Studying Starlight from Distant Galaxies with SIRTF

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ABSTRACT

Starlight from distant galaxies (z > 3) is redshifted into the near infrared band with observed wavelengths from 2-8 μm. Most of the light is emitted by stars that have a peak emission at the 1.6 μm wavelength of the minimum of the H^− opacity. We present simulated images of galaxy and star fields at 3, 4.7 and 8 μm, using the expected performance of the infrared camera on the Space InfraRed Telescope Facility (SIRTF). Standard astronomical image processing tools are used to locate sources, distinguish stars from galaxies, and create color-magnitude and color-color diagrams for the galaxies.

1. Simulation

The following steps have been taken in generating and analyzing the SIRTF images.

The galaxy population in these images was generated in clusters with redshifts ranging from 0 to 10. Clusters were assumed to form with an exponential distribution of formation times having a mean time of formation corresponding to z = 5 in an \( H_0 = 50, \Omega = 1 \) cosmology. The density of galaxies has been increased slightly over the value given by Schechter in order to match Cowie’s deep K-band counts. Luminosities and colors evolve using Bruzual \( \mu \)-models with a \( \mu \) that depends on galaxy type.

Stars were added to the images using the populations used by Elias. Brown dwarfs are also included, but because we have assumed only old cold brown dwarfs (\( M = 0.05 \, M_\odot, \, t = 10^{10} \) yrs, \( T_{\text{color}} = 462 \) K, \( L = 10^{-6}L_\odot \)), none of the detected sources were brown dwarfs. Of the 32 stars in the field brighter than 0.1 \( \mu \)Jy at 4.7 μm, 6 are brown dwarfs, but the brightest is just fainter than the 4.7 μm flux limit at 0.6 \( \mu \)Jy. Its 8 μm flux is 1.5 \( \mu \)Jy which is under the 8 μm limit as well. Note that the color is redder than any of the galaxies that we do detect.

Galaxy spectra are based on the spectral energy distributions for ellipticals and spirals by Marcia Rieke, which were combined with various weights to match Bruzual \( \mu \)-models in the optical. This allowed us to include the broad IR features due to the H^− opacity minimum. This peak at 1.6 μm rest wavelength can be seen in the bluing of the 4.7:8 μm color at \( z = 2 \).

800×800 pixels images covering 5.3333′ were generated, and then convolved with the SIRTF beam. We assumed the diffraction limit of an 85 cm telescope with a 30% linear obscuration. In order to not exceed the SIRTF specification of 50% encircled energy in a 2′ diameter circle, this diffraction-limited beam was further convolved with a 1.657′ FWHM Gaussian.

These 800×800 pixel images with 0.39′′ pixels were then made into 256×256 pixel images with 1.17′′ pixels by summing 3×3 blocks of pixels. This array was sub-stepped across the field in
a 3×3 pattern giving a final picture with 768×768 pixels of size 1.17″ on 0.39″ centers. Noise was added to each pixel in this image, using the following noise levels: 3 μm, 20.4 nJy, corresponding to 2500 seconds; 4.7 μm, 74 nJy, corresponding to 2500 seconds; 6.2 μm, 155 nJy, corresponding to 10,000 seconds; and 8 μm, 217 nJy, corresponding to 10,000 seconds. Because of the 3×3 substepping, a total of 9 frames at each wavelength are needed, giving a total exposure time of 22500+22500+90000 seconds or 1.6 days for the image shown.

The first step after getting the 3×3 sub-stepped images is to smooth with a 3×3 box. These images were written out as FITS files and displayed by SAOIMAGE. The RGB image was created using a FORTRAN program to convert the intensities into a PPM (Portable Pixel Map) file which was converted into a JPEG file using xv, and then printed to a HP Deskjet 1200C printer using Adobe Photoshop. Prints were also obtained using a Kodak XL 7700 dye sublimation printer and a Polaroid Palette film recorder.

2. Analysis

The 8 μm image was analyzed first. A baseline was subtracted from the frame. The level was chosen by finding the smallest range of values that covered 1/4 of the pixels in the frame, and then taking the mean of this range. This is an approximate way to find the mode of an image.

With the baseline subtracted, a 7 pixel (2.73″) diameter circle was scanned across the image. Places where the flux within this circle reached a local maximum over at least a 5×5 pixel square, and with fluxes greater than 3 σ above the baseline, were identified as 8 μm sources and listed. This list was then truncated at 2 μJy total flux, yielding 346 sources.

A similar list was constructed at 4.7 μm, truncated at 2/3 μJy total flux. The source positions found from the 8 μm image were replaced by the closest source position from the 4.7 μm image in order to get better centroids from the higher SNR 4.7 μm image.

The flux within a 2.73″ diameter circle was then found in the 3 images at 3, 4.7 and 8 μm, giving the observed colors of the sources. The ratio of the flux within a 5 pixel (1.95″) circle to the flux contained within 2.73″ was taken on the 4.7 μm image in order to see if source size could be used to separate stars from galaxies using the SIRTF beam.

Finally we have used the extra knowledge that comes from controlling the simulations to generate three more data per source. A noiseless 4.7 μm image was generated using the same beam convolution and smoothing, as well as a noiseless image of redshift times 4.7 μm flux. From these images we generate the noise-free flux in a 7 pixel circle, F[2.73″], the noiseless F[1.95″]/F[2.73″] ratio, and the noiseless (z × F) : F ratio, which gives us the mean redshift of the light seen in 2.73″ diameter circle centered on the source.

Looking at these mean redshifts for the stars in the image suggests that there is about (0.5 μJy)*(z unit) of redshifted 4.7 μm flux in the 2.73″ aperture. Thus these images are pushing the confusion limit.
3. Conclusions

The SIRTF image quality is marginal for discriminating between galaxies and stars. The low-z clump of sources with high $F'[1.95'']/F'[2.73'']$ ratios are stars, but several galaxies have higher ratios and thus appear more compact than some of the stars. Fortunately almost all the faint sources in a high latitude deep survey will be galaxies.

Photometric redshifts using colors out to $\lambda = 8 \mu m$ appear to be reliable. There are 40 galaxies with $z > 3$ in the sample of 346 sources. Sorting the 346 sources by $4.7:8 \mu m$ color, the 41 reddest sources contain 39 out of these $z > 3$ galaxies. The $4.7:8 \mu m$ color redshift diagram appears to be saturating at $z = 5$. The $3:4.7 \mu m$ color saturated at $z = 2$ and then became bluer for higher redshifts, so the longer wavelength data is needed for reliable photometric redshifts at high $z$.

4. Captions

The 5' x 5' SIRTF field of view, showing the 8 $\mu m$ image as red, the 4.7 $\mu m$ image as green, and the 3 $\mu m$ image as blue.

The same region with detected sources color coded by redshift. Dark blue for $0 < z < 1$, light blue for $1 < z < 2$, green for $2 < z < 3$, orange for $3 < z < 4$, and red for $4 < z$.

A color-color plot showing the 3:4.7 and 4.7:8 colors in magnitudes (relative to $F_\nu = \text{constant}$) for the detected sources, color coded by redshift. Dark blue for $0 < z < 1$, light blue for $1 < z < 2$, green for $2 < z < 3$, orange for $3 < z < 4$, and red for $4 < z$. The lines show the locations of blackbodies (upper) and power law spectra (lower).

A size vs. redshift plot for the detected sources.
This figure "RGB1decB.jpg" is available in "jpg" format from:

http://arxiv.org/ps/astro-ph/9407055v2
A color-color plot showing the [3]-[4.7] and [4.7]-[8.0] colors in magnitudes [relative to $F_\nu = \text{constant}$] for the detected sources, color coded by redshift.
This figure "zlistnew.gif" is available in "gif" format from:

http://arxiv.org/ps/astro-ph/9407055v2
The figure shows a scatter plot of redshift against the logarithm of the ratio of fluxes, $\log(F[1.95'']/F[2.73''])$. The data points are distributed across a range of redshift values, with a noticeable spread in the logarithmic flux ratio.