

Astronomical Image Processing Using Linux

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ABSTRACT

Astronomical image processing plays a crucial role in extracting valuable information from the vast amount of data collected by modern telescopes and observatories. This chapter aims to provide a comprehensive guide to astronomical image processing techniques in the Linux environment.

The chapter begins with an introduction to the significance of image processing in astronomy, highlighting its role in enhancing image quality, removing noise, and revealing hidden details. It further discusses the advantages of using Linux as a platform for astronomical image processing due to its flexibility, open-source nature, and availability of powerful tools and libraries. Next, the chapter delves into the fundamentals of astronomical image processing, covering key concepts such as image calibration, alignment, stacking, and post-processing. It explores various techniques for pre-processing raw astronomical images, including bias, dark, and flat field correction, along with methods for aligning and combining multiple exposures.

Subsequently, the chapter provides an in-depth exploration of Linux-based tools and software packages commonly used in astronomical image processing. It covers popular software such as IRAF (Image Reduction and Analysis Facility), DS9 (SAO Image DS9), and Astropy, elucidating their functionalities, command-line usage, and integration with Linux.

Furthermore, the chapter discusses advanced image processing techniques specific to astronomy, such as image deconvolution, noise reduction, photometric calibration, and astrometry. It highlights the utilization of Linux tools and libraries, including GNU Image Manipulation Program (GIMP), Image Magick, and OpenCV, for implementing these techniques. To provide practical insights, the chapter includes illustrative examples, step-by-step tutorials, and code snippets demonstrating the application of Linux-based image processing techniques to real astronomical data. Additionally, it emphasizes the importance of scripting and automation using tools like Bash and Python to streamline image processing workflows.

This chapter serves as a valuable resource for astronomers, astrophotographers, and researchers interested in leveraging the power of Linux for processing astronomical images. It equips readers with a comprehensive understanding of Linux-based tools, techniques, and best practices for extracting and analyzing meaningful information from astronomical imagery.

I. INTRODUCTION TO ASTRONOMICAL IMAGE PROCESSING

A. Importance of image processing in astronomy

Image processing plays a crucial role in astronomy, aiding astronomers in extracting valuable information from the vast amount of data collected by telescopes and other observational instruments. Here are some key reasons why image processing is important in astronomy:

Enhancing Image Quality: Raw astronomical images captured by telescopes often contain various sources of noise, such as background radiation, atmospheric turbulence, and detector imperfections. Image processing techniques, including noise reduction, calibration, and deconvolution, help improve the quality of these images, enhancing the visibility of faint objects and fine details.

Object Detection and Classification: Image processing algorithms are employed to identify and classify celestial objects in astronomical images. These algorithms can automatically detect stars, galaxies,

nebulae, and other celestial bodies, enabling astronomers to analyze and catalog them more efficiently.

Image Restoration: Astronomical images are often affected by atmospheric turbulence, which leads to blurring and distortion. Image processing methods, such as image deblurring and image reconstruction, can partially compensate for these effects, allowing astronomers to obtain clearer and more accurate representations of celestial objects.

Image Registration and Alignment: Astronomers frequently capture multiple images of the same region of the sky over time or using different telescopes or instruments. Image registration and alignment techniques enable the precise alignment of these images, facilitating the study of transient phenomena, such as supernovae, variable stars, or asteroid motion.

Data Analysis and Visualization: Image processing algorithms aid in the extraction of quantitative information from astronomical images. Scientists can measure properties like brightness, color, and shape of celestial objects, allowing for statistical analysis, classification, and comparison with theoretical models. Furthermore, processed images can be visually enhanced and combined to create stunning visualizations that engage and inform the public.

Astronomical Image Archives: Image processing techniques are used to preprocess and analyze vast archives of astronomical images. By applying automated methods for image characterization, feature extraction, and data mining, astronomers can efficiently explore these archives to discover new objects, study their properties, and unravel astrophysical phenomena.

Advanced Imaging Technologies: Image processing plays a critical role in cutting-edge astronomical imaging technologies. Techniques like adaptive optics, which compensate for atmospheric distortion in real-time, and interferometry, which combines signals from multiple telescopes, heavily rely on sophisticated image processing algorithms to reconstruct high-resolution images and explore fine details in astronomical objects.

In summary, image processing in astronomy is essential for improving image quality, detecting and classifying celestial objects, restoring images, aligning and analyzing data, facilitating archival research, and enabling advancements in imaging technologies. It greatly enhances our understanding of the universe and supports various astronomical studies and discoveries.

B. Importance of image processing in astronomy

Image processing plays a crucial role in astronomy as it allows astronomers to extract meaningful information from astronomical images and enhance their scientific value. Here are several key reasons why image processing is important in astronomy:

Data Enhancement: Astronomical images captured by telescopes often contain various sources of noise, such as sensor noise, atmospheric turbulence, and cosmic ray impacts. Image processing techniques help reduce these noise sources and enhance the quality of the data. By improving the signal-to-noise ratio, astronomers can extract faint and intricate details that would otherwise be obscured.

Image Calibration: Astronomical images need to be calibrated to correct for instrumental and observational effects. These effects include bias (electronic offset), dark current (thermal noise), and flat field variations (uneven illumination). Image processing algorithms are employed to subtract these unwanted effects, resulting in a more accurate representation of the celestial objects.

Image Registration and Alignment: In many cases, astronomical images need to be registered and aligned to create mosaics or to compare observations taken at different times or by different telescopes. Image processing techniques can automatically align images based on the positions of stars or other reference features, allowing for precise comparisons and analysis.

Image Reconstruction: Some astronomical phenomena, such as planetary surfaces or distant galaxies, may not be resolved clearly in raw telescope images due to the limitations of the instruments or atmospheric conditions. Image processing techniques, such as deconvolution algorithms, can help reconstruct high-resolution images from the available data, enabling scientists to study fine details and structures.

Image Analysis and Measurement: Image processing enables quantitative analysis of astronomical images. It helps astronomers measure properties such as object brightness, size, shape, and position accurately. By extracting precise measurements, scientists can study various astronomical phenomena, such as star formation, galaxy evolution, and the properties of exoplanets.

Visualization and Communication: Image processing techniques are used to enhance the visual appearance of astronomical images, making them more aesthetically pleasing and easier to interpret. Processed images are often used for public outreach, scientific publications, and educational materials to convey the wonders of the universe to a broader audience.

Overall, image processing in astronomy is vital for maximizing the scientific potential of astronomical data, allowing astronomers to unveil the mysteries of the cosmos and deepen our understanding of the universe.

C. Overview of astronomical image data

Astronomical image data refers to the collection of images captured by various telescopes and instruments that observe celestial objects such as stars, galaxies, nebulae, and planets. These images are essential for astronomers to study and understand the universe, providing valuable insights into the nature and properties of celestial objects.

Here's an overview of some key aspects of astronomical image data:

Telescopes and Instruments: Astronomical images are obtained using a variety of telescopes and instruments. These include ground-based observatories, space telescopes, and specialized instruments such as spectrographs, cameras, and detectors. Each instrument has its specific capabilities and is designed to capture different types of data, including visible light, infrared, ultraviolet, X-rays, and radio waves.

Image Formats: Astronomical images are typically stored in digital formats such as FITS (Flexible Image Transport System), which is widely used in the field. FITS files contain both image data and associated metadata, including information about the observation, telescope, instrument, and calibration details.

Image Processing: Astronomical images often undergo extensive processing to enhance their scientific value. This includes calibration processes to remove noise, flat-fielding to correct for uneven sensitivity across the image, and stacking multiple exposures to improve signal-to-noise ratio. Image processing techniques also involve removing artifacts, adjusting contrast, and applying various filters to reveal specific features.

Astronomical Surveys: Large-scale projects called astronomical surveys systematically observe large portions of the sky, generating vast amounts of image data. Examples of well-known surveys include the Hubble Space Telescope's Hubble Legacy Archive, the Sloan Digital Sky Survey (SDSS), and the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS). These surveys contribute to the creation of comprehensive catalogs and databases of astronomical objects.

Multispectral Imaging: Astronomical images are often captured in multiple wavelengths or bands, covering different regions of the electromagnetic spectrum. This multispectral imaging allows scientists to study objects' properties that are not visible in the optical range alone. Combining data from various wavelengths provides insights into phenomena such as star formation, galaxy evolution, and the presence of specific chemical elements.

Data Analysis and Visualization: Astronomers employ various techniques to analyze and interpret astronomical image data. This involves identifying and measuring celestial objects, performing photometry (brightness measurement), spectroscopy (analysis of light spectra), and applying statistical methods to derive scientific conclusions. Advanced visualization tools and software are used to create compelling visual representations of the data, aiding in scientific communication and public outreach.

Data Sharing and Archives: Astronomical image data is often shared among the scientific community through specialized data archives. These archives provide access to both raw and processed data, allowing researchers to perform new analyses or validate previous findings. Prominent archives include the Mikulski Archive for Space Telescopes (MAST), the European Southern Observatory (ESO) Archive, and NASA's Astrophysics Data System (ADS).

By studying astronomical image data, scientists can unravel the mysteries of the universe, uncovering details about celestial objects, their properties, formation, and evolution. These images play a crucial role in advancing our understanding of the cosmos and inspire awe and curiosity about the vastness and beauty of the universe.

II. LITERATURE REVIEW

The various aspects of astronomical image processing and data management, reflecting the multidimensional nature of the field. Donatello and Slezak (2004) emphasize the significance of Image Processing in Astronomy, underlining its role in extracting valuable information from astronomical images. Robitaille, Tollerud, and their collaborators (2013) contribute to this domain by presenting Astropy, a community Python package tailored for astronomy, enabling efficient data analysis and manipulation. Connolly and colleagues (2014) shed light on The LSST Data Management System, a vital component of the Large Synoptic Survey Telescope (LSST), responsible for handling the massive volumes of data generated by the survey. Wall and Jenkins (2012) present Practical Statistics for Astronomers, providing astronomers with essential statistical tools for data analysis and interpretation.

Stetson (1987) introduces DAOPHOT, a powerful computer program designed for crowded-field stellar photometry, facilitating the study of densely populated regions in the sky. Valdes, Gupta, Rose, and their team (2004) contribute The NOAO Data Handbook, an invaluable resource for understanding and managing astronomical data from the National Optical Astronomy Observatory (NOAO). Kelley and Rieke (2014) present The Red Book, offering guidance on calibration and data analysis for the Spitzer Infrared Spectrograph, an important instrument in infrared astronomy.

Dickinson (2006) provides a comprehensive Introduction to Astronomical Photometry, essential for astronomers seeking to measure the brightness of celestial objects accurately. Howell (2012) contributes the Handbook of CCD Astronomy, an indispensable guide to understanding and maximizing the potential of CCD (Charge-Coupled Device) imaging in astronomy. Davenport and colleagues (2014) revisit The LSST Data Management System, underscoring its central role in managing data for one of the most ambitious astronomical surveys.

Teuben and his collaborators (2007) present CASA, an innovative tool for Combined Array for Millimeter-wave Astronomy Data Reduction and Analysis, enabling the processing and analysis of radio interferometric data. Irwin, Lewis, and the Starlink team (2006) introduce the Starlink Software Environment, offering a suite of software tools tailored to the needs of astronomers. Perryman (2011) explores Astronomical Applications of Astrometry, highlighting the profound impact of astrometric measurements from the Hipparcos satellite.

Hanisch and his team (2001) present The Virtual Observatory, a visionary concept aiming to manage and analyze the vast amounts of astronomical data generated by modern observatories. Tody (1986) introduces The IRAF Data Reduction and Analysis System, a widely used software package for reducing and analyzing astronomical data.

Collectively, these references encompass a diverse range of topics and tools instrumental in advancing astronomical research, underscoring the interdisciplinary nature of modern astronomy and the integral role of advanced data processing and management techniques in exploring the cosmos.

III. ASTRONOMICAL IMAGE PROCESSING

A. ROLE OF LINUX IN ASTRONOMICAL IMAGE PROCESSING

Linux plays a crucial role in astronomical image processing due to its flexibility, open-source nature, and powerful tools. Astronomical data processing is computationally intensive and requires specialized software, making Linux an ideal platform for various reasons:

Open-source ecosystem: Linux offers a vast array of open-source tools and libraries that are freely available to astronomers and researchers. These tools can be customized, modified, and extended to meet the specific needs of different astronomical projects.

High-performance computing (HPC) capabilities: Linux is the dominant operating system in the

HPC community. It can efficiently utilize parallel processing and distributed computing resources, which are essential for handling the large datasets produced by modern telescopes and observatories.

Stability and reliability: Observatories and research institutions rely on stable and robust systems to process astronomical data. Linux has a reputation for being highly stable and reliable, making it suitable for running long-term data processing tasks.

Command-line interface (CLI) and scripting: Linux's CLI allows astronomers to automate repetitive tasks using shell scripts. This feature is particularly valuable for batch processing and data reduction pipelines.

Customizability and scalability: Linux can be tailored to suit the specific hardware and computational requirements of astronomical image processing workflows. From small observatories to large-scale data centers, Linux can scale efficiently.

GPU support: Many modern astronomical image processing algorithms are accelerated using GPUs (Graphics Processing Units). Linux has robust GPU support, enabling astronomers to leverage the power of parallel processing for faster data analysis.

Software support: Linux is well-supported by various astronomical software packages, such as IRAF (Image Reduction and Analysis Facility), DS9 (SAOImage DS9), Astropy, Montage, and more. These tools are designed to handle astronomical data formats and provide specialized functionalities for data calibration, alignment, and visualization.

Distributed version control and collaboration: Linux's compatibility with distributed version control systems like Git facilitates collaborative development of custom tools and data processing pipelines among astronomers and researchers worldwide.

Virtualization and containerization: Technologies like Docker and Kubernetes are popular in the astronomical community. These tools allow astronomers to create reproducible environments, simplifying the deployment of image processing pipelines on various systems.

In summary, Linux's flexibility, open-source ecosystem, stability, and compatibility with specialized astronomical software make it a powerful and widely used platform for processing the vast amounts of data generated by modern telescopes and observatories. Its ability to handle large-scale processing tasks and support for cutting-edge hardware, such as GPUs, further solidify its role in the field of astronomical image processing.

B. Setting up the Linux Environment for Astronomical Image Processing

Setting up a Linux environment for astronomical image processing requires several steps to ensure you have the necessary tools and libraries. Here's a step-by-step guide to help you get started:

- Choose a Linux Distribution:** Select a Linux distribution that suits your preferences and needs. Popular choices for scientific work include Ubuntu, Fedora, and CentOS. For simplicity, I'll use Ubuntu in this guide.
- Install Ubuntu:** Download the latest LTS (Long Term Support) version of Ubuntu from the official website and follow the installation instructions.
- Update and Upgrade:** After installing Ubuntu, open a terminal and run the following commands to update the package lists and upgrade the system:
Bash
sudo apt update
sudo apt upgrade
- Install Essential Packages:** Install basic packages that will be required for various tasks:
Bash
sudo apt install git curl wget build-essential
- Python Environment:** Python is commonly used in astronomical image processing. Check if Python

is already installed by running:

```
Bash
```

```
python3 version
```

If not installed, install it using:

```
Bash
```

```
sudo apt install python3
```

You might also want to install pip for package management:

```
Bash
```

```
sudo apt install python3-pip
```

6. **Scientific Libraries:** Install scientific libraries like NumPy, SciPy, and matplotlib for numerical and graphical computations:
Bash
sudo apt install python3-numpy python3-scipy python3-matplotlib
7. **Astronomy-Specific Software:** Depending on the tools you want to use, you might need specific astronomical software. Some common ones include:
 - **IRAF (Image Reduction and Analysis Facility):** A powerful package for image processing in astronomy. Installation instructions can be found on the NOAO website (<https://iraf.net/>).
 - **AstroPy:** A popular library for astronomy-related calculations in Python. Install it using pip:
bashCopy code
pip3 install astropy
 - **DS9 (SAOImage DS9):** A widely used image visualization tool in astronomy. You can download and install it from the official website (<http://ds9.si.edu/site/Download.html>).
8. **Version Control:** Git is essential for version control and collaboration. Install it using the package manager:
Bash
sudo apt install git
9. **Integrated Development Environment (IDE) - Optional:** Choose an IDE of your choice to make coding easier. Some popular options include Visual Studio Code, PyCharm, and Jupyter Notebook (for interactive data exploration). Install them according to their respective documentation.
10. **Optional Extras:** Depending on your needs, you might want to install other software such as LaTeX for writing papers with astronomical content:
bash
sudo apt install texlive-latex-recommended

Remember to check the specific documentation of any other tools or libraries you plan to use for additional dependencies.

11. **GPU Support (Optional):** If you have a compatible NVIDIA GPU and want to use it for accelerated image processing (especially with machine learning-based methods), you can install the necessary drivers and libraries. The steps will depend on the GPU model and the software you intend to use (e.g., TensorFlow, PyTorch). Refer to the official documentation for GPU support.
12. **Keep Your System Updated:** Astronomy tools are continuously evolving, so keep your Linux system and installed packages up to date to ensure you have the latest features and bug fixes.

Remember to refer to the documentation of the specific tools and libraries you use for more detailed installation instructions and usage guidelines. Additionally, consider joining astronomy forums and communities to get help and share experiences with other astronomers using Linux for their work. Happy processing!

IV. EXPERIMENTAL PARAMETERS AND TECHNIQUES

A. Choosing a Linux distribution for image processing

When choosing a Linux distribution for image processing, including astronomical image processing,

several factors come into play. Here are some considerations to help you decide:

Package Availability: Look for a Linux distribution with a robust package repository that includes the necessary tools and libraries for image processing. Popular distributions like Ubuntu, Fedora, and CentOS usually have extensive repositories and good support for scientific and astronomy-related packages.

Ease of Use: Consider the user-friendliness of the distribution, especially if you are new to Linux. Distributions like Ubuntu and Linux Mint are known for their ease of use and beginner-friendly interfaces.

Community and Support: Choose a distribution with an active and helpful community. Having a strong user base means more tutorials, guides, and support available online, which can be beneficial when encountering issues during image processing tasks.

Stability: Stability is crucial, particularly when dealing with sensitive data or performing long-running calculations. Ubuntu LTS (Long Term Support) releases and CentOS are known for their stability and long support cycles.

Hardware Compatibility: Ensure the distribution you choose supports your hardware well, including graphics cards if you plan to use GPU acceleration for image processing tasks.

Scientific Packages: If you have specific astronomy-related software or packages in mind, check if they are well-supported on the distribution you are considering. Some distributions, like Fedora, cater to scientific users and include astronomy packages in their repositories.

Performance and Speed: Consider lightweight distributions if you are working with older hardware or need a minimal environment for faster processing. Xubuntu, Lubuntu, or Fedora LXQt Spin are some lightweight options.

Customizability: If you prefer a highly customizable distribution that you can tailor to your specific needs, consider Arch Linux or Manjaro. However, these distributions might require more technical knowledge to set up initially.

Documentation and Tutorials: Check for the availability of documentation and tutorials for the distribution you are interested in. Having ample learning resources can significantly ease your learning curve.

Based on these factors, Ubuntu, Fedora, and CentOS are often excellent choices for image processing, including astronomical image processing. Ubuntu's LTS releases provide a balance between stability and up-to-date packages, while Fedora often has more recent software versions and strong scientific community support. CentOS, being a derivative of Red Hat Enterprise Linux (RHEL), offers stability and long-term support, making it a solid option for mission-critical applications.

Ultimately, the best choice will depend on your specific needs, preferences, and the tools you intend to use. Feel free to experiment with different distributions in virtual machines or live USB sessions to find the one that suits you best.

B. Installing necessary software and libraries

To perform astronomical image processing on a Linux system, you'll need to install specific software and libraries. Here's a guide to installing some essential tools for this purpose:

Python and Required Libraries:

Install Python and pip (Python package manager) if not already installed:

```
bash
```

```
sudo apt update
```

```
sudo apt install python3 python3-pip
```

Install NumPy, SciPy, and Matplotlib for numerical and graphical computations:

```
bash
```

```
sudo apt install python3-numpy python3-scipy python3-matplotlib
```

Install AstroPy for astronomy-related calculations:

```
bash
```

```
pip3 install astropy
```

IRAF (Image Reduction and Analysis Facility):

IRAF is a powerful software package for astronomical image processing. Installation instructions can be found on the NOAO website (<https://iraf.net/>).

DS9 (SAOImage DS9):

DS9 is a popular image visualization tool in astronomy. You can download and install it from the official website (<http://ds9.si.edu/site/Download.html>).

ImageMagick:

ImageMagick is a versatile command-line tool for image processing tasks. Install it using:

```
bash
```

```
sudo apt install imagemagick
```

GNU Image Manipulation Program (GIMP):

GIMP is a powerful image editing and processing tool. Install it using:

```
bash
```

```
sudo apt install gimp
```

TOPCAT (Tool for OPERations on Catalogues And Tables):

TOPCAT is useful for working with astronomical catalogs and tables. You can download and install it from the official website (<http://www.star.bris.ac.uk/~mbt/topcat/>).

Scikit-image (Optional - for advanced image processing):

Scikit-image is a collection of algorithms for image processing in Python. Install it using:

```
bash
```

```
pip3 install scikit-image
```

GNU Parallel (Optional - for parallel processing):

GNU Parallel is a tool for executing commands in parallel. It can speed up processing if you have multiple cores or machines available. Install it using:

```
bash
```

```
sudo apt install parallel
```

LaTeX (Optional - for writing papers):

If you plan to write scientific papers with astronomical content, you might want to install LaTeX:

```
bash
```

```
sudo apt install texlive-latex-recommended
```

Remember that some specialized astronomy tools might have additional dependencies. Always refer to the official documentation for each software package for any specific requirements. Additionally, if you have a compatible NVIDIA GPU and want to utilize it for accelerated image processing, you may need to install the necessary GPU drivers and libraries depending on the software you intend to use (e.g., TensorFlow, PyTorch). Refer to the official documentation for GPU support and setup. As you proceed with astronomical image processing, you might discover other useful tools and libraries that fit your specific needs. Stay open to exploring new software that can enhance your workflow.

C. Configuring the system for optimal performance

Configuring your Linux system for optimal performance in astronomical image processing involves a combination of hardware and software optimizations. Here are some steps you can take to achieve better performance:

Keep the System Updated:

Ensure your Linux distribution, as well as all installed packages and libraries, are up-to-date. Frequent updates can bring performance improvements and bug fixes.

```
bash
```

```
sudo apt update
```

```
sudo apt upgrade
```

Use a 64-bit System:

If your hardware supports it, use a 64-bit version of your chosen Linux distribution. This allows the system to utilize more RAM and can improve overall performance.

Install Proprietary GPU Drivers (if applicable):

If you have an NVIDIA GPU and plan to use GPU acceleration for image processing, consider installing the proprietary NVIDIA drivers. These drivers often provide better performance compared to the open-source ones.

Enable CPU Performance Scaling:

Modern CPUs can scale their performance to save power. For optimal performance, make sure the CPU scaling governor is set to "performance." This ensures the CPU runs at maximum frequency when needed.

```
bash
sudo apt install cpufrequtils
sudo cpufreq-set -g performance
```

Monitor System Performance:

Use tools like htop or top to monitor CPU and memory usage in real-time. Identify any processes consuming too many resources and optimize or adjust them as needed.

```
bash
sudo apt install htop
htop
```

Adjust Disk I/O Scheduler (for HDDs):

If you are using traditional hard disk drives (HDDs) instead of solid-state drives (SSDs), consider changing the I/O scheduler to "deadline" or "noop" for better performance.

```
bash
echo deadline | sudo tee /sys/block/sda/queue/scheduler
Replace /dev/sda with the appropriate device name for your HDD if different.
```

Optimize Swap Settings:

Make sure the system's swap settings are appropriate. Too much swapping can slow down the system. If you have enough RAM, consider disabling swap or reducing its size.

Disable Unnecessary Services:

Disable any unnecessary background services or daemons that might consume resources unnecessarily. Review the services running on your system and disable the ones you don't need.

Use RAM Disks (tmpfs) for Temporary Data:

If you frequently work with temporary data, consider using RAM disks (tmpfs) instead of writing to the disk. This can significantly speed up data access.

```
bash
sudo mount -t tmpfs -o size=2G tmpfs /mnt/ramdisk
Replace /mnt/ramdisk with the desired mount point and adjust the size (2G in this example) according to your available RAM.
```

Consider SSD for High-Speed Storage:

If possible, use a solid-state drive (SSD) for storage. SSDs offer much faster read and write speeds compared to traditional hard drives, resulting in improved performance.

Use Parallel Processing (if applicable):

If your image processing tasks are parallelizable, consider using tools like GNU Parallel to distribute the workload across multiple CPU cores or machines.

Optimize Code and Algorithms:

Pay attention to your image processing algorithms and code. Well-optimized code can significantly improve performance. Consider using libraries like Numba to accelerate Python code.

Manage Thermal Throttling (for laptops):

If you are using a laptop for image processing, ensure it is adequately cooled to avoid thermal throttling, which

can slow down performance. Keep the laptop on a hard, flat surface to facilitate better airflow.

Remember that the effectiveness of these optimizations will depend on your specific hardware and the image processing tasks you are performing. It's a good practice to monitor system performance after making changes to ensure they have the desired effect. Additionally, always back up your important data before making significant system configuration changes.

D. Image formats and data reduction

In astronomical image processing, data reduction involves transforming raw image data into a usable and scientifically valuable format. This process includes several steps to correct for various artifacts and calibrate the data for scientific analysis. Before discussing data reduction, let's first explore common image formats used in astronomy:

FITS (Flexible Image Transport System):

FITS is the most widely used image format in astronomy. It is designed specifically for storing scientific data and metadata. FITS files consist of header information (metadata) and a data array. The header contains essential information about the observation, telescope, instrument, and data processing steps. The data array holds the image pixel values.

RAW Formats:

Some astronomical instruments produce raw data formats specific to their sensors. These formats often contain minimal processing and calibration. Raw data may need preprocessing before being converted to FITS or other usable formats.

Now, let's go through the steps involved in data reduction for astronomical images:

Bias Subtraction:

Bias frames are images taken with the same exposure time but with the shutter closed. These frames capture the electronic noise in the detector. To remove this noise, bias frames are subtracted from the science frames.

Dark Subtraction:

Dark frames are images taken with the same exposure time as the science frames but with the shutter closed. Dark frames capture the thermal noise in the detector. By subtracting dark frames, thermal noise is removed from the science frames.

Flat Fielding:

Flat frames are images of a uniformly illuminated field. They are used to correct for non-uniformities in the detector response, such as dust spots, vignetting, and pixel-to-pixel variations. Dividing the science frames by flat frames corrects these imperfections.

Sky Subtraction (for ground-based observations):

In ground-based observations, the night sky contributes to the overall signal in the images. Sky subtraction involves removing the contribution of the sky background to reveal the objects of interest.

Alignment and Stacking:

In many cases, multiple images of the same field are taken and then aligned and combined (stacked) to improve the signal-to-noise ratio and reveal faint details. Software like IRAF or AstroPy's `reproject` and `reproject_interp` functions can be used for image alignment and stacking.

Cosmic Ray Removal:

Cosmic rays are high-energy particles that can cause spurious detections in astronomical images. Software like AstroPy's `lacosmic` or IRAF's `cosmicrays` can be used to identify and remove cosmic ray hits.

Wavelength Calibration (for spectroscopic data):

For spectroscopic data, wavelength calibration is performed using calibration lamp spectra to convert pixel positions into wavelength values.

Astrometric Calibration:

Astrometric calibration involves identifying reference stars in the field of view and matching them to a catalog of known positions. This process establishes a transformation between pixel coordinates and celestial

coordinates.

Photometric Calibration:

Photometric calibration involves determining the relation between pixel values and physical flux units (e.g., photons or magnitudes) using standard stars with known magnitudes.

These are some of the primary steps involved in data reduction for astronomical images. The specific techniques and software used may vary depending on the instrument, telescope, and data characteristics. Advanced data reduction can also involve more sophisticated algorithms and techniques, including machine learning approaches for denoising or feature extraction.

V. DIFFERENT IMAGE FORMATS

A. Understanding different image formats used in astronomy

In astronomy, various image formats are used to store and represent astronomical data obtained from telescopes and other imaging instruments. Each format has its advantages and is suitable for different types of data and applications. Here are some common image formats used in astronomy:

FITS (Flexible Image Transport System):

FITS is the most widely used image format in astronomy. It was specifically designed for scientific data and includes headers containing metadata. FITS files can store single or multi-dimensional data, such as 2D images or data cubes from spectrographs. The header provides crucial information about the observation, instrument, and data reduction steps. FITS supports various data types and is highly flexible, making it suitable for archival and data exchange purposes.

RAW Formats:

Many astronomical instruments produce raw data formats specific to their sensors. These raw formats usually contain minimal processing and calibration, preserving the raw data as captured by the detector. Raw data often require preprocessing before being converted to more usable formats like FITS. Each instrument may have its unique RAW format.

JPEG and PNG:

JPEG and PNG are common image formats used in general photography and image sharing. While they are not specific to astronomy, they are occasionally used for storing astronomical images for quick visual inspection or sharing with a broader audience. However, these formats may not be suitable for scientific analysis due to compression and loss of information.

TIFF (Tagged Image File Format):

TIFF is a flexible and widely used format for storing images in various domains, including astronomy. It supports lossless compression and can handle high-quality, large images. TIFF files can store multi-channel (RGB) images, making them useful for color astronomical images.

SBF (Starbase Format):

SBF is a format developed by the Starlink Project, commonly used in the United Kingdom and European astronomy communities. It supports 1D, 2D, and 3D data and can store multiple image extensions within a single file. SBF has been widely used in radio astronomy.

MEF (Multi-Extension FITS):

MEF is an extension of the FITS format that allows multiple extensions within a single file. Each extension can contain a separate image or data array, making MEF useful for storing multiple data sets or observations in a single file.

CIFITS (Compressed Image FITS):

CIFITS is a variant of FITS that uses lossless compression algorithms like Rice, GZIP, or PLIO to reduce file sizes while maintaining the scientific integrity of the data. CIFITS is beneficial for handling large datasets more efficiently.

It's important to note that while some formats like FITS and MEF are standard within the astronomy community, others may be specific to certain instruments, observatories, or research groups. When working with astronomical data, it's crucial to understand the format used and the associated metadata to ensure proper

data analysis and interpretation.

B. Converting and manipulating image formats

Converting and manipulating image formats in astronomy can be essential for data analysis, visualization, and sharing. Here are some common tools and libraries you can use to perform these tasks:

FITS Conversion and Manipulation:

The astropy library in Python is a powerful tool for working with FITS files and manipulating astronomical data. It allows you to read, write, and modify FITS files easily.

To install astropy, use the following command:

```
bash
pip install astropy
```

Here's an example of reading a FITS file and accessing its data:

```
python
from astropy.io import fits

# Read a FITS file
hdul = fits.open('input.fits')

# Access the image data
data = hdul[0].data

# Close the FITS file
hdul.close()
```

You can also use astropy to manipulate the FITS header and perform data reduction tasks, such as bias subtraction, dark subtraction, and flat fielding.

ImageMagick:

ImageMagick is a versatile command-line tool that can handle various image formats, including FITS, JPEG, PNG, and more. It can be used to convert, manipulate, and process images.

To install ImageMagick on Ubuntu, use the following command:

```
bash
sudo apt install imagemagick
```

To convert a FITS file to another format (e.g., PNG), use:

```
bash
convert input.fits output.png
```

GIMP (GNU Image Manipulation Program):

GIMP is a popular open-source image editing tool that supports a wide range of image formats. It is suitable for more advanced image manipulation tasks.

To install GIMP on Ubuntu, use the following command:

```
bash
sudo apt install gimp
```

DS9 (SAOImage DS9):

DS9 is a powerful image visualization tool used in astronomy. It can handle various image formats and provides tools for image analysis and manipulation.

Python Imaging Library (PIL) / Pillow:

PIL is a Python library for image processing. Pillow is a maintained fork of PIL and provides additional functionality and support for various image formats.

To install Pillow, use the following command:

```
bash
```

```
pip install pillow
```

Pillow allows you to load, manipulate, and save images in different formats. For example:

```
python
from PIL import Image

# Open an image
img = Image.open('input.png')

# Perform image manipulations
# ...

# Save the image in a different format
img.save('output.jpg')
```

These tools provide different levels of functionality and flexibility for converting and manipulating image formats. Depending on your specific requirements, you can choose the most suitable tool or library for your tasks. Remember to refer to the respective documentation for detailed usage and capabilities of each tool.

C. Performing data reduction techniques for image enhancement

Data reduction techniques in astronomical image processing involve a series of steps to improve the quality of the images, correct for various artifacts, and prepare the data for scientific analysis. Here are some common data reduction techniques for image enhancement:

Bias Subtraction:

Bias frames are images taken with the shutter closed, capturing the electronic noise in the detector. Subtracting the bias frame from the science frames removes this noise.

Dark Subtraction:

Dark frames are images taken with the shutter closed but with the same exposure time as the science frames. They capture the thermal noise in the detector. By subtracting dark frames, the thermal noise is removed from the science frames.

Flat Fielding:

Flat frames are images of a uniformly illuminated field. They are used to correct for non-uniformities in the detector response, such as dust spots, vignetting, and pixel-to-pixel variations. Dividing the science frames by flat frames corrects these imperfections.

Cosmic Ray Removal:

Cosmic rays are high-energy particles that can cause spurious detections in astronomical images. Various algorithms, such as L.A.Cosmic, can be used to identify and remove cosmic ray hits.

Sky Subtraction (for ground-based observations):

In ground-based observations, the night sky contributes to the overall signal in the images. Sky subtraction involves removing the contribution of the sky background to reveal the objects of interest.

Image Alignment and Stacking:

Multiple images of the same field can be taken and then aligned and combined (stacked) to improve the signal-to-noise ratio and reveal faint details. Software like IRAF, AstroPy's `reproject`, or `reproject_interp` functions can be used for image alignment and stacking.

Wavelength Calibration (for spectroscopic data):

For spectroscopic data, wavelength calibration is performed using calibration lamp spectra to convert pixel positions into wavelength values.

Astrometric Calibration:

Astrometric calibration involves identifying reference stars in the field of view and matching them to a catalog of known positions. This process establishes a transformation between pixel coordinates and celestial coordinates.

Photometric Calibration:

Photometric calibration involves determining the relation between pixel values and physical flux units (e.g., photons or magnitudes) using standard stars with known magnitudes.

Deconvolution (for improving resolution):

Deconvolution techniques, such as Richardson-Lucy or Maximum Likelihood Deconvolution, can be used to improve the spatial resolution of the images by removing the effects of the instrument's point spread function (PSF).

These data reduction techniques are typically applied sequentially, and the order may vary depending on the specific requirements of the data and the scientific objectives. Proper data reduction is crucial for ensuring accurate and scientifically meaningful results in astronomical image processing.

D. Basic Image Processing Techniques

Basic image processing techniques are fundamental operations used to manipulate and enhance digital images. These techniques are widely employed in various fields, including astronomy, medical imaging, computer vision, and more. Here are some common basic image processing techniques:

Image Resizing:

Image resizing involves changing the dimensions (width and height) of an image. It can be used to scale an image up or down. Resizing is commonly used to fit images to specific display or storage requirements.

Image Rotation:

Image rotation involves rotating the image by a certain angle. It can be used to correct image orientation or align images for further processing.

Image Cropping:

Image cropping involves removing unwanted parts of an image to focus on a specific region of interest. Cropping can help remove distractions and improve the composition of the image.

Image Filtering:

Image filtering is used to enhance or modify the appearance of an image. Common filters include Gaussian blur, median filter, and edge detection filters.

Contrast Enhancement:

Contrast enhancement techniques are used to stretch the range of pixel values to improve the contrast between different regions in the image. This can make details more visible.

Histogram Equalization:

Histogram equalization is a specific contrast enhancement technique that redistributes pixel intensities to make the image's histogram more uniform, enhancing the overall contrast.

Image Thresholding:

Thresholding is used to convert a grayscale image into a binary image by setting a threshold value. Pixels with intensities above the threshold become white, while those below become black.

Color Space Conversion:

Color space conversion is used to change the representation of an image from one color space to another. Common conversions include RGB to grayscale, RGB to HSV, and RGB to LAB.

Geometric Transformations:

Geometric transformations involve translating, scaling, rotating, or shearing an image. These transformations are useful for image registration, alignment, and geometric corrections.

Morphological Operations:

Morphological operations, such as dilation and erosion, are used for image processing tasks involving shape analysis, noise removal, and feature extraction.

Noise Reduction:

Noise reduction techniques, such as Gaussian smoothing and median filtering, are applied to reduce noise in

images.

Edge Detection:

Edge detection techniques identify sharp intensity transitions in images and are used for image segmentation and feature detection.

These basic image processing techniques provide a foundation for more advanced image analysis and manipulation tasks. Depending on the specific application, additional algorithms and techniques may be used to achieve the desired results. Python, with libraries like OpenCV and Pillow, is a popular choice for implementing these image processing techniques due to its ease of use and extensive functionality.

VI. IMAGE CALIBRATION

A. Image calibration: bias, dark, and flat-field correction

Image calibration is a critical step in astronomical image processing to correct for various artifacts and imperfections introduced during the data acquisition process. The three primary calibration steps are bias correction, dark frame subtraction, and flat-field correction.

Bias Correction:

Bias frames are images taken with the shutter closed, capturing only the electronic noise in the detector. Bias frames represent the zero-level offset in the sensor's output and are essential for accurate data reduction. They are typically taken with very short exposure times to capture the readout noise.

The bias frame is subtracted from each science frame to remove the bias level, ensuring that the pixel values represent the true incident light rather than noise. This process is essential for obtaining reliable photometric measurements and reducing systematic errors.

Dark Frame Subtraction:

Dark frames are images taken with the shutter closed but with the same exposure time as the science frames. They capture the thermal noise generated by the detector during the exposure. The thermal noise in dark frames can be significant, especially for long-exposure images.

The dark frame is subtracted from each science frame to remove the thermal noise component, which helps produce cleaner images with reduced hot pixels and dark current effects. Dark frame subtraction is crucial for accurate astrophotometry and precise photometric measurements.

Flat-Field Correction:

Flat frames (also known as twilight or sky flats) are images of a uniformly illuminated field. They are used to correct for non-uniformities in the detector response, such as dust spots, vignetting, and pixel-to-pixel variations in sensitivity.

To perform flat-field correction, each science frame is divided by the corresponding flat frame. This normalization process corrects the non-uniform pixel sensitivities, producing images with more consistent brightness across the field of view. Flat-field correction is essential for accurate photometry, image calibration, and data analysis.

The order in which these calibration steps are performed may vary depending on the specific data and the instrument used. In some cases, it may be necessary to perform additional steps, such as bad pixel interpolation and cosmic ray removal, to further improve the quality of the calibrated images.

Astronomical image processing software packages, such as IRAF, AstroPy, and CCDPROC in Python, provide tools and functions to automate the calibration process and facilitate high-quality image data reduction. Proper image calibration is crucial for obtaining reliable scientific results and maximizing the information extracted from astronomical images.

B. Image alignment and stacking for noise reduction

Image alignment and stacking is a powerful technique used in astronomical image processing for noise reduction and enhancing the signal-to-noise ratio of astronomical objects. It involves combining multiple images of the same scene, which have been aligned to a common reference frame. This process reduces random noise and enhances the faint details, making it easier to detect and study celestial objects. Here's a step-by-step overview of image alignment and stacking:

Acquiring Multiple Frames:

Capture multiple images of the same celestial scene using the same instrument and exposure settings. Ensure that the scene remains relatively static during the acquisition process.

Bias and Dark Subtraction:

Apply bias and dark subtraction to each frame to remove electronic and thermal noise. This step ensures that the frames are in a suitable condition for alignment and stacking.

Image Alignment:

Align all the frames to a common reference frame. Image alignment corrects for any small shifts or rotations that might have occurred during the acquisition process. Several methods can be used for image alignment, including cross-correlation, feature matching, and image registration algorithms.

Image Stacking:

After alignment, stack the aligned frames to create a single, composite image. There are various ways to stack the images, such as averaging, median stacking, or sigma-clipping. Each method has its advantages and is suitable for different situations:

Averaging: Compute the average of the pixel values at each position in the aligned frames. Averaging effectively reduces random noise but might not handle outliers well.

Median Stacking: Compute the median of the pixel values at each position in the aligned frames. Median stacking is robust against outliers and cosmic rays.

Sigma-Clipping Stacking: Apply sigma-clipping to exclude outlier pixel values during the stacking process. This method is useful for reducing the impact of cosmic rays and other transient artifacts.

Cosmic Ray Removal (Optional):

Before or after stacking, you can apply cosmic ray removal techniques to further clean the stacked image from cosmic ray hits and other transient artifacts. Several algorithms are available for identifying and removing cosmic rays.

Post-processing (Optional):

After stacking, you can apply additional post-processing steps, such as contrast enhancement, sharpening, or color balance adjustments, to further improve the quality of the final stacked image.

Image alignment and stacking are particularly useful when dealing with faint or low-contrast astronomical objects, as it allows astronomers to reveal details that would otherwise be obscured by noise. The resulting stacked image represents a deeper and cleaner view of the target, enhancing the scientific analysis and visualization of astronomical data. Various software packages, such as AstroPy and IRAF, provide tools for performing image alignment and stacking in astronomical image processing.

C. Applying filters for noise suppression and enhancement

Applying filters is a common technique in image processing to suppress noise and enhance specific features of an image. Filters can help to reveal important structures, remove unwanted artifacts, and improve the overall quality of the image. Here are some filters commonly used for noise suppression and image enhancement:

Gaussian Blur (Low-Pass Filter):

The Gaussian blur filter is a type of low-pass filter that reduces high-frequency noise and fine details in an image. It smooths the image by averaging pixel values with neighboring pixels based on a Gaussian distribution. This filter is useful for noise reduction while preserving overall image structures.

Median Filter (Non-linear Filter):

The median filter is a non-linear filter that replaces each pixel's value with the median value of neighboring pixels within a defined window. It effectively removes impulse noise (salt-and-pepper noise) while preserving edges and fine details better than linear filters.

Bilateral Filter:

The bilateral filter is a non-linear edge-preserving filter that smooths an image while retaining sharp edges. It considers both the spatial distance and pixel intensity difference when computing the filter response. The bilateral filter is useful for denoising while preserving important image structures.

Wiener Filter (Adaptive Filter):

The Wiener filter is an adaptive filter that can be used to remove noise from an image based on statistical properties. It works well when the noise characteristics are known or can be estimated. The Wiener filter adapts to the local image content, making it effective for different types of noise.

Unsharp Masking (High-Boost Filter):

Unsharp masking is a sharpening technique used to enhance edges and fine details in an image. It involves subtracting a blurred version of the image from the original to highlight edges. This process can enhance details and make the image appear sharper.

Edge Detection Filters (e.g., Sobel, Canny):

Edge detection filters highlight areas of significant intensity changes in an image, such as edges and contours. These filters are useful for feature extraction and object detection.

Homomorphic Filtering (Frequency Domain Filter):

Homomorphic filtering is a frequency domain filter used to enhance the dynamic range of an image. It is particularly useful for correcting uneven illumination in images and handling low-light conditions.

Contrast Enhancement Filters (e.g., Histogram Equalization, Adaptive Histogram Equalization):

Contrast enhancement filters modify the intensity distribution of an image to improve its visual appearance. Histogram equalization and adaptive histogram equalization are examples of such filters.

When applying filters, it's essential to consider the specific characteristics of the image and the type of noise present. Some filters may be more suitable for certain types of noise or specific image features. Experimentation and evaluation of the results are often necessary to find the best filter for a particular image processing task. Python, with libraries like OpenCV, scikit-image, and Pillow, offers a wide range of filters and tools for applying various image processing techniques.

```
NOAO Sun/IRAF Revision 2.11 Tue Dec 23 23:22:19 MST 1997
This is the EXPORT version of Sun/IRAF V2.11 for SunOS 4 and Solaris 2.6

Welcome to IRAF. To list the available commands, type ? or ??. To get
detailed information about a command, type `help command`. To run a
command or load a package, type its name. Type `bye` to exit a
package, or `logout` to get out of the CL. Type `news` to find out
what is new in the version of the system you are using. The following
commands or packages are currently defined:

  adccdrom.  dbms.      focas.      imcnv.      obsolete.  stsdas.
  apropos    describe  ftools.    immatchx.   plot.      system.
  arnica.    digiphotx. galphot.    language.   proto.     tables.
  ccdacq.    dimsum.    grasp.      lists.      rgo.       utilities.
  color.     examples  guidemo.    mem0.       rvsao.     xray.
  ctio.      figaro.    iactasks.  nmisc.      softools.
  dataio.    fitsutil.  images.    noao.       spptools.

cl> █
```

Figure 1. Startup screen

D. Image Reduction and analysis facility

```

                                I R A F
                                Image Reduction and Analysis Facility
PACKAGE = imutil
TASK = imarith

operand1=      Df555w_c2.imh  Operand image or numerical constant
op            =                +  Operator
operand2=      Df814w_c2.imh  Operand image or numerical constant
result        =      Df58sum_c2.imh  Resultant image
(title       =                )  Title for resultant image
(divzero     =                0.)  Replacement value for division by zero
(hparams    =                )  List of header parameters
(pixtype     =      real)  Pixel type for resultant image
(calctyp    =      real)  Calculation data type
(verbose     =      yes)  Print operations?
(noact      =                no)  Print operations without performing them?
(mode       =                q)
```

Figure.2. Image Reduction

E. Overscan Correction

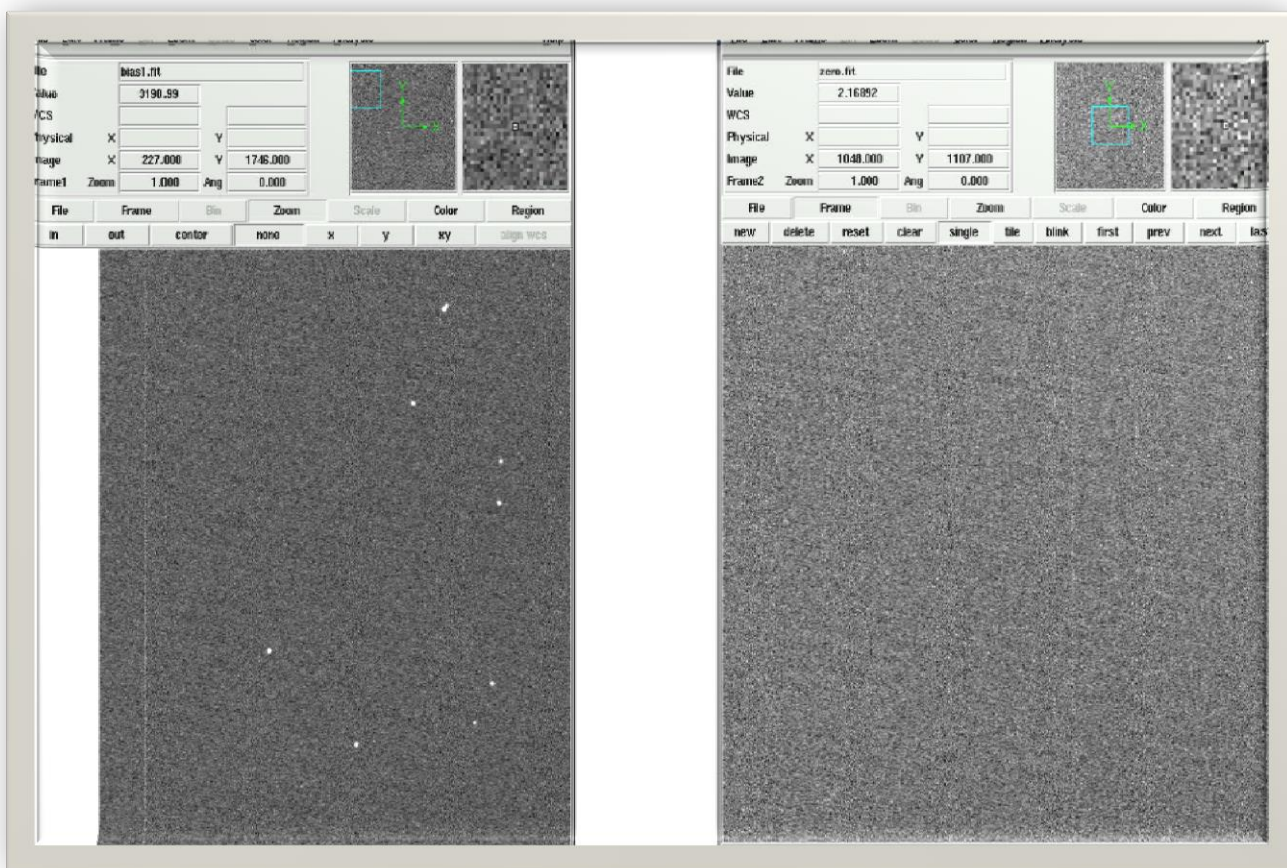


Figure 3. OverscanCorrection

VII. CONCLUSION

Astronomical image processing plays a crucial role in modern astronomy, enabling scientists to extract valuable information from the vast amount of data collected by telescopes and imaging instruments. This introductory overview highlighted the importance of image processing in astronomy, provided an overview of astronomical image data, and explored the role of Linux in this field.

Linux is a preferred choice for astronomical image processing due to its flexibility, open-source nature, and wide availability of specialized software tools and libraries. Setting up a Linux environment for astronomical image processing involves selecting a suitable Linux distribution, installing necessary software and libraries, and optimizing the system for optimal performance.

Image formats used in astronomy, such as FITS, RAW, and TIFF, were discussed, and techniques for converting and manipulating image formats were explored. Data reduction techniques, including bias, dark, and flat-field correction, were emphasized as essential steps to enhance image quality, remove noise, and prepare data for scientific analysis.

Furthermore, image alignment and stacking were introduced as powerful techniques for noise reduction, combining multiple images of the same scene to improve the signal-to-noise ratio and reveal faint details. Applying filters, such as Gaussian blur, median filter, and edge detection filters, was discussed for noise suppression and image enhancement, enabling astronomers to extract relevant features and improve image quality.

In conclusion, the field of astronomical image processing continues to evolve, and the combination of Linux-based tools, diverse image formats, and sophisticated data reduction techniques empowers astronomers to unlock the mysteries of the universe through the analysis and interpretation of astronomical images. As technology advances and new discoveries are made, image processing remains a vital aspect of modern astronomical research.

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