applied to each. Right: Photoshop layers palette representing separate image layers for each filter dataset as well as adjustment layers to change the brightness profile (curves adjustments) for each layer and apply hue to each filter layer (Hue/Saturation adjustments). Additional curves adjustments apply to the composited image.

Adjustments and Retouching

Beyond the basic image compositing paradigm, established digital darkroom techniques make features in the data visible, and common aesthetic principles make science images more visually appealing. The kinds of adjustments we use are generally intended to improve the overall contrast and tonal range and produce images within the expectations of visualizing physical phenomena. The deep dynamic range of HST's detectors enables recording structures across a broad range of luminosity, from faint outer structures of distant galaxies, to complex morphologies of bright emission nebulae, often in the same image. Translating that range of brightness into the more limited dynamic range of displays and prints while preserving visible structure requires remapping tonalities and locally adjusting contrast.

Techniques such as “dodging,” “burning” and “unsharp masking” were developed in the days of film and darkrooms to compress the broad tonal range of a photographic negative into the more constrained range of a print with rich tonalities and plenty of detail in “highlights” and “shadows.” The same kinds of

techniques are accomplished easily in image-editing software using brightness/contrast adjustments, masks, and other tools.

We expect the sky background in most astronomical images to be neutral in color and nearly black, and the brightest galaxy nuclei and emission features to be bright and white. Intensity scaling, tonal, contrast and color adjustments allow us to make images conform to these expectations. Color adjustments are intended to remove colorcasts and render features in their expected colors: reddish hydrogen emission, bluish young clusters, red/yellow dust lanes or old, cool, stellar populations, etc. The underlying goal of these adjustments is to visualize as much information as possible inherent in the data without misrepresentation so as to inform without misleading the viewer.

We keep other common, more sophisticated image editing techniques to a minimum to avoid introducing artifacts and departing from the original data. We do use “cosmetic retouching” to remove telescope and instrument artifacts such as reflection ghosts, CCD charge transfer bleeding, residual cosmic rays, hot pixels, etc., and judiciously apply minimal noise reduction and sharpening. These are intended to reduce distracting elements that would otherwise take the viewer’s attention away from the main subject.

The most significant aesthetic decisions can be seemingly the simplest. Image cropping and orientation can dramatically change the power and appeal of an image. For this reason, we don’t stay constrained to a north-up, or as-observed orientation and framing. By the same token, science observation design and constraints can limit the available options for the best aesthetics. Unfortunately, what’s best for science and most efficient observing is not always the best for the most pleasing pictures. An additional filter could provide a better rendering of the color space, or an additional pointing or different orient could include some especially interesting feature in the subject. The ACS and WFC3 chip gaps and the “bat-wing” WFPC2 footprint present challenges to producing a pleasing composition.



Figure 4. Left: Initial color composite from HST WFC3 images of Stephan's Quintet rendered in hues assigned to datasets from several separate filters. Right: The same image adjusted to improve the contrast, tonal range, and color.

The details of scaling, hue selection, etc., vary depending on the nature of the data. Broadband filters respond differently than narrow band (nebular) filters or a mix of filters. Nevertheless, the overall visualization paradigm applies, not only to visible-light images, but any datasets that represent different physical conditions in the same spatial area. We have constructed effective composites spanning the entire available range of the spectrum, from x-rays to radio.

Philosophy

In some cases, the resulting images may be relatively close to a visually accurate rendering of the target, provided the filter/detector response matches the human visual system model, and taking into account the enhancement afforded by optics and detectors. In most cases, the rendering is a visualization of phenomena outside the limits of human perception of brightness and wavelength. Nevertheless, the goal in producing presentation images remains to stay honest to the data, and to avoid misleading the viewer, but also to produce an aesthetically pleasing image.

The resulting images can be spectacularly beautiful but also deeply informative. Anyone is more likely to want to look at an aesthetically pleasing image, even though the subject matter may be unfamiliar, indeed quite abstract. Further, someone looking at an attractive image is much more likely to want to learn more about what the image is telling them. Upon understanding the nature of the subject, the image takes on a deeper meaning, much like experiencing another dimension.