Deblurring and Enhancing Astrophotographs Using PSF-Based Digital Image Processing

Group 19

0.1 Introduction

Astrophotography, the practice of photographing celestial objects is significantly limited by image degradation due to both atmospheric turbulence and optical diffraction. Ground telescopes have image distortions caused by atmospheric seeing, wherein variations of the refractive index of the atmosphere distort incoming light waves. In addition, the optical elements of a telescope cause diffraction-type blurring, dispersing the light intensity distribution and producing a pattern defined by the Point Spread Function (PSF). The PSF is the response of an imaging system to a perfect point source and is a simple model of how a telescope forms images. To deblurring astrophotographs and having them appear improved properly, it's essential to know and to simulate the PSF. We are focusing on restoring and enhancing astrophotographs using PSF-based digital image processing techniques.

0.2 Methodology

During this week, we simulated PSF on the raw FITS image(acquired by the Hubble Telescope) using different methods. We tried to implement the Gaussian, Moffat and Airy methods of PSF using python. Manual extraction of PSF identified bright, isolated spots in the image. However, that required bright contrast and visibility which might often not be there in raw, unprocessed images. A gaussian PSF will depict a smooth decay, whereas a Moffat will have a longer tail, and Airy will have ring-like frequency patterns. These are the results obtained:

Implementation:

We began by importing necessary libraries for the implementation of functions and convolution. Then, we normalize the image to increase the contrast and improve the visualization. We also implement CLAHE, to enhance the faint features. Implementation:

Listing 1: Load FITS image and normalize

```
hdul = fits.open('/content/Bcomb.fits')


img -= np.min(img)
img /= np.max(img)
img_eq = exposure.equalize_adapthist(img, clip_limit=0.03)
```

Then, we apply the Gaussian psf:

0.2.1 Gaussian PSF

$$\text{PSF}_{\text{Gaussian}}(x, y) = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{x^2 + y^2}{2\sigma^2} \right)$$

Implementation:

Listing 2: Gaussian PSF

```
def gaussian_psf(size=64, sigma=3):
    x = np.linspace(-size//2, size//2, size)
    X, Y = np.meshgrid(x, x)
    psf = np.exp(-(X**2 + Y**2) / (2 * sigma**2))
    psf /= np.sum(psf)
    return psf
```

Then, we apply the Moffat psf:

0.2.2 Moffat PSF

$$\text{PSF}_{\text{Moffat}}(x, y) = \frac{\beta - 1}{\pi\alpha^2} \left[1 + \frac{x^2 + y^2}{\alpha^2} \right]^{-\beta}$$

Implementation:

Listing 3: Moffat PSF

```
def moffat_psf(size=64, alpha=5, beta=2.5):
    x = np.linspace(-size//2, size//2, size)
    X, Y = np.meshgrid(x, x)
    R2 = X**2 + Y**2
    psf = (1 + R2 / alpha**2)**(-beta)
    psf /= np.sum(psf)
    return psf
```

Then, we apply the Airy psf:

0.2.3 Airy PSF

$$\text{PSF}_{\text{Airy}}(r) = \left[\frac{2J_1\left(\frac{\pi r}{R_0}\right)}{\frac{\pi r}{R_0}} \right]^2, \quad r = \sqrt{x^2 + y^2}$$

Implementation:

Listing 4: Airy PSF

```
def airy_psf(size=64, radius=10):
    x = np.linspace(-size//2, size//2, size)
    X, Y = np.meshgrid(x, x)
    R = np.sqrt(X**2 + Y**2) + 1e-8
    psf = (2 * j1(np.pi * R / radius) / (np.pi * R / radius))**2
    psf /= np.sum(psf)
    return psf
```

We convolve the results of each PSF with the original images, and obtained these results.

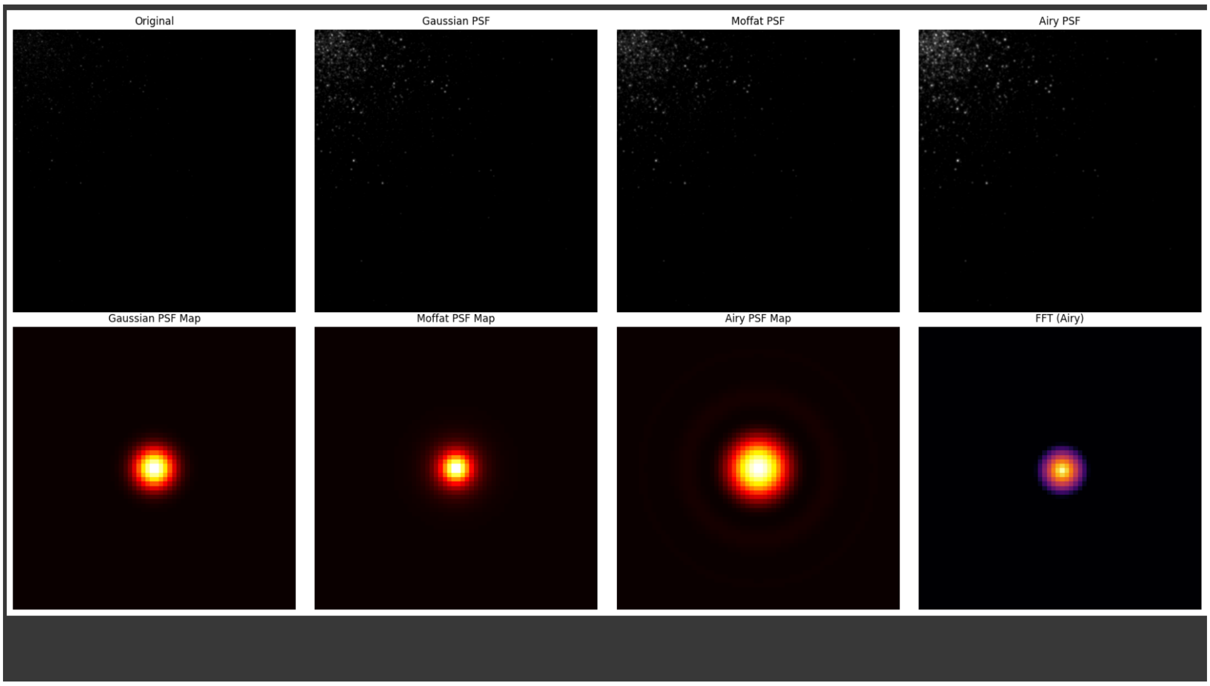
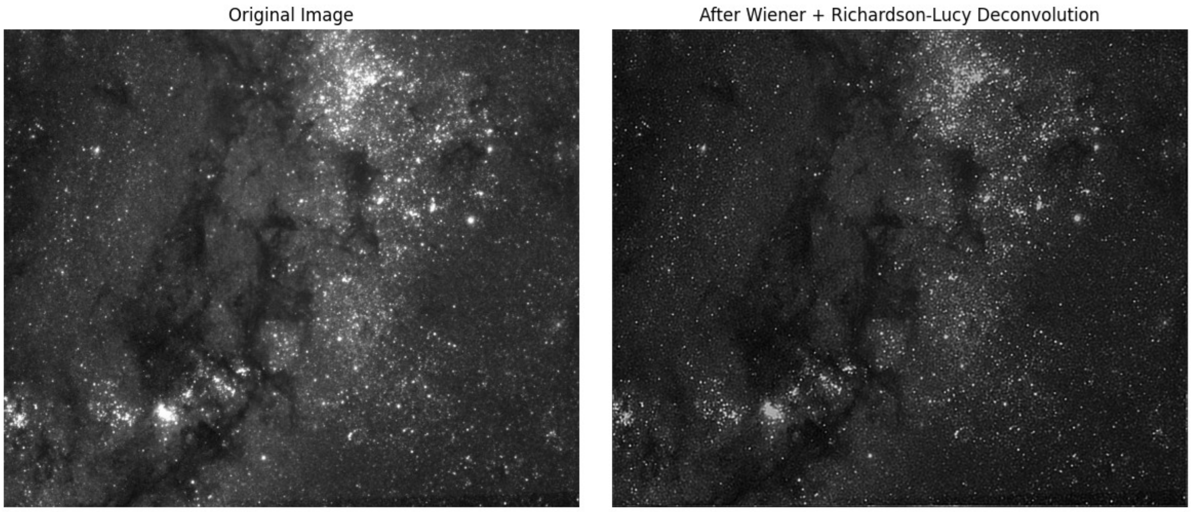
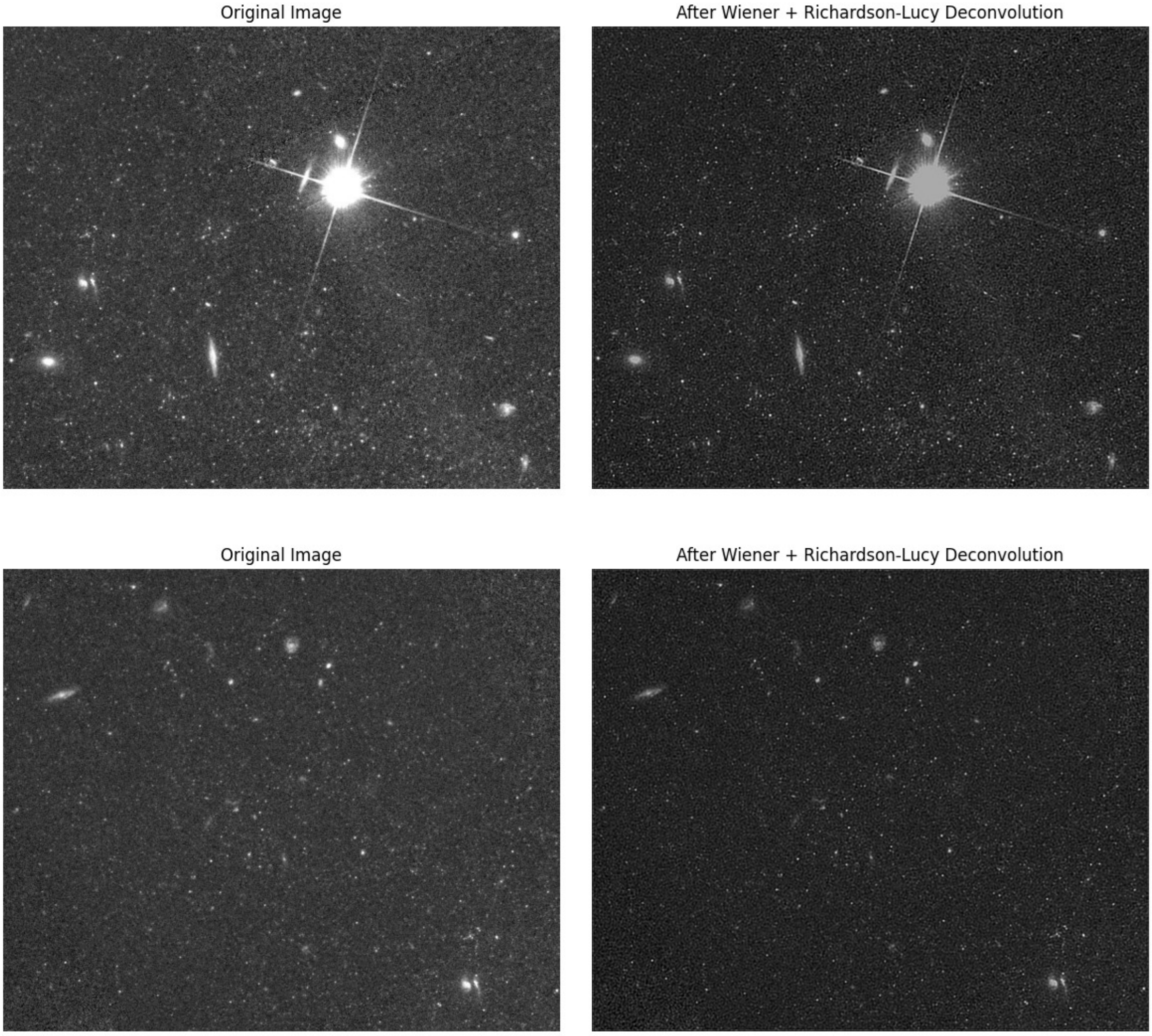


Figure 1: Results

Following that, we applied a gaussian psf to .JPG preprocessed image, and then applied Richard-Lucy deconvolution to obtain an enhanced image. The results of that implementation are:





0.3 Problems Faced

During this phase of the project, several technical challenges were encountered while implementing PSF-based image deblurring and enhancement:

1. **PSF estimation:** The process of estimating a suitable point spread function was difficult because of insufficient knowledge regarding the telescope parameters, and atmospheric distortion error that would project their 'wobble' into the PSF. Small errors in estimating the PSF altered the restoration resulting in over-restored or under-restored images. Stacking could be used to apply advanced processing techniques, but that would require multiple raw dataset of the same view which is difficult to obtain. Plus, the alignment of the the stacked images proves to be huge challenges. Color mapping has proven to be difficult because it requires specific calibration which differs from image to image due to the type of imaging system used.

2. **Noise:** The deblurring process frequently heightened the existing noise in the original astrophotographs. In the case of the two methods of Lucy-Richardson and

Wiener filtering, the small, high-frequency bandwidths of noise were amplified inadvertently which reduced the quality of the overall image.

3. **Visualization Issues:** A key aspect of showing and comparing the original, lasered, and deblurred images was managed for scale and contrast features. Due to inconsistent intensity normalization it was difficult to draw an objective, visual assessment of apparent improvements.

4. **Limitations:** The lack of a diverse set of blurred and ground-truth astronomical images restricted the ability to fully validate the effectiveness of the implement model. The size of the images was too large (FITS) which posed a challenge for the implementation of code. A lot of images acquired were already preprocessed which made it difficult to acquire proper raw data.

0.4 Next set of work

The next set of work will include optimizing the deconvolution to get better images. We will also perform color mapping to get better, more exact output. Further, pre and post processing of the raw image will be done to get better quality output with minimal blurriness.

0.5 Conclusion

We were able to successfully simulate a PSF for deblurring. We used Gaussian PSF and deconvolved the original image with the PSF to get enhanced image using Richard-Luch deconvolution and Wiener deconvolution. The output image had enhanced visibility with increased contrast of fainter features of the image. Further improvements can be made to increase the visibility of the image. Future work could include color mapping for near exact restoration of the raw image (FITS format).

Bibliography

[1] Telescope Optics, “Diffraction Image of a Point Source,” 2025. [Online]. Available: https://www.telescope-optics.net/diffraction_image.htm. [Accessed: 13-Oct-2025].

[2] É. Thiébaut, L. Denis, F. Soulez, and R. Mourya, “Spatially variant PSF modeling and image deblurring,” *Proceedings of SPIE - The International Society for Optical Engineering*, vol. 9908, pp. 99080E, 2016. [Online]. Available: https://doi.org/10.1117/12.2233647. [Accessed: 13-Oct-2025].

[3] J. Anderson, “One-Pass HST Photometry with hst1pass,” WFC3 Instrument Science Report WFC3-ISR-2022-05, 2022. [Online]. Available: https://www.stsci.edu/files/live/sites/www/files/home/hst/instrumentation/wfc3/documentation/instrument-science-reports-isrs/_documents/2022/WFC3-ISR-2022-05.pdf. [Accessed: 13-Oct-2025].

[4] Space Telescope Science Institute, “WFC3 PSF Analysis Overview,” 2025. [Online]. Available: https://www.stsci.edu/hst/instrumentation/wfc3/data-analysis/psf. [Accessed: 13-Oct-2025].

[5] R. H. D. Miora, E. Rohwer, M. Kielhorn, C. Sheppard, G. Bosman, and R. Heintzmann, “Calculating Point Spread Functions: Methods, Pitfalls, and Solutions,” *Optics Express*, vol. 32, no. 16, pp. 27278–27302, 2024. [Online]. Available: https://opg.optica.org/oe/fulltext.cfm?uri=oe-32-16-27278. [Accessed: 13-Oct-2025].

Bibliography