PHOTOMETRIC REDUCTION OF JCB TELESCOPE DATA OF THE YEAR 2017 USING JCBT PIPELINE

Dissertation submitted to Mahatma Gandhi University in

partial fulfillment of the requirement for the award of degree of

Master of Science in Space

By

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MAY 2024

CERTIFICATE

This is to certify that, MUHAMMED SINAN T S pursuing master of science in space science 2022 – 2024 at BHARATA MATA COLLEGE, hereby declare that this report of work on **"PHOTOMETRIC REDUCTION OF JCB TELESCOPE DATA OF 2017 USING JCBT PIPELINE"** has been done during March 2024 – May 2024, in VAINU BAPPU OBSERVATORY Kavalur (IIA Bangalore) under the valuable guidance of assistant professor Dr VIVEK M in the partial fulfilment of the requirements for the award of the masters degree in space science and that no part of this work has been submitted earlier for the award of any degree.

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This is to certify that this project work titled **"Photometric Data Reduction JCB Telescope Data (2017) Using Pipeline"** is a record of bonafide work done by **Mr. Muhammed Sinan T S** (Reg.No: 220011023282) in partial fulfilment of the requirements for the award of M.Sc. Degree form Mahatma Gandhi University and no part of this has been submitted earlier for the award of any degree.

External Examiner

DECLARATION

I hereby declare that the project report titled **“Photometric Data Reduction JCB Telescope Data (2017) Using Pipeline”** is an original record of work carried out by me under the supervision of **Dr. Vivek M** at Vainu Bappu Observatory (Indian Institute of Astrophysics Bangalore), Kavalur during the year 2024 and it has not been submitted to any other University or Institution for the award of any other degree.

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ABSTRACT

Photometry is a method used to measure the intensity of light emitted by celestial bodies, allowing us to study various properties and behaviours of these objects and other astronomical phenomena. From the raw data obtained through the optical telescope to the final analysis, the data must undergo several procedures. This project focuses on the initial step of this process: photometric data reduction. The data source is the J C Bhattacharya Telescope situated at the Vainu Bappu Observatory, Kavalur, a research institute under the Indian Institute of Astrophysics.

Photometric data reduction for the JCBT can be done in two ways: the classical method using IRAF software and the JCBT pipeline. In this project, the second method is used. The JCBT pipeline is a Python code that automates all the steps in the reduction process.

Apart from data reduction, this project also includes the analysis of the reduced data in terms of Full Width at Half Maximum (FWHM) and Universal Time (UT). This analysis helps in assessing the atmospheric conditions of the sky at the time of data collection. By reducing data observed over a year, we can determine how the sky conditions vary monthly and estimate the best times for observations with the JCB Telescope. The reduced photometric data is not included in this project due to confidentiality.

CONTENTS

CHAPTER-1

INTRODUCTION

1.1 PHOTOMETRY

Photometry is simply the measurement of light. Literally speaking, it is a fundamental technique in astronomy that allows us to measure the brightness of celestial objects, providing valuable insights into their properties, behaviour, and evolution. From distant galaxies to nearby stars, Photometry plays a crucial role in unravelling the mysteries of the cosmos.

Here are some common types of photometric observation:

Visual Photometry: This is the oldest and simplest form of photometry, involving the direct observation of the brightness of celestial objects using the human eye. Observers compare the brightness of stars to standard reference stars with known magnitudes.

Photographic Photometry: This involves using photographic plates or films to capture images of the night sky. The density of the developed emulsion on the plate or film correlates with the intensity of light recorded, allowing astronomers to measure the brightness of stars and other objects.

Photoelectric photometry: uses photodetector to capture the light.
Here, we use this method. It is highly sensitive, fast response, provides quantitative results and the ability to measure different bands. CCD photometry involves using these digital detectors to capture images of celestial objects. Software is then used to analyse the digital images and measure the brightness of stars and other targets.

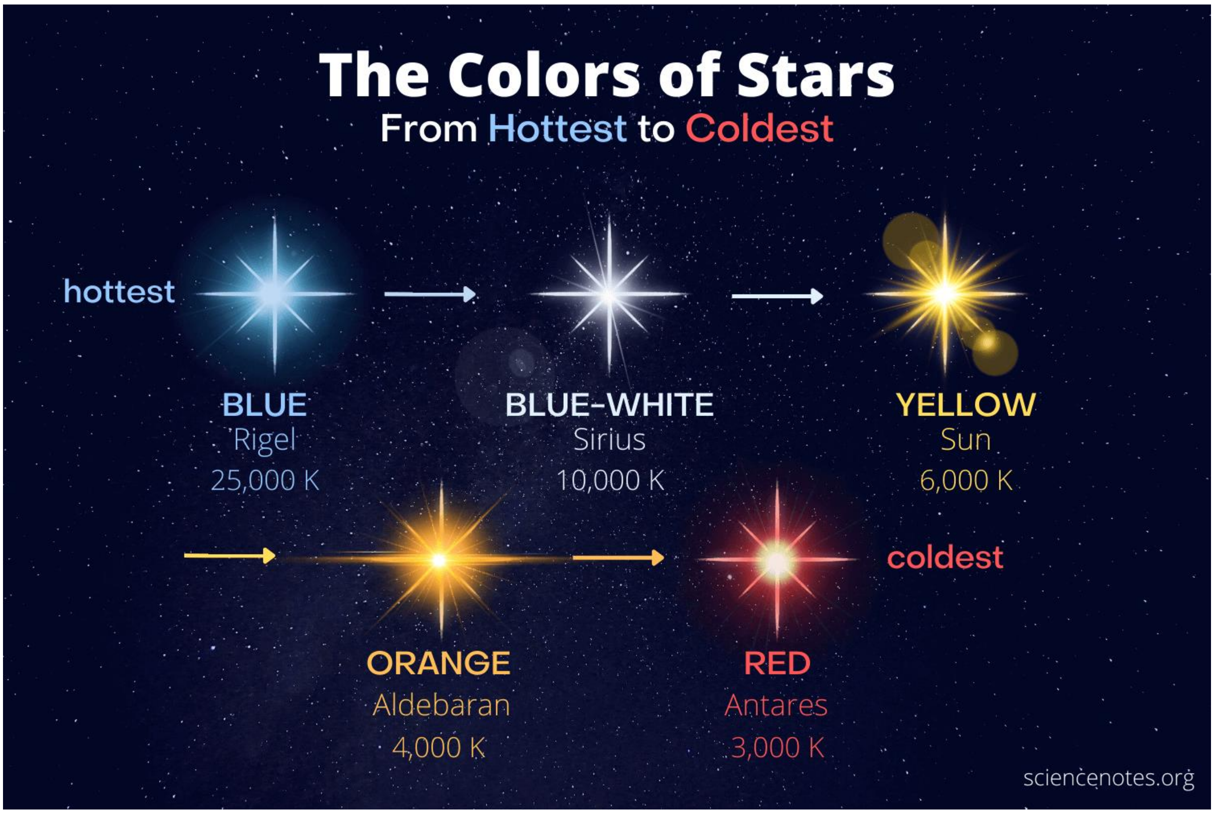
Stellar photometry relies on the idea of magnitude, which is the measure of the brightness of a star or other celestial body. The brighter the object, the lower the number assigned as a magnitude. The fundamental relation between a star's apparent magnitude (m), absolute magnitude(M) and distance (d) is given by

$$\mathbf{m - M = 5 \log d - 5}$$

where 'd' is measured in parsec.
The Sun has an apparent magnitude of approximately -26.74, making it exceptionally bright compared to most stars visible from Earth. This brightness is primarily because the Sun is relatively close to Earth compared to other stars in the universe.
For instance, Sirius, the brightest star in the night sky, has an apparent magnitude of around 1.46. However, there are many stars visible to the naked eye with magnitudes ranging from around 1 to 6, and fainter stars have higher positive magnitudes. It's crucial to consider that a star's apparent magnitude is influenced not only by its intrinsic brightness but also by its distance from Earth. Thus, stars that are intrinsically brighter than the Sun might appear fainter if they are located much farther away.

1.1.1. WHAT CAN WE DERIVE FROM PHOTOMETRIC OBSERVATION?

By measuring the brightness of stars in different wavelengths of light, astronomers can determine their temperature, size, and distance. For example, the colour of a star, derived from its photometric measurements, provides crucial information about its surface temperature. Cooler stars appear redder, while hotter stars appear bluer. By analysing the brightness variations of stars over time, photometry also helps in identifying and studying variable stars, which undergo periodic changes in brightness due to intrinsic or extrinsic factors.



In addition to stars and galaxies, photometry plays a crucial role in the search for exoplanets. One of the primary methods used to detect exoplanets is the transit method, where the slight dimming of a star's brightness as a planet passes in front of it is observed. Precise photometric measurements are essential for detecting these subtle changes in brightness and determining the characteristics of exoplanetary systems, such as the size, orbital period, and atmospheric composition of the planets. Not only planets, it can also take observation of comets. It all depends upon the magnitude that the telescope can measure.

In JCBT the maximum magnitude it can measure is 19. Remember, the higher the magnitude the fainter the object.

1.2. SPECTROSCOPY

Spectroscopy involves breaking down the light from an object into its constituent wavelengths, creating a spectrum. Spectroscopy allows astronomers to study the chemical composition, temperature, density, and motion of celestial objects. By analysing the spectral lines produced by different elements, astronomers can determine the chemical makeup of stars, galaxies, and other astronomical phenomena. Spectroscopy also provides information about the velocity of objects, such as stars moving towards or away from us.

Types of Spectra:

Continuous Spectrum: Produced by a hot, dense object like a blackbody radiator, it contains a continuous range of wavelengths without any distinct lines.
Emission Spectrum: Produced when atoms or molecules emit light at specific wavelengths after being excited. It consists of bright emission lines at characteristic wavelengths.
Absorption Spectrum: Produced when a continuous spectrum passes through a cool, dilute gas, absorbing specific wavelengths of light. It results in dark absorption lines superimposed on the continuous spectrum.

1.3. DIFFERENCE BETWEEN PHOTOMETRY AND SPECTROSCOPY

Aspect	Photometry	Spectroscopy
Purpose	Measures the brightness or intensity of light	Analyses the distribution of light into its constituent wavelengths
Information Provided	Overall brightness across a specific wavelength range	Chemical composition, temperature, density, motion, and magnetic properties
Instrumentation	Uses instruments like photometers or CCD cameras	Requires specialized instruments called spectrographs.
Temporal Resolution	Provides good temporal resolution for monitoring brightness changes	Can provide both temporal and spatial resolution.
Applications	Study of brightness variations, transits, and eclipses	Study of chemical composition, stellar evolution, and galactic dynamics

1.5. JC BHATTACHARYA TELESCOPE

J.C Bhattacharya Telescope or JCBT Telescope was installed in April 2014.It is named after Dr Jagadish Chandra Bhattacharya, the former Director of IIA. It possesses three instrument ports and a Ritchey-Chretien f/8 optical arrangement, with a primary mirror of 1.3m diameter (aperture). The field of view of the telescope is 30 minutes of arc second and the plate scale is 20arc sec/mm. The main port consists of a 2K X 4K CCD system for direct imaging purpose.

Figure: The 1.3m JCB telescope (credit: https://www.iiap.res.in/vbo.htm)

JCB Telescope is used for photometric observation. It is a Cassegrain telescope with equatorial mounting. That is, it is tilted at the same angle as the Earth's axis of rotation (12^{o} 34.6': latitude of Kavalur). We use this type of mounting because this place is close to Earth's equator.

JCBT PARAMETERS:

Focal ratio = 8
Diameter = 1300mm

ANGULAR RESOLVING POWER:

R = 1.22 x λ/ D radian
R = 1.22 x 206265 λ / 1300 arcsecond
= 193.57 λ
Plate scale = 206265 / focal length
= 206265 / 1300 x 8
=19.833 arc sec/mm

2K X 4K CCD (UKATC) = 2048 X 4096:

Pixel size =15µm
Image scale = 19.833 x 0.015 arc sec / pixel
= 0.297 arc sec / pixel
Field of view = (2048 x 0.297) x (4096 x 0.297)
= (10.1 x 20.2) arc min

Pro EM CCD (1K X 1K) = 1024 X 1024:

Pixel size = 13 µm
Image scale = 19.833 x 0.013
= 0.257 arc sec / pixel
Field of view = 1024 x 0.257 x 1024 x 0.257
= (4.3 x 4.3) arc min

JCBT BROAD BAND FILTERS:

U = 365 nm
B = 445 nm
V = 551 nm
R = 658 nm
I = 806 nm

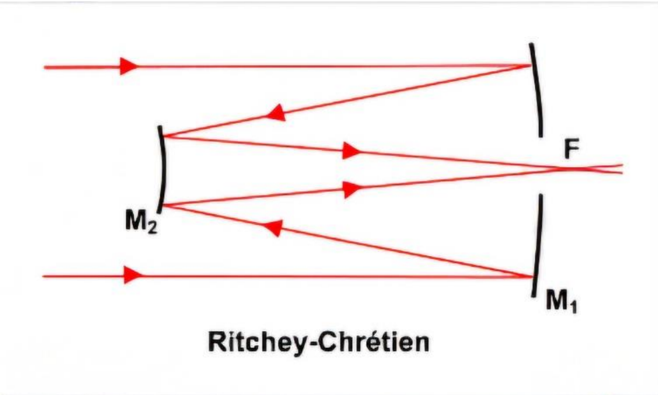
JCBT NARROW BAND FILTERS:

H-alpha = 656.3 nm
H-beta = 486.1 nm

1.6. DESIGN AND WORKING OF JCB TELESCOPE

The **Ritchey-Chrétien** telescope design, utilized in professional astronomy, offers exceptional image quality across a wide field of view. Its focus employs two hyperbolic mirrors to minimize optical aberrations such as coma and astigmatism, which are common in other telescope configurations. This setup renders it particularly well-suited for astrophotography and scientific investigations demanding high precision.
The optical excellence of the Ritchey-Chrétien design makes it an ideal choice for space-based observatories like the Hubble Space Telescope, where pristine image clarity is paramount. Despite being more intricate and costly to manufacture compared to

alternative designs, its superior performance justifies its widespread adoption in advanced astronomical research.



Credit: wikipedia

The Ritchey-Chrétien focus offers substantial enhancements in optical performance by effectively addressing chromatic and spherical aberrations. This correction capability results in images characterized by exceptional resolution across expansive fields of view, making it indispensable for tasks such as deep-sky photography and precise astrophysical observations. However, the adoption of the Ritchey-Chrétien focus comes with certain constraints. Its construction and implementation tend to be costly and intricate. Additionally, maintaining optimal optical alignment can pose challenges, necessitating regular adjustments and corrections.

Despite these limitations, many research-grade telescopes prioritize the Ritchey-Chrétien focus due to its unparalleled image quality, which significantly outweighs the associated challenges.

Here's how the telescope works:

1. **Light Collection**: When light from distant objects enters the telescope, it first encounters the primary mirror, which is a concave mirror. This mirror reflects the incoming light rays toward a focal point located in front of the mirror.

2. **Secondary Mirror:** The light rays reflected by the primary mirror converge at the focal point. However, instead of being intercepted by an eyepiece or camera at this point, they pass through an aperture in the centre of the primary mirror.

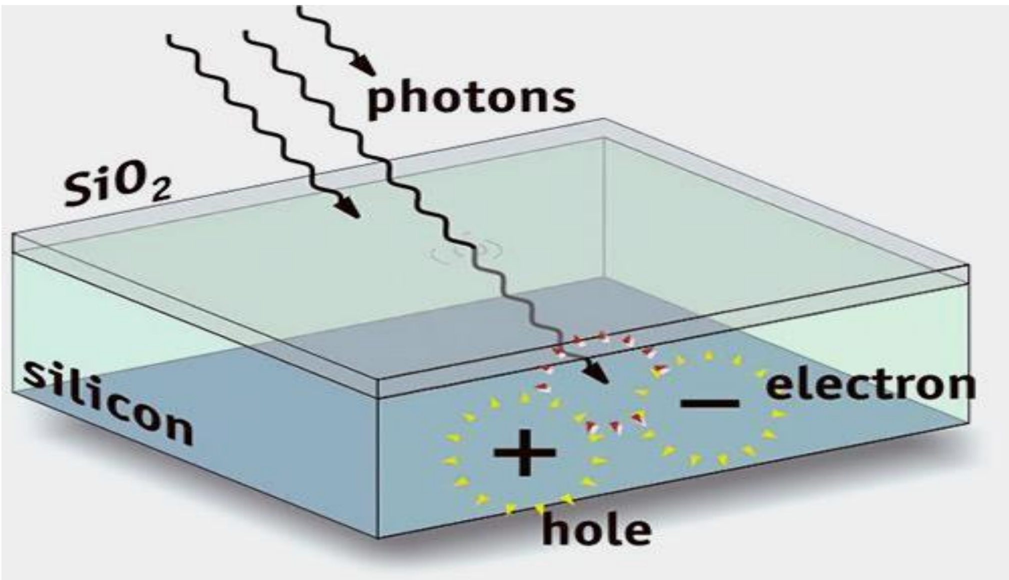
3. **Secondary Mirror Reflection**: The converging light rays then encounter the secondary mirror, which is a convex mirror located at the centre of the primary mirror. The secondary mirror reflects the light rays back toward the primary mirror.

4. **Final Focusing**: The reflected light rays from the secondary mirror are directed back through the aperture in the primary mirror and converge at a focal point behind the primary mirror. This is where the eyepiece or camera is placed to observe or capture the image.

5. **Observation:** The eyepiece or CCD collects the focused light rays, allowing the observer to view or record the magnified image of the observed object.

1.7. CHARGED COUPLED DEVICE (CCD)

The Charged-Coupled Device (CCD) revolutionized imaging technology and has become ubiquitous in various fields, from astronomy to digital photography and medical imaging.
At its core, a CCD is a semiconductor device that converts light into electrical signals. It consists of an array of light-sensitive pixels, each capable of detecting photons and converting them into electrons. These electrons are then transferred and stored in capacitors within the device, creating an electrical charge proportional to the intensity of the incident light. In a CCD sensor, each pixel's charge undergoes a transfer process through a limited number of output nodes, typically just one. This charge is then converted to voltage, buffered, and transmitted off-chip as an analogue signal. This design ensures that all pixels can be solely dedicated to light capture, resulting in high uniformity in the output, which is critical for image quality.



©https://www.teledynedalsa.com/en/learn/knowledge-center/ccd-vs-cmos/.

Imagine you have a large bucket representing the CCD sensor. This bucket is divided into many small compartments, each representing a pixel on the sensor.

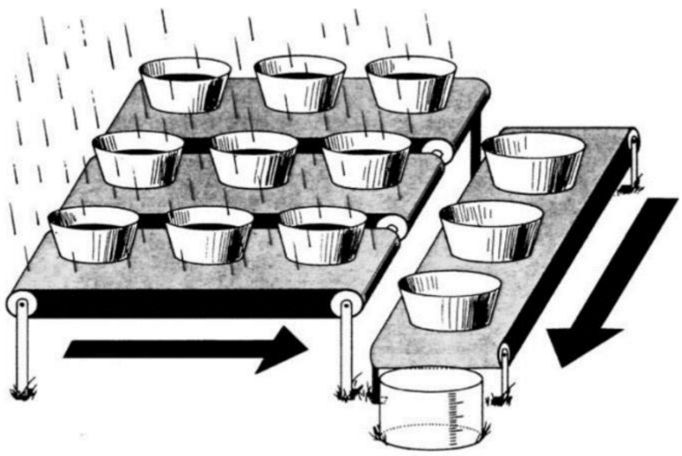
1. **Light Capture:** Imagine the CCD sensor as a large bucket divided into small compartments, each representing a pixel on the sensor. Just like raindrops falling

into each compartment of the bucket, photons of light fall onto each pixel of the CCD sensor when an image is captured. Each compartment (pixel) collects and holds onto the light it receives.

2. **Charge Transfer:** To empty the water from the bucket, we would manually transfer the water from each compartment to the next until it reaches the edge of the bucket. Similarly, in a CCD sensor, after the light is collected by each pixel, the electrical charge generated by the light is transferred from one pixel to the next in a controlled manner, row by row, until it reaches the edge of the sensor.

3. **Readout:** Once all the charge has been transferred to the edge of the sensor, it is then read out by electronics attached to the sensor. This is like emptying the water from the bucket into another container for further processing. The amount of charge read out from each pixel corresponds to the intensity of light that fell on it during exposure.

4. **Conversion and Transmission:** The electrical charge read out from each pixel is converted into a voltage signal, amplified, and transmitted off the sensor as an analogue signal. This analogue signal can then be further processed or converted into digital data for storage or display.



©handbook of CCD Astronomy by Steve B. Howell

1.8. PARAMETERS FOR RAW DATA PROCESSING

A raw data obtained from the telescope contains lots of noises and background errors from the instrument and the sky. In order to minimise these errors, the observer usually takes four frames with the telescope. They are Bias frames, Flat frames, Dark frames and Object frames.

1.8.1. Bias Frames:

Bias frames in astronomy are short exposures captured with the telescope or camera's optics fully covered, preventing any light from reaching the detector. Since no light is recorded during these exposures, any signal detected is purely the result of electronic noise inherent to the detector system. This noise can arise from various sources, including the readout electronics and the detector itself.
Several bias frames are taken before, during, and after the observation. This is to test the detector's temperature/noise stability.

1.8.2. Flat Frames:

In CCD imaging, each pixel may have a slightly different gain or quantum efficiency (QE) compared to its neighbouring pixels. This non-uniformity can lead to variations in the response of the sensor to incoming radiation, resulting in uneven brightness across the image. To address this, a flat field image is acquired. The purpose of a flat field image is to provide a reference for correcting these pixel-to-pixel variations in sensitivity. Ideally, the flat field image should be obtained under uniform illumination conditions, where every pixel receives the same intensity of light. This uniform illumination helps to "flatten" the relative response of each pixel, ensuring that they all respond similarly to incoming radiation. In JCBT, astronomers utilize sky flats by directing the telescope towards the twilight sky

1.8.3. Dark Frames:

As telescopes contain electronic components, they generate heat during operation, leading to the production of thermal electrons. These electrons can introduce noise in the CCD (charge coupled device) sensor.
Additionally, dark frames can offer insights into the presence of defective or "hot" pixels within the sensor array. Moreover, they can serve to estimate the frequency of cosmic ray impacts at the observing site.
Dark frames are images taken with the shutter closed but for some time period, usually equal to that of your object frames. We can neglect the dark current using any cooling method. In JCBT, liquid nitrogen is used for 2k/4k UKATC CCD and Peltier cooling is used for 1k/1k proEM CCD.

1.8.4. Object Frames:

These frames contain the actual astronomical data of interest and are typically acquired using specific observational filters or wavelength ranges to capture the desired features or characteristics of the objects being studied. They are of some exposure length from 1 second or less up to many hours, varying for reasons of type of science, brightness of object, desired temporal sampling, etc. Object frames serve as the primary data for astronomical analysis and are often processed and combined with calibration frames, such as dark frames and flat frames, to enhance their quality and extract meaningful information about the observed celestial phenomena.

1.9. SOFTWARE, APPLICATIONS AND FORMATS USED

1.9.1. IRAF-IMAGE REDUCTION AND ANALYSIS FACILITY

IRAF is a general purpose software system for the reduction and analysis of astronomical data. The software was written by the national optical astronomy observatories (NOAO) in Tucson, Arizona. The IRAF system provides a good selection of programmes for general image processing and graphics applications, plus a large selection of programmes for the reduction and analysis of optical astronomy data.

IRAF comes with a wide set of features designed specifically for astronomical needs. In the area of data reduction, it offers tools such as bias correction, flat fielding, dark frame subtraction, and photometry etc. These processes are essential for preparing raw data, for eliminating noise and other instrumental effects and errors that occur during data collection. For spectral analysis, IRAF provides facilities for spectrum extraction, wavelength calibration, continuum normalization etc. These tasks help astronomers to separate spectra from 2d images, change pixel dispersion axis to wavelength and thus analysing spectral features of various astronomical entities.

image processing is another strength of IRAF, offering tools for photometry, astrometry and image analysis. These features help astronomers measure the brightness and positions of celestial objects, process images, and analyse the shapes and structures of astronomical objects.

The major component of the IRAF system is the command language or cl. It is used to run the application's programmes which are grouped into two classes the system utilities and the scientific application programmes. Both the cl and all standard IRAF applications programmes depend upon the facilities of the IRAF Virtual Operating System (VOS) for their finding .CL has responsibilities which include task initiation, termination, parameter retrieval, updating and error handling.

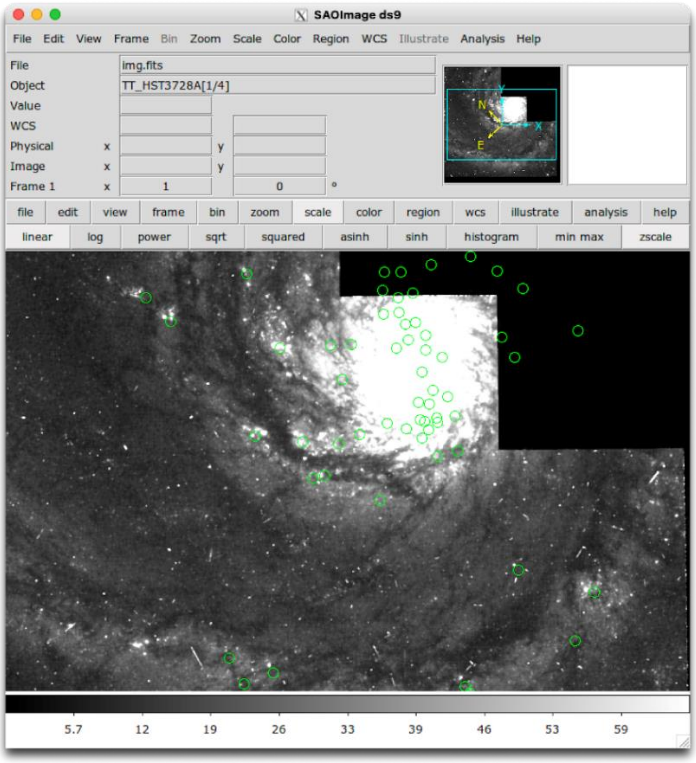
IRAF commands (known as tasks) are organized into package structures. Additional packages may be added to IRAF. Packages may contain other packages. There are many packages available by NOAO and external developers often focusing on a particular branch of research or facility.

One of IRAF's main advantages is its comprehensive toolset, which covers a broad spectrum of data reduction and analysis tasks. This extensive functionality is supported by a well-established user base and a wealth of documentation, community support, and user-contributed scripts and tutorials. Additionally, IRAF's modular architecture allows for easy addition of new tasks and customization, making it adaptable to various research needs.

Despite the development of newer software tools, IRAF's powerful features and strong community support ensure its ongoing relevance and utility. By enabling precise and efficient processing of astronomical data, IRAF continues to facilitate significant scientific discoveries and advancements in the field of astronomy.

1.9.2. SAOImage Ds9

SAOImage (Smithsonian Astrophysical Observatory) DS9, often referred to simply as DS9, stands as a pivotal tool within the realm of astronomical imaging and data visualization. Its versatile capabilities encompass the handling of FITS images, binary tables, and the management of multiple frame buffers.



© https://sites.google.com/cfa.harvard.edu/saoimageds9

In addition to its fundamental functions, DS9 boasts a rich array of advanced features tailored to meet the demanding needs of astronomical research. Among these features are the ability to handle mosaic images and tiling, facilitating the seamless integration of large-scale datasets. The tool also offers functionalities such as blinking, which aids in the detection of transient phenomena, geometric markers for precise measurements, and colormap manipulation for enhanced data interpretation.

One of the defining characteristics of DS9 is its high degree of configurability and extensibility. Users have the freedom to tailor the interface and workflow to suit their specific requirements, whether through customizing display settings or integrating external analysis tasks seamlessly into their workflow.

In essence, DS9 serves as a cornerstone for astronomers and researchers, providing them with a powerful platform to visualize, analyse, and interpret complex astronomical data with unparalleled precision and efficiency.

1.9.3. FITS FORMAT

In astronomy, observers use a standard file format called **FITS** file. FITS was designed to transport scientific information – data such as 16-bit raw image data from a CCD and to retain every bit of it. FITS files include extensive metadata, providing detailed information about the observations, calibration, and processing steps applied to the data. This metadata is crucial for understanding and interpreting the contents of the file.

FITS is designed to be flexible, allowing for the storage of various types of data, including multidimensional arrays (like images) and tables. This flexibility makes it suitable for a wide range of astronomical observations and analyses.

Fits file is mainly of three parts. They are

1. Header: It contains data that allows the observer to read and interpret image stored in the file. The header contains metadata, which is information about the data stored in the FITS file. This metadata includes details such as the observation date, telescope used, instrument configuration, exposure time, and more.

```
SIMPLE  =                    T / file does conform to FITS standard
BITPIX  =                   16 / number of bits per data pixel
NAXIS   =                    3 / number of data axes
NAXIS1  =                 2148 / length of data axis 1
NAXIS2  =                 4102 / length of data axis 2
NAXIS3  =                    1 / length of data axis 3
EXTEND  =                    T / FITS dataset may contain extensions
COMMENT   FITS (Flexible Image Transport System) format is defined in 'Astronomy
COMMENT   and Astrophysics', volume 376, page 359; bibcode: 2001A&A...376..359H
BZERO   =                32768 / offset data range to that of unsigned short
BSCALE  =                    1 / default scaling factor
VERSION =                90925 / Application parameter value
DWELL   =                60000 / Application parameter value
RD_TIME =                    0 / Application parameter value
RS_TIME =                 1000 / Application parameter value
FRM_TYPE=                    1 / Application parameter value
NUM_EXPS=                    1 / Application parameter value
LED_FLSH=                    0 / Application parameter value
EL_GAIN =                    0 / Application parameter value
SPEED   =                    0 / Application parameter value
OUTPUT  =                    1 / Application parameter value
HIERARCH COM_TAB_START =     0 / Application parameter value
GAIN    =                0.745 / Gain of CCD in e/ADU for EL_GAIN 0
READNOIS=                  4.3 / Read Noise in electrons for SPEED 0
INSTRUME= 'IMAGING '           / DIRECT IMAGING (2K X 4K UKATC CCD)
OBSERVER= 'RB,AB   '           / Observers' Name
OBJECT  = 'WASP-13 '           / Description of the Object
FILTER  = 'I       '           / Filter used
IMAGETYP= 'object  '           / type of the image
OBJNAME = 'WASP-13 '           / Name of the Object
DATE    = '2023-02-22'         / Date of observation
OBSERVAT= 'VBO     '           / VAINU BAPPU OBSERVATORY
TELESCOP= '1.3M JCBT'          / 1.3 Meter JCB Telescope
PI      = 'Suman Saha'         / Principal Investigator
EPOCH   =                2000. / Epoch
OBJRA   = '09:20:24.7'         / Object RA
OBJDEC  = '+33:52:56.6'        / Object DEC
UT      = '15:59:11.3964'
EXPTIME =                  60. / Exposure time in seconds
LST     = '7:23:55.02'
RA      = '9:21:14.15'
DEC     = '33:46:54.26'
HA      = '-1:57:19.13'
AIRMASS =              1.20678 / Airmass at start of exposure
EQUINOX =               2023.5
FOCUS   =              1838.04 / Focus reading of the Telescope
TIMESYS = 'UTC     '           / Explicit time scale specification
DATE-OBS= '2023-02-22T15:57:59.673' / Date and time of start of obs. in UTC
PROCESS = 'Single raw read'    / Data processing mode
FRM_STAT= '0x8001  '           / Data frame status word
FRM_NUM =                    1 / Data frame number
FRM_TIME=                60000 / Data frame elapsed exposure time
END
```

SCREENSHOT 1

2. The image data: the image data is encoded as binary data using specific, well-defined binary formats. The binary encoding allows for efficient storage and transmission of large volumes of image data, which is essential for handling the vast amounts of data generated by astronomical observations.
3. Tailer: it adds extra bytes to pad the files to a standard length. In FITS files, the tailer serves as a marker denoting the end of the file, ensuring that software parsing the file knows precisely where it concludes. This is particularly important in scenarios where the file size isn't predetermined or fixed.

CHAPTER-2
METHODOLOGY

2.1. OBSERVATION PROCEDURE OF JCB TELESCOPE

STEP-1

To initiate observations, provided the weather permits, certain steps need to be followed accordingly. Firstly, ensure favourable sky conditions. Then, proceed to prepare the telescope for operation by opening the dome, dome shutter, and windows on the telescope floor. Next, activate essential instruments like the CCD and guider. Simultaneously, power up all necessary equipment in the operation room.

STEP-2

Before commencing observations, it's crucial to awaken the telescope from its hibernation mode. The telescope will be initially pointed towards the zenith. We have to move the telescope to the reference points marked on the oil pad either towards east or west. So that we get the true value on the observation system. Then press the initialization button. The telescope is ready for tracking any source.

STEP-3

After the initialisation flat frames are taken by opening the dome and pointing the telescope towards the twilight sky in east direction for 2.5 hours. Three flat frames are taken in each filter. Likewise, three bias frames are also taken for each filters by closing the dome every one hour during the observation with zero exposure.

STEP-4

The telescope is synched with “The sky6” program. Pointing the telescope towards a bright star just above the zenith is called zero correction. By applying the offset we can bring the star to center of the telescope.

The value of offset is calculated mechanically, according to that we have to set RA and Dec manually. Now we can see that our telescope is pointed towards the object we are observing.

STEP-5

Next, to ensure proper focusing, it's necessary to conduct a focus test exposure. Begin by selecting the "FITS" option within the WXU cam tab. This will allow us to edit the header of the FITS file before saving it. Following this, proceed to the application settings to adjust observational parameters like exposure time (minimum 4 seconds) and frame type.

Since we require faster read-out for testing purposes, we'll adjust the camera aperture application accordingly. Once all settings are adjusted, proceed to click "execute" to initiate the test exposure.

STEP-6

After capturing the image, we'll analyse it in DS9 to confirm whether the object is accurately centred. If it appears off-centre, we need to assess its radial plot by pressing 'r' and its contour plot by pressing 'e'. If the object is indeed centred, we proceed to Comp 2. Within the Object Information tab, select the 'telescope' option and click 'sync' to synchronize the star's position with the telescope. With this synchronization complete, we can confidently point the telescope towards the intended object source for observation.

STEP-7

To align the telescope with the object we intend to observe, navigate to Comp 1. Within the DFM tab, select the telescope, then proceed to movement and click on mark/move table. Access the folder containing the .mrk file, which stores details of stars for specific observers. Choose the relevant observer's file and select the desired observation source. In the DFM control system, locate the telescope position section, where the "next object" option displays details such as HA (Hour Angle), RA, Dec, Air Mass, and epoch. Click on "start slew" to initiate telescope movement towards the designated object. This will align the telescope for observation.

STEP-8

To verify if our target object is accurately aligned, access the DFM control system and compare the Dome & Telescope azimuth values. They should match, indicating proper alignment. Once confirmed, the setup is ready for observation to commence.

STEP-9

To select the appropriate filter for observation on the DFM-IIU controller, follow these steps:

1. Access the comp 3 menu on the DFM-IIU controller.
2. Navigate to the filter section within the menu.
3. By default, the B filter is usually selected.
4. Review the available options which may include narrow band, broad band, B, V, I, and R filters.
5. Determine the specific filter needed for your observation requirements.
6. Use the controller interface to select the desired filter according to the observer's needs.

STEP-10

To begin data acquisition, follow these steps:

1. Navigate to the comp -4 menu.
2. Select the "Fits" option.
3. Provide a suitable file name and edit the header parameters as needed.
4. Save the settings.

Proceed with setting up the application:

1. Access the application section.
2. Set the frame type according to your observation requirements.
3. Configure the exposure time in milliseconds.
4. Once all settings are configured, click on the "Execute" option to initiate data acquisition.

After obtaining the image, verify the focus:

1. Check if the object is accurately focused.
2. If the focus is not optimal, proceed to the DFM Control system.
3. Navigate to the telescope option and select "Mics."
4. Adjust the focus manually by providing the necessary value.
5. After adjusting the focus, verify the modified focus.
6. Obtain the test image to ensure the focus is now satisfactory.

STEP-11

Once you have obtained the test data and verified the focus, you can proceed to analyse the data:

1. Press 'r' to view the radial plot.
2. Press 'e' to view the counterplot.
3. Analyse the plots to ensure they meet the requirements and satisfy your observation criteria.

If the plots meet your expectations and requirements, you are ready to begin the observation process.

GUIDING STAR:

A guiding star typically refers to a bright and stable star that is used as a reference point for tracking and guiding telescopes during observations.

For 1- or 2-minutes exposure guiding star is not necessary. When exposure time increases the position of the object may change. In order to avoid that we use guiding star, as it corrects the position. While the offset is set once a day, a guiding star is set for each object.

EXPOSURE TIME:

Exposure time depends upon the observer and object. It should not exceed the saturation value. Each CCD have different saturation values. For 2k X 4k (16-bit CCD) it should not exceed 65000-pixel counts ($2^{16} = 65536$).

Exposure time varies with sky condition.

2.2. MANUAL PHOTOMETRIC REDUCTION METHOD

Photometric reduction refers to a process used in astronomy to correct and analyse observations made with imaging devices, such as telescopes equipped with cameras or other detectors. The goal of photometric reduction is to remove systematic errors and inconsistencies in the data caused by various factors such as instrumental effects, atmospheric conditions, and variations in the sensitivity of the detectors.

It includes two parts involving various steps. They

are:

i) PRE-PROCESSING

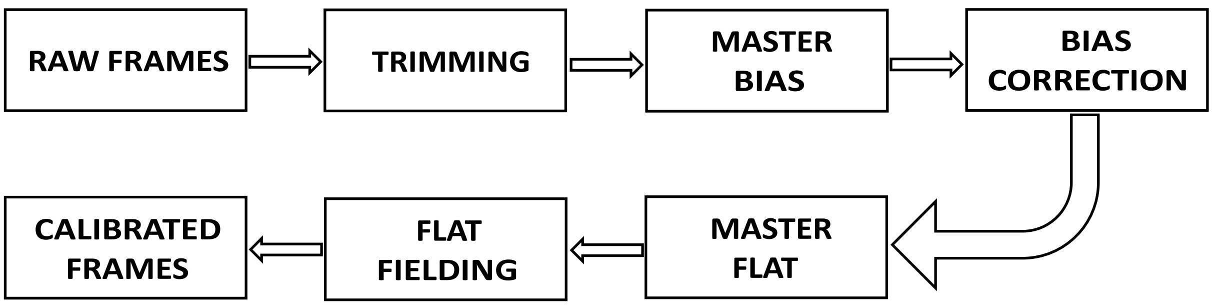
1. RAW FRAME SELECTION
2. TRIMMING THE RAW FRAME
3. MASTER BIAS CREATION
4. BIAS CORRECTION
5. MASTER FLAT CREATION
6. FLAT FIELDING

ii) PHOTOMETRY

1. PARAMETER FILES
2. DAOFIND TASK
3. APERTURE PHOTOMETRY
4. PSTSELECT TASK
5. POINT SPREAD FUNCTION (PSF) MODEL CREATION
6. ALLSTAR TASK

i. PRE-PROCESSING

Pre-processing refers to a series of initial steps and tasks performed in photometric reduction before the photometry part. It includes processes such as trimming, bias correction, dark correction, flat fielding and other related steps. Pre-processing makes the raw images frames obtained from telescope suitable for photometry by removing all types of instrumental errors and defects.



Trimming: Removal of overscan regions and undesired areas of the image frames refines the analysis scope, focusing solely on the relevant sections of the data.

Bias Correction: Bias frames, which account for the electronic noise inherent to the detector, are subtracted from the raw image frames to eliminate unwanted signals that could skew subsequent analysis.

Dark Current Correction: Dark frames, capturing the detector's thermal signal, are subtracted from the raw frames to counter temperature-induced noise, thereby addressing issues like hot pixels and thermal effects.

Flat Fielding: Employing flat field frames, which document pixel-to-pixel sensitivity variations and optical imperfections, corrects these discrepancies in the raw frames. This process involves dividing the science frames by the flat field frames to ensure uniform sensitivity across the entire detector.

We obtain calibrated image frames as the result of pre-processing that are free from all instrumental effects.

$$\text{Calibrated image frames} = \frac{\text{raw image frames} - \text{bias frames} - \text{dark frames}}{\text{Normalized master flat frames}}$$

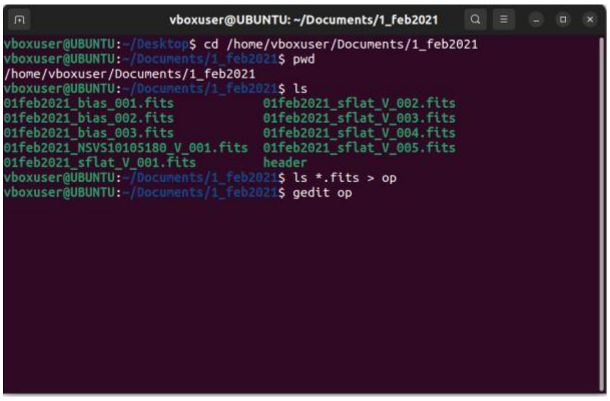
Thus, pre-processing is essential for high quality data processing and analysis in astronomy to produce calibrated images that are true to the actual signals received from the astronomical object and thus producing reliable data for further interpretation.

STEP-1 RAW FRAMES SELECTION

For the photometric reduction of stellar data obtained from the JCBT in fits format, first we have to open the terminal and change the directory to the location which contains the raw frames in fits file format using the command

- **cd /'desired directory path' # changes the directory to desired location.** Or you can just open the terminal within the folder containing the fits files itself.

- **pwd # to see the current directory.**
- **ls # shows the list of contents within the selected directory.**



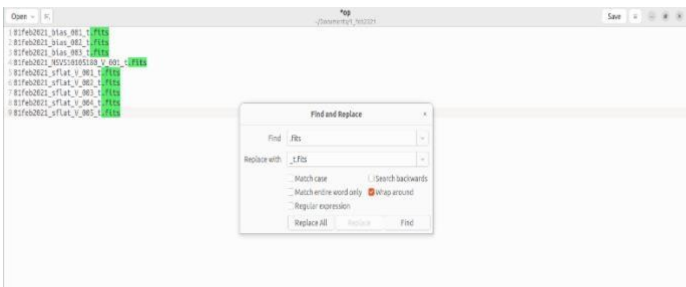
SCREENSHOT 2

STEP-2

Now a list (say 'op') is created containing all the fits file within the directory.

- **ls *.fits > op # a list named op will be created inside the directory.**
- **gedit op # opens the list op using gedit text editor.**

Then replace all '.fits' part in the file names with '_t.fits' using the find and replace option in the text editor and save this edited list as a new list 'op_t'. Close the text editor and return to the terminal. We can see the lists created (op and op_t) in the directory by using the 'ls' command.



SCREENSHOT 3

STEP-3 TRIMMING THE RAW FRAMES

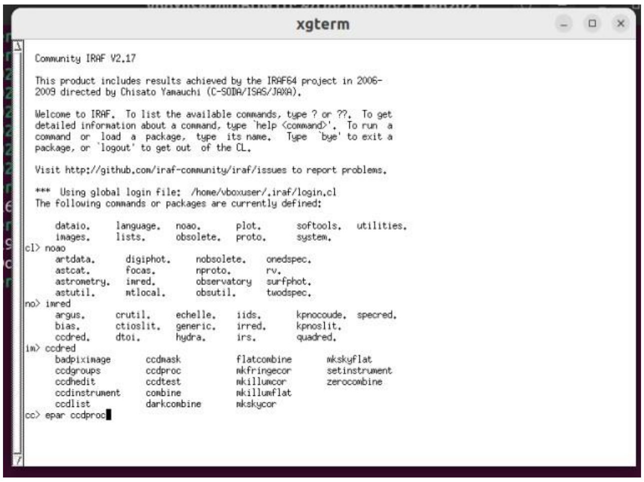
In IRAF raw frames for reduction are trimmed down to reduce the areas in the raw image frames that are over scanned other than object and containing noise and other unwanted features. By trimming we can make sure that only essential part of the raw frames is left for reduction and analysis and thus increasing the accuracy and reliability of the procedure.

In this step now we open the xg terminal for running IRAF tasks and load various packages necessary for performing reduction.

- **xgterm -sb& # opens the xg terminal console. The '&' sign will enable to continue using terminal for running other tasks while the IRAF console is open.**

In the newly opened console type

- **cl # invoke the primary interface through which users can execute IRAF tasks.**
- **noao # loads the NOAO packages containing various IRAF tasks and tools.**
- **imred # calls IMRED package designed for image reduction from NOAO.**
- **ccdred # invokes package for CCD reduction from 'imred' package.**
- **epar ccdproc # opens a new package for CCD processing in parameter editor window.**



SCREENSHOT 4

After this command a new window will open with parameters and values are entered as follows:

PACKAGE = ccdred

TASK = epar ccdproc

(images = @op) List of CCD images to correct

(output = @op_t) List of output CCD images

(ccdtype=) CCD image type to correct

(maxcac= 0) Maximum image caching memory (in Mbytes) (noproc = no) List processing steps only?

(fixpix = no) Fix bad CCD lines and columns?

(oversca= no) Apply overscan strip correction?

(trim = yes) Trim the image?

(zerocor= no) Apply zero level correction?

(darkcor= no) Apply dark count correction?

(flatcor= no) Apply flat field correction?

(illumco= no) Apply illumination correction?

(fringec= no) Apply fringe correction?

(readcor= no) Convert zero level image to readout correction

(scancor= no) Convert flat field image to scan correction?

(readaxi= line) Read out axis (column—line)

(fixfile=) File describing the bad lines and columns

(biassec=) Overscan strip image section

(trimsec= [50:2100,5:4090]) Trim data section

(zero =) Zero level calibration image

(dark =) Dark count calibration image

(flat =) Flat field images

(illum =) Illumination correction images

(fringe =) Fringe correction images

(minrepl= 1.) Minimum flat field value

(scantyp= shortscan) Scan type

(nscan = 1) Number of short scan lines

(interac= no) Fit overscan interactively?

(function= legendre) Fitting function

(order = 1) Number of polynomial terms or spline pieces

(sample = *) Sample points to fit

(naverag= 1) Number of sample points to combine

(niterat= 1) Number of rejection iterations

(low_rej= 3.) Low sigma rejection factor

(high_re= 3.) High sigma rejection factor

(grow = 0.) Rejection growing radius

(mode = ql)

Then type

- **:go # to apply the changes in the parameters and execute the task with the updated parameter values**

After executing the task if we open an object frame using the DS9 image viewer application from the working directory we can see that the frame size is trimmed. To open the DS9 image viewer in xg terminal type

- **!ds9 &**

STEP-4 MASTER BIAS CREATION

The bias signal that is generated during the read out of CCD must be removed from the observed raw data. All read out of CCD will produce noise and so does the bias frame readout too. So, to minimise the noise produced during the subtraction of bias frames, we take many bias frames and combine them together as one master bias and then remove them altogether.

In the terminal open the 'op_t' list using 'gedit' and cut out all the bias frame, paste them in a new list and save it as 'bias_tlist' and the old list from which we cut the bias frames are saved as 'op1_t'. We can see both lists created in the directory by using the 'ls' command in the terminal. Now we have to check the statistics of the bias_tlist. For that we can use the command:

- **Imstat @bias_tlist # to check the statistics.** Now we perform another task using:

- **epar zerocombine # combines multiple bias frames into single master bias frame.**

PACKAGE = ccdred

TASK =epar zerocombine

(input = @bias_tlist) List of zero level images to combine

(output = masterbias_av.fits) Output zero level name

(combine= average) Type of combine operation

(reject = minmax) Type of rejection

(ccdtype=) CCD image type to combine

(process= no) Process images before combining?

(delete = no) Delete input images after combining?

(clobber= no) Clobber existing output image?

(scale = none) Image scaling

(statsec=) Image section for computing statistics

(nlow = 0) minmax: Number of low pixels to reject

(nhigh = 1) minmax: Number of high pixels to reject

(nkeep = 1) Minimum to keep (pos) or maximum to reject (ne

(mclip = yes) Use median in sigma clipping algorithms?

(lsigma = 3.) Lower sigma clipping factor

(hsigma = 3.) Upper sigma clipping factor

(rdnoise= 4.2) ccdclip: CCD readout noise (electrons)

(gain = 0.745) ccdclip: CCD gain (electrons/DN)

(snoise = 0.) ccdclip: Sensitivity noise (fraction)

(pclip = -0.5) pclip: Percentile clipping parameter

(blank = 0.) Value if there are no pixels

(mode = ql)

After entering the parameter values as per the header parameter given in the DS9 image viewer, enter ':go'. We can use 'ls' command in terminal to see 'masterbias_av.fits' created in the directory. Again we check the statistics of this output file by using the command 'imstat masterbias_av.fits'. Now using 'gedit op1_t' command we open the corresponding op1_t list and in the list replace all 't.fits' part in the name of all files with 'tb.fits' using the 'find and replace' option in the gedit editor. Save this as 'op1_tb'.

STEP-5 BIAS CORRECTION

Now we have to subtract the master bias frame from the raw image frames. This process of subtracting the bias frames from the raw image frames is called bias correction. For that we use the 'ccdproc' parameter task to apply the bias correction. In the xg terminal, type 'epar ccdproc' and enter the parameter values as given below.

PACKAGE = ccdred

TASK = epar ccdproc

(images = @op1_t) List of CCD images to correct

(output = @op1_tb) List of output CCD images

(ccdtype=) CCD image type to correct

(maxcac= 0) Maximum image caching memory (in Mbytes)

(noproc = no) List processing steps only?

(fixpix = no) Fix bad CCD lines and columns?

(oversca= no) Apply overscan strip correction?

(trim = no) Trim the image?

(zerocor= yes) Apply zero level correction?

(darkcor= no) Apply dark count correction?

(flatcor= no) Apply flat field correction?

(illumco= no) Apply illumination correction?

(fringec= no) Apply fringe correction?

(readcor= no) Convert zero level image to readout correction

(scancor= no) Convert flat field image to scan correction?

(readaxi= line) Read out axis (column—line)

(fixfile=) File describing the bad lines and columns

(biassec=) Overscan strip image section

(trimsec= [50:2100,5:4090]) Trim data section

(zero = masterbias_av.fits) Zero level calibration image

(dark =) Dark count calibration image

(flat =) Flat field images

(illum =) Illumination correction images

(fringe =) Fringe correction images

(minrepl= 1.) Minimum flat field value

(scantyp= shortscan) Scan type

(nscan = 1) Number of short scan lines

(interac= no) Fit overscan interactively?

(function= legendre) Fitting function

(order = 1) Number of polynomial terms or spline pieces

(sample = *) Sample points to fit

(naverag= 1) Number of sample points to combine

(niterat= 1) Number of rejection iterations

(low_rej= 3.) Low sigma rejection factor

(high_re= 3.) High sigma rejection factor

(grow = 0.) Rejection growing radius

(mode = ql)

Type ':go' to execute the task. Now a new list op1_tb can be seen in the directory by typing 'ls' command in the terminal. Now we have successfully subtracted the bias frames altogether by combining them as master bias.

STEP-6 MASTER FLAT CREATION

In a CCD the signal generated by each pixel will not be the same even if it is uniformly illuminated. This is due to the pixel-to-pixel variation of the CCD. The flat field images or flat frames are created by uniformly illuminating the CCD without any astronomical objects.
Multiple such flat frames are combined together to create a single master flat image.
In terminal use 'gedit op1_tb' and select only the flat files and copy them into a new list and save it as 'flat_tblist'. From the flat files copy only the B filtered flat files into a new list and save as 'flat_B'. Similarly copy the flat files with others filters (I, R, V etc) too into new lists and name them accordingly. Now we have to create the master flat.

For that we use:

- **epar flat combine # combines multiple flat frames into single master flat.**

Enter the parameters as below.

PACKAGE = ccdred

TASK =epar flatcombine

(input = @flat_B) List of flat field images to combine

(output = masterflat_B) Output flat field root name

(combine= average) Type of combine operation

(reject = avsigclip) Type of rejection

(ccdtype=) CCD image type to combine

(process= no) Process images before combining?

(subsets= no) Combine images by subset parameter?

(delete = no) Delete input images after combining?

(clobber= no) Clobber existing output image?

(scale = mode) Image scaling

(statsec=) Image section for computing statistics

(nlow = ; 1) minmax: Number of low pixels to reject

(nhigh = 1) minmax: Number of high pixels to reject

(nkeep = 1) Minimum to keep (pos) or maximum to reject

(mclip = yes) Use median in sigma clipping algorithms?

(lsigma = 3.) Lower sigma clipping factor

(hsigma = 3.) Upper sigma clipping factor

(rdnoise= 4.2) ccdclip: CCD readout noise (electrons)

(gain = 0.745) ccdclip: CCD gain (electrons/DN)

(snoise = 0.) ccdclip: Sensitivity noise (fraction) (pclip = -0.5) pclip: Percentile clipping parameter

(blank = 1.) Value if there are no pixels

(mode = ql)

Execute the task by ':go'. Repeat the flat combine for other filters (I, R, V etc) too by entering the input and output names accordingly. All other parameters should be the same.

Now in the terminal open 'op1_tb' using gedit editor. Now select all files from it except the flat files and copy them into a new list 'obj_tblist'. Then from this, copy objects with specific filters such as B,I,R,V etc into corresponding new lists with names 'obj_B', 'obj_I', 'obj_R' etc. Now in terminal open 'obj_B' using gedit editor and in the list replace 'tb.list' part of the file names with 'tbf.list' and save it as 'obj_B_tbf'. Do the same for others ('obj_I', 'obj_R', 'obj_v' etc) too and save them as new lists with names.

STEP-7 FLAT FIELDING

We have created master flat for each filters separately. Now we normalize this master flat by dividing each pixel in it by its mean or median value to remove any intensity differences to provide more precision for flat fielding. We divide all the object frames (raw frames after all other corrections) with this normalized master flat. As a result, we get corrected image frames with brightness and intensity that is true to the actual signal of the astronomical object. This process of eliminating pixel-to-pixel variation of CCD is called flat fielding.

For that we use the 'ccdproc' task.

PACKAGE = ccdred

TASK =epar ccdproc

images = @obj_b List of CCD images to correct

(output = @obj_B_tbf) List of output CCD images

(ccdtype=) CCD image type to correct

(max_cac= 0) Maximum image caching memory (in Mbytes)

(noproc = no) List processing steps only?

(fixpix = no) Fix bad CCD lines and columns?

(oversca= no) Apply overscan strip correction?

(trim = no) Trim the image?

(zerocor= no) Apply zero level correction?

(darkcor= no) Apply dark count correction?

(flatcor= yes) Apply flat field correction?

(illumco= no) Apply illumination correction?

(fringec= no) Apply fringe correction?

(readcor= no) Convert zero level image to readout correction

(scancor= no) Convert flat field image to scan correction?

(readaxi= line) Read out axis (column—line)

(fixfile= badpix) File describing the bad lines and columns

(biassec= image) Overscan strip image section

(trimsec= [x1:x2,y1:y2]) Trim data section

(zero = masterbias) Zero level calibration image

(dark =) Dark count calibration image

(flat = nmasterflat blue.fits) Flat field images

(illum =) Illumination correction images

(fringe =) Fringe correction images

(minrepl= 1.) Minimum flat field value

(scantyp= shortscan) Scan type (shortscan—longscan)

(nscan = 1) Number of short scan lines

(interac= yes) Fit overscan interactively?

(functio= legendre) Fitting function

(order = 1) Number of polynomial terms or spline pieces

(sample = *) Sample points to fit

(naverag= 1) Number of sample points to combine

(niterat= 1) Number of rejection iterations

(low_rej= 3.) Low sigma rejection factor

(high_re= 3.) High sigma rejection factor

(grow = 0.) Rejection growing radius

(mode = ql)

Execute this by ':go'. Do this task similarly for other filters too with corresponding values for images and output parameters. After completing the ccdproc task for all available filters within the raw frames we will get the calibrated frames after all types of corrections.

All these tasks and procedures until now forms the preprocessing part of the photometric reduction. The calibrated frames produced as a result are the ones that are used for the next part of the reduction process that is photometry.

ii.PHOTOMETRY

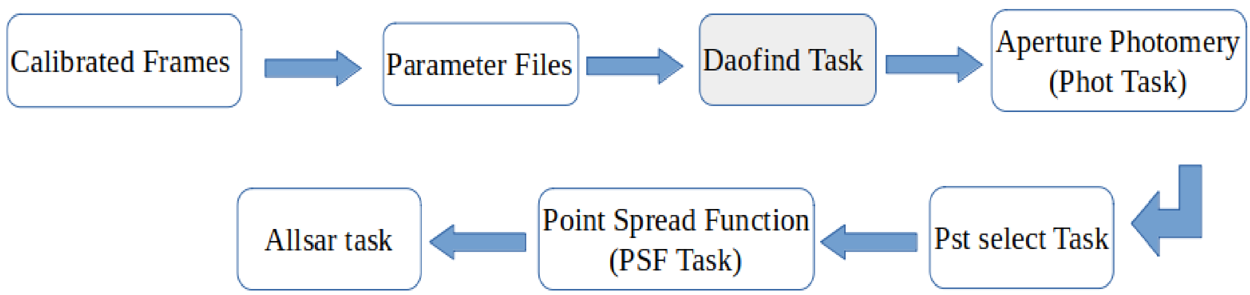
After obtaining the calibrated frames, we derive the instrumental magnitude via object detection, parameter identification, and photometric analysis.

Calibrated Frames Acquisition: Begin by obtaining calibrated frames of your target object through processes such as bias subtraction, dark frame subtraction, and flat-fielding to correct for instrumental and environmental effects.

Source Detection: Use software tools or algorithms to identify and locate your target objects within the calibrated frames. In IRAF we use the daofind task inside the daophot package to do the source detection.

Parameter Identification: Determine the necessary parameters for photometric analysis, such as the aperture size for extracting flux measurements, background estimation regions, and any other relevant settings.

Photometry: Perform photometric measurements on the detected objects within the calibrated frames. This involves integrating the flux within the defined aperture for each object while carefully subtracting background contributions. Here we do the aperture photometry i.e measuring or counting the light within an aperture around an object to measure it's brightness accurately. Also we do the PSF modelling in which we define a point spread function which tells us about how the light from the object spreads out in the image.

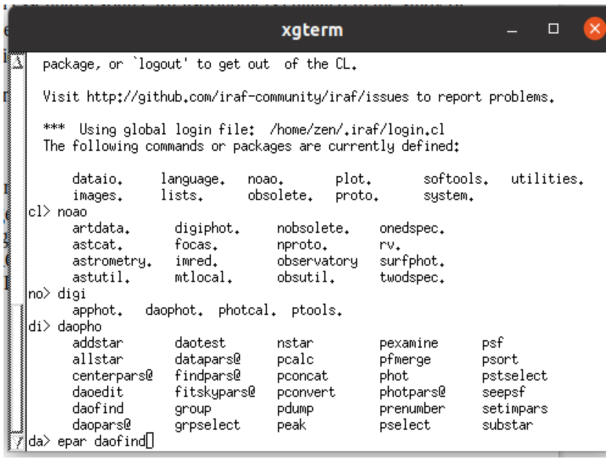


STEP-1
Source Detection

The "daofind" function in IRAF is used for identifying astronomical sources, particularly stars, within image datasets. By using thresholding algorithms and background subtraction techniques, daofind effectively isolates regions exhibiting intensity levels exceeding the background, suggestive of potential celestial entities. Its output provides vital details including object coordinates and characteristics, facilitating analyses like photometry.

We start by opening xgterminal for running photometric IRAF tasks and loading necessary packages for photometry.

- xgterm -sb &   #opens xgterminal
- cl   #invokes the primary interface
- noao   #loads the NOAO packages
- digiphot   #calls DIGIPHOT package designed for doing photometry
- daophot   #invokes the package DAOPHOT which is inside the DIGIPHOT package
- epar daofind   #opens the task DAOFIND which is used for detecting stellar sources



SCREENSHOT 5

PACKAGE = daophot
TASK = epar daofind
(image =   ) Input image(s)
(output =   default Output coordinate file(s) (default: image.coo.?)
(starmap=   )Output density enhancement image(s)
(skymap=   ) Output sky image(s)
(datapar=   ) Data dependent parameters
(findpar=   ) Object detection parameters
(boundar   nearest) Boundary extension (constant—nearest —reflect—wra
(constan=   0.) Constant for boundary extension
(interac=   no) Interactive mode?

(icomman=   ) Image cursor: [x y wcs] key [cmd]
(gcomman=   ) Graphics cursor: [x y wcs] key [cmd]
(wcsout =   ) . wcsout) The output coordinate system (logical, tv,physica
(cache=   no) .cache) Cache the image pixels?
(verify =   yes) .verify) Verify critical daofind parameters?
(update=   yes) .update) Update critical daofind Parameters?
(verbose=   yes) .verbose) Print daofind messages?
(graphic=   ) .graphics) Graphics device
(display=   ) .display) Display device
(mode = q1)

Before completing this task, we need to set datapars and findpars.. To do this, press:q to exit
the current task and go to the finding parameter task.

• Defining Parameters

1. datapars: In the IRAF's photometry tasks, the tool "**datapars**" assumes a pivotal role in configuring parameters for processing image data. It empowers users to customize settings like gain, read noise, and saturation level, thereby refining the calibration of pixel values. Moreover, datapars offers the flexibility to specify the data format, image section, and coordinate system to be employed. Inside the daofind task by typing ':e' in front of datapars opens the task datapars for editing.

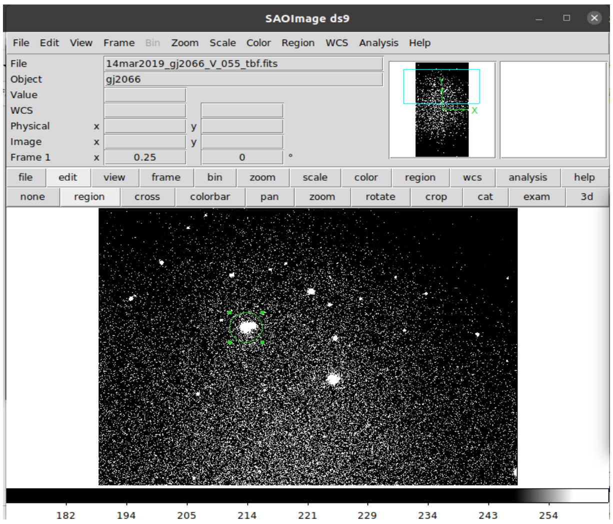
PACKAGE = daophot
TASK = datapars
(scale =   1.) Image scale in units per pixel
(fwhmpsf=   2.5) FWHM of the PSF in scale units
(emissio=   yes) Features are positive?
(sigma=   0.) standard deviation of background in counts
(datamin=   INDEF) Minimum good data value
(datamax=   INDEF) Maximum good data value
(noise=   poisson) Noise model
(codread=   ) CCD readout noise image header keyword
(gain=   0.745)CCD gain image header keyword
(readnoi=   4.22) CCD readout noise in electrons
(epadu=   1.) Gain in electrons per count
(exposure=   ) Exposure time image header keyword
(airmass=   ) Airmass image header keyword
(filter=   )Filter image header keyword
(obstime=   ) Time of observation image header keyword
(itime=   ) Exposure time
(xairmas=   INDEF) Airmass

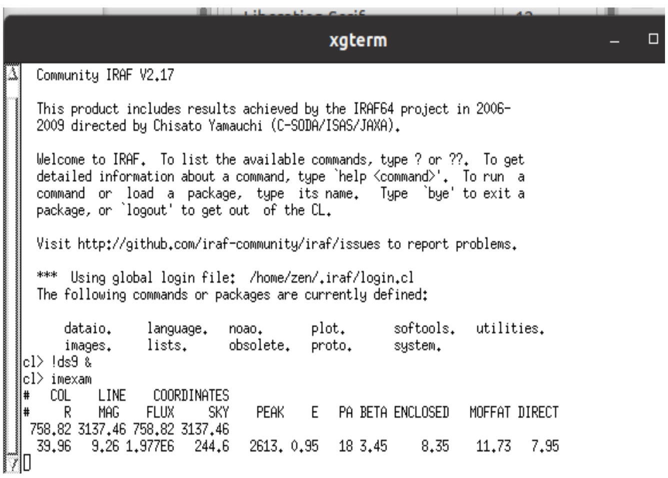
(ifiter= INDEF) Filter
(otime= INDEF) Time of Observation
(mode= q1)
: go

Read-out-noise: The electronic noise that arises during the process of converting the charge collected by the ccd into digital signal. It is typically measured in electrons or ADUs (Analog to digital units and impacts the quality of observations. Rdnoise tells us about the ability to detect faint objects. For JCB Telescope the rdnoise value is 4.22.

Gain: The factor between the number of electrons generated in the detector by incoming photons and the digital values produced in output signal. It is measured in electrons per analogue to digital unit. High gain value implies that only a few electrons are required to produce a given digital value. High Gain and low rdnoise are ideal for detecting faint objects. The gain of JCB Telescope is 0.745.

FWHM or Full Width at Half Maximum: The measure the describes the width of a peak or distribution at half of its maximum value. FWHM is used to quantify the resolving power of the telescope or seeing conditions. A smaller FWHM Value indicate a sharp and more precise image.
To determine the Full-width Half magnitude (FWHM) in this task, you first need to open any image in DS9 and then find the FWHM. To do this, give the command" imexam" in the Irafconsole, and select a bright source in the image that opens in DS9. Then, press "r" for radial plot and "a" to get the necessary data, including the FWHM. Check the Header parameters by inputting the values for readnoise, gain, exposure time, and airmass. filter. We set the sigma value according to the background counts; typically, we use 10-20 counts. We also set datamin and datamax based on the counts. then set all values we just save and exit to press "ctrl d".





SCREENSHOT-6 & 7

Calibrated Frame opened in DS9 and A bright source is **The FWHM Value is generated by using the command**

Selected 'imexam'

Sigma or **Standard Deviation of backgrounds:** The measure of background noise level in the calibrated image. It quantifies the amount of dispersion in the pixel values from the mean background level.
In order to determine the standard deviation, we have to know the mean sky value which is the average background intensity level. The sky value can be known from the image by using the 'imstat' task or opening the image in DS9 Image viewer and using 'imexam' task. Once the sky value is known, substituting it in the below equation would give us the sigma value.

$$\sigma = \sqrt{\left(\frac{\text{Mean Sky Value + Readnoise}}{\text{Gain}}\right)}$$

2. findpars: The **findpars** tool in IRAF's photometry tasks is super flexible. It helps astronomers adapt how they find objects in raw images. We can change settings like sensitivity to balance finding everything with not finding false stuff, especially in busy or noisy pictures. Tweaking the size settings helps filter out fake objects or find specific ones better, making the results more accurate. And we can choose which method works best for your data. When you get findpars set up right, you can work faster and get better results from raw astronomical images.
Similar to the datapars task typing ':e' in front of findpars opens task findpars.

PACKAGE = daophot
TASK = findpars
(thresho= 5.) Threshold in sigma for feature detection
(nsigma= 1.5) Width of convolution kernel in sigma
(ratio = 1.) Ratio of minor to major axis of Gaussian Kernel
(theta = 0.) Position angle of major axis of Gaussian Kernel
(sharplo= 0.2)Lower bound on sharpness for feature detection
(sharphi= 1.)upper bound on sharpness for feature detection
(roundlo= -1.)Lower bound on roundness for feature detection
(roundhi= 1.)upper bound on roundness for feature detection
(mkdetec= no) Mark detect on the image display?
(mode = ql)

Once the threshold is set using the standard deviation to find sources, it's important to make sure it matches the sigma parameter in the datapars section. Multiplying these gives the sky value, which is crucial for getting rid of the background accurately. After making these changes, saving them, and exiting by pressing 'Ctrl + D' finishes the setup. Going back to the IRAF console and using the 'epar dofind' command takes users back to the previous task screen. Here, specifying the input image as the calibrated ones and making sure they match the datapars and findpars settings prepares for running the task smoothly. Starting the task with ': go' starts the automated process, letting users move forward confidently with their photometry goals. After completing this ,a ' .coo' file is created in the respective directory.

STEP-2
Aperture photometry: phot task

The "phot" task in IRAF (Image Reduction and Analysis Facility) is a powerful tool for performing aperture photometry on astronomical images. Aperture photometry involves measuring the total flux or brightness of celestial objects by integrating the pixel values within a defined circular or elliptical aperture. This technique is particularly useful for point-like sources, such as stars or galaxies, where the majority of the light is concentrated within a small region. The "phot" task offers several options for customizing the aperture size, shape, and background estimation method, allowing users to optimize the photometric measurements according to the characteristics of their data. Additionally, it provides the ability to apply necessary calibrations, such as zero-point adjustments and extinction corrections, to obtain accurate magnitudes and flux values for the observed objects.
After detecting the sources by defining the necessary parameters.
Now we type:

- epar phot #edit parameter of phot task

```
PACKAGE = daophot
TASK= phot
image =          Input image(s)
coords =         default Input coordinate list(s) (default: image.coo.?)
output =          default Output photometry file(s) (default: image.mag.?)
skyfile  =        Input sky value file(s)
(plotfil=          )Output plot metacode file
(datapar=         )Data dependent parameters
(centerp=         )Centering parameters
(fitskyp=         )Sky fitting Parameters
(photpar=         )Photometry parameters
(interac=       no) Interactive mode?
(radplot=       no) Plot the radial profiles?
(icomman=         )Image cursor: [x y wcs] key [cmd]
(gcomman=         ) Graphics cursort [x y wcs] key [cmd]
(wcsin=           ) .wcsin) The input coordinate system (logical, tv,Physical)
(wcsout =         ) .wcsout) The output coordinate system (logical, tv.physical
(cache=         no) .cache) Cache the input image Pixels in memory?
(verify =      yes) .verify) Verify critical phot parameters?
(update=       yes) .update) Update critical phot parameters?
(verbose=      yes) .verbose) Print phot messages?
```

(graphic=) .grapics)Graphics device
(display= .display) Display device
(mode = q1)

- **Defining parameters: datapars, centerpars, fitskypars, photpars**

1. The **datapars** is already set in the previous task.
2. **centerpars**: The **centerpars** parameter set controls how the photometry task finds the center of objects. DAOPHOT users only need to focus on two of these parameters: calgorithm and cbox. Calgorithm decides which method to use for centring, while cbox sets the size of the box used to find the center. It's best to keep the other centerpars parameters at their default values. This ensures that the centring process works smoothly and accurately, without adding unnecessary complications. By sticking to these two important parameters and leaving the rest unchanged, DAOPHOT users can perform photometry more effectively and get reliable results. Typing ':e' in front of centerpars in phot ask opens he centerpars task.

PACKAGE = daophot
TASK= centerpars
(calgori= none) Centering algorithm
(cbox= 5.) Centering box width in scale units
(cthresh= 0.) Centering threshold in sigma above background
(minshra= 1.) Minimum signal-to-noise ratio for centering algorithm
(cmaxite= 10) Maximum iterations for centering algorithm
(maxshif= 1.) Maximum center shift in scale units
(clean= no) Symmetry clean before centering
(rclean = 1.) Cleaning radius in scale units
(rclip = 2.) Clipping radius in scale units
(kclean = 3.) K-sigma rejection criterion in skysigma
(mkcente= no) Mark the computed center
(mode = q1)
Here are the different types of algorithms used. Set the default width of the centering box and the centering threshold in sigma above the background. Then, save and exit by pressing "ctrl+d".

3. **fitskypars**: The **fitskypars** task within the DAOPHOT package is essential for aperture photometry. It allows users to fine-tune parameters related to estimating and subtracting the sky background. Two key parameters to focus on are annulus and dannulus. **Annulus** sets the size of the outer annulus used to estimate the sky background, while **dannulus** specifies the width of the annulus. These parameters play a crucial role in accurately measuring the sky background, which is vital for precise photometry results. It's important to adjust these parameters based on the characteristics of the image and the objects being analysed. By optimizing fitskypars

settings, users can improve the accuracy and reliability of their aperture photometry measurements.

PACKAGE = daophot
TASK = fitskypars
(salgori= mode) Sky fitting algorithm
(annulus= 10.) Inner radius of sky annulus in scale units
(dannulu= 10.) Width of sky annulus in scale units
(skyvalu= 0.) User sky value
(smaxite= 10.) Maximum number of sky fitting iterations
(sloclip= 0.) Lower clipping factor in percent
(shiclip= 0.) Upper clipping factor in percent
(snrejec= 50) Maximum number of sky fitting rejection interaction
(sloreje= 3.)Lower K-sigma rejection limit in sky sigma
(shireje= 3.)Upper K-sigma rejection limit in sky sigma
(khist= 3.) Half width of histogram in sky sigma
(binsize= 0.1) Binsize of histogram in sky sigma
(smooth = no) Boxcar smooth the histogram
(grow = 0.)Region growing radius in scale units
(mksky = no) Mark sky annuli on the display
(mode= ql)
: go

The annulus, positioned outside the aperture, plays a critical role in isolating background counts from those of the source. Typically, a value around 5 times the Full-Width Half-Maximum (FWHM) is chosen to ensure an adequate separation. The width of this sky annulus, denoted as "dannulus," is commonly set to approximately 2 times the FWHM. While other parameters are often left at default values, adjusting these key parameters optimizes the accuracy of subsequent photometric measurements. Once all settings are adjusted according to the user's preferences, saving the changes and exiting the interface by pressing "Ctrl + D" ensures that the configurations are saved for future analysis.

4. photpars: The photpars parameter set manages the settings for the aperture photometry algorithm in the phot task. For DAOPHOT users, the main focus should be on one parameter: apertures, which determines the radius of the aperture used for calculating initial magnitudes. The aperture radii is set as [a value greater than the fwhm : a value below the annulus value : no of units after which we need the next aperture to appear]. Although measurements can be taken through multiple apertures, only the magnitude from the smallest aperture, along with zmag and exposure time, establishes the DAOPHOT instrumental magnitude scale. Magnitudes from other apertures don't contribute until accurate aperture corrections are computed later.

PACKAGE = daophot
TASK= photpars
(weight=   constant) Photometric weighting scheme
(apertur=   8:36:4)List of aperture radii in scale units
(zmag=   25.) Zero point of magnitude scale
(mkapert=   no.) Draw apertures on the display
(mode=   q1)
: go

• Pstselect task

The PSF model fitting needs a bunch of bright stars that are all by themselves and spread out across the picture. These stars are used as templates for the PSF model. To pick the right stars, we use the pstselect tool. It looks through the photometry file and chooses the best stars to use for making the PSF model. The critical pstselect algorithm parameters are psfrad, fitrad, datamin, and datamax. Psfrad and fitrad are used by pstselect to eliminate potential psf stars which have bright neighbours. The datamin and datamax settings help filter out PSF stars with bad data within a certain range of pixels. If we set datamin and datamax correctly before running the phot task, we don't need these settings anymore. This is because stars with bad data inside the photometry aperture will automatically have INDEF magnitudes. Now we type:

- **epar pstselect**

PACKAGE = daophot
TASK = pstselect
image =   Image for which to build psf star list
photfile=   default Photometry file (default: image.mag.?)
pstfile=   default Output psf star list file (default: image.pst.?)
maxnpsf=   25 Maximum nunber of psf stars
(mkstars=   no) Mark deleted and accepted psf stars
(plotfil=   )Output plot metacode file
(datapar=   )Data dependent parameters
(daopars=   )Psf fitting parameters
(interac=   no) Select psf stars interactively?
(plottyp=   mesh) Default plot type (mesh—contour—radial)
icomman =   )Image cursor: [x y wcs] key [cmd]
(gcomman=   ) Graphics cursor: [x y wcs] key [cmd]
(wcsin =   ) .wcsin) The input coordinate system (logical,tv,physical)
(wcsout=   ) .wcsout) The output coordinate system (logical,tv,physical)
(cache=   no) .cache) Cache the input image pixels in memory?
(verify =   yes) .verify) Verify critical pstselect parameters?
(update =   yes) .update) Update critical pstselect parameters?
(verbose =   ) .verbose)Print pstselect messages?

```
(graphic =            ) .graphics)Graphics device
(display=             ) .display)Image display device
(mode =          ql)
:go
```

- **Finding parameters: datapars, daopars**

1. **datapars** is defined in the previous task
2. **daopars:** In PSF modelling, the DAOPARS settings play a crucial role in determining the accuracy of the model. DAOPARS contains parameters that control various aspects of the PSF fitting process. One important parameter to focus on is the "function" parameter, which determines the mathematical function used to represent the PSF. Another key parameter is "fitrad," which sets the radius around each star used for fitting the PSF model. Additionally, "recentre" specifies whether to recentre stars during the PSF fitting process. By adjusting these parameters appropriately, users can optimize the PSF modelling procedure for their specific dataset. It's important to carefully tune these settings to achieve the best possible PSF model, which in turn leads to more accurate photometry results.

PACKAGE = daophot
TASK = daopars

```
(functio=   gauss) Form of analytic component of psf model
(varorde=        2) Order of empirical component of psf model
(nclean=         0) Number of cleaning iterations for computing psf
(saturat=       no) Use wings of saturated stars in psf model comput
(matchra=       3.) 0bject matching radius in scale units
(psfrad=       11.) Radius of psf model in scale units
(fitrad =       3.) Fitting radius in scale units
(recente=      yes) Recenter stars during fit?
(fitsky =       no) Recompute group sky value during fit?
(groupsk=      yes) Use group rather than individual sky values?
(sannuly=       0.) Inner radius of sky fitting annulus in scale uni
(wsannul=      11.) width of sky fitting annulus in scale units
(flaterr=     0.75) Flat field error in percent
(proferr=       5.) Profile error in percent
(maxiter=       50) Maximum number of fitting iterations
(clipexP=        6) Bad data clipping exponent
(lipran=       2.5) Bad data clipping range in sigma
(mergera=    INDEF) Critical object merging radius in scale units
(critsnr=       1.) Critical S/Ň ratio For group membership
(maxnsta=    10000) Maximum number of stars to fit
(naxgrou=       60) Maximum number of stars to fit Per group
(mode =         ql)
```

:go

In our analytical method, we've used various math functions, notably including the Gauss function with a second-order part. Important parameters like psfradius, set to four times the Full Width at Half Maximum (FWHM), and fitradius, equal to FWHM, are crucial for shaping our analysis. Once these settings are adjusted, saving and exiting the interface is as easy as pressing "ctrl+d". Returning to the IRAF console, we access the "pstselect" task by typing 'epar pstselect', allowing us to fine-tune datapars and daopars settings before running the task with ': go'. If the PSF model struggles with selecting GOTO parameters, we quickly locate the task and adjust the values, ensuring the reliability and precision of our analysis. After completing the phot task we obtain .mag file inside the respective directory.

STEP-3
Point Spread Function model:psf task

The DAOPHOT package, part of the IRAF system, is a specialized tool designed for creating point spread function (PSF) models. Its main task, "psf," carefully builds these models by fitting the profiles of identified stars. It handles the complex effects caused by optical distortions and atmospheric changes, ensuring an accurate representation. These PSF models are crucial for precise photometry, providing essential references for deconvolution algorithms and aiding in accurately measuring the flux from celestial objects. The psf task calculates the PSF model, which is utilized by peak, nstar, and allstar tasks for PSF fitting photometry. It's also used by the group task to estimate magnitudes for stars with undefined initial magnitudes, and by addstar and substar tasks to add or remove stars from an image. Now we type:

- **epar psf**

PACKAGE = daophot
TASK = psf
image Input image(s) for which to build PSF
photfile= default Input photometry file(s) (default: image.mag.?)
pstfile= Input psf star list(s) (default: image.pst.?)
psfimage= default) Output PSF image(s) (default: image.psf.?)
opstfile= default Output PSF star list(s) (default: image.pst.?)
groupfil= default Output PSF star group file(s) (default: image.psf.?)
(plotfil=)Output plot metacode file
(datapar=)Data dependent parameters
(daopars=)Psf fitting Parameters
(matchby= yes) Match psf star list to photonetry file(s) by id

(interac= yes) Compute the psf interactively?
(mkstars= no) Mark deleted and accepted psf stars?
(showplo= yes) Show plots of PSF stars?
(plottyp= mesh) Default Plot type (mesh—contour—radial)
icomman=) Image cursor: [x y wcs] key [cmd]
gcomman= Graphics cursor: [x y wcs] key [cmd]
(wcsin=) .wcsin) The input coordinate system (logical,tv,physical)
(wcsout =) .wcsout) The output coordinate system (logical,tv,physical)
(cache = no) .cache) Cache the input image Pixels in memory?
(verify = yes) .verify) Verify critical Psf parameters?
(update = yes) .update) Update critical psf parameters?
(verbose=) .verbose) Print psf messages?
(graphic=) .graphics) Graphics device
(display=) .display) Display device
: go
The input image refers to the calibrated image. (i.e the tbf file)

- **Allstar task**

The "allstar" tool in IRAF's DAOPHOT package improves the accuracy of photometry by fitting the point spread function (PSF) to all stars in an image together. It uses the PSF model created by the "psf" function and adjusts the photometric data step by step. This helps it handle problems like crowded and blended stars. By doing this, it makes the brightness measurements more reliable, giving astronomers accurate brightness and position information for stars in crowded parts of the sky. This makes it easier for astronomers to study these areas in detail. In short allstar groups, fits, and subtracts stars automatically from the image. It's better at handling crowded fields than nstar and replaces group, grpselect, nstar, and allstar tasks. Now we type:

- **epar allstar**

PACKAGE = daophot
TASK =allstar
image = Image corresponding to photometry
Photfile= default Input photometry file (default: image.mag.?)
psfimage= default PSF image (default: image.psf.?)
allstarf= default Output photometry file (default: image.als.?)
rejfile = default Output rejections file (default: image.arj.?)
subimage= default Subtracted image (default: image.sub.?)
(datapar= Data dependent parameters
(daopars= Psf fitting parameters

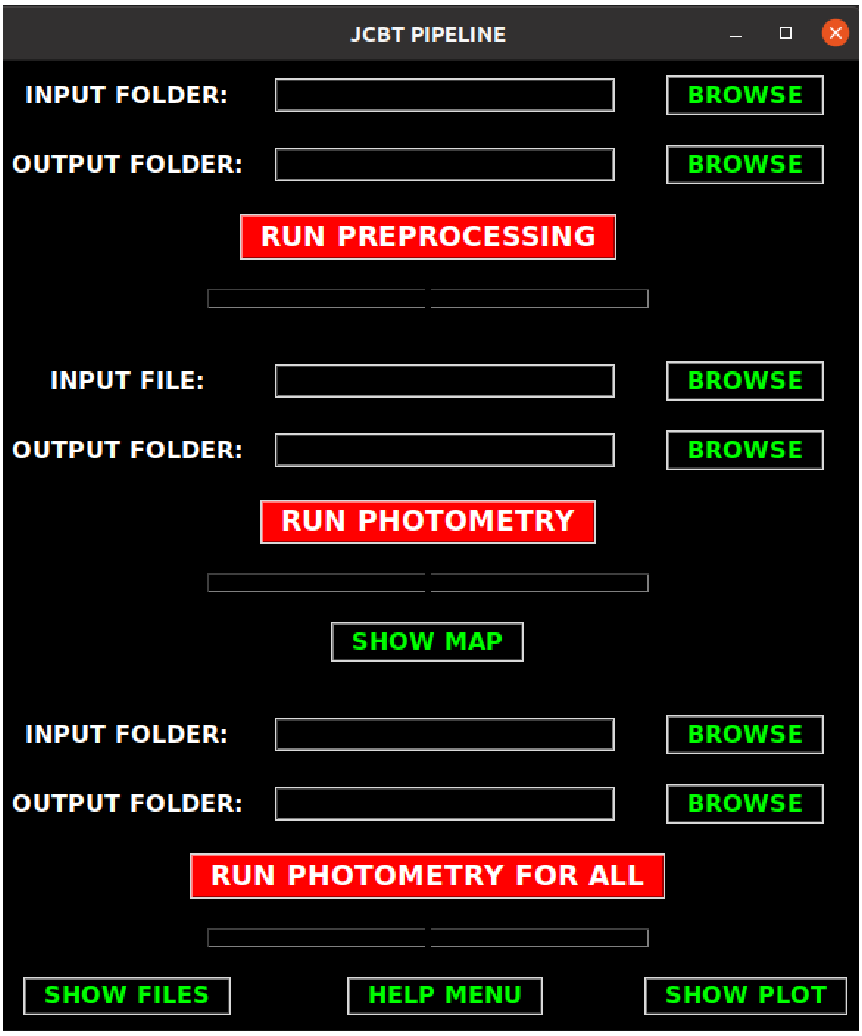
```
(wcsin =             ) .wcsin) The input coordinate system (logical,tv,physical)
(wcsout=             ) .wcsout) The output coordinate system (logical,tv,physical)
(wcspsf=             ) .wcspsf) The psf coordinate system (logical,tv,physical)
(cache            yes) Cache the data in memory?
(verify =            ) .verify) Verify critical allstar parameters?
(update =            ) .update) Update critical allstar parameters?
(verbose=            ) .verbose) Print allstar messages?
(version=           2) Version
(mode =             ql)
: go
```

After running the allstar task we obtain .als file and .arj files .Now go to the .als file which contain the ID, x, and y positions, and instrumental magnitude of the objects. In total we would obtain 7 files in formats such as .coo,.mag,.pst1,pst2,.psg1,.psf,.als,.arj for a particular calibrated frame. Each of these files a formed when we complete each steps in the photometry part. The .coo file which is formed after performing the daofind task contains the coordinates of the detected stars, the .mag file obtained after the phot task contains the measurements of magnitudes for the detected objects. The .psf file contains the point spread function which tells about the spread of light from the point source star ,information such as PSF model and size and shape of PSF which are relevant for further photometric analysis. The .als file contains the measured fluxes after performing the allstar ask ,it also has info regarding the background estimation ,aperture sizes etc. With these files in hand we have successfully transformed the raw brightness measurements from the images into calibrated magnitudes. The final result is a dataset of instrumental magnitudes that can be used for scientific analysis, such as studying variability of stars, determining object properties or exploring astronomical phenomena.

2.3. JCBT PIPELINE

The JCBT pipeline is a python code which is designed for automating the complete photometric data reduction of raw frames obtained from the 1.3 m JCB Telescope at Vainu Bappu Observatory at Kavalur. The code is written in such a way the it includes the preprocessing part and the photometry part that are discussed in the classical method. We are limited to do reduction on individual frames using the classical method. But with pipeline we can perform photometry for all frames collectively. Also, there is option for performing it individually. The preprocessing is also done collectively. Thus the pipeline saves a lot of time than the manual method. The pipeline interface is divided into three parts:

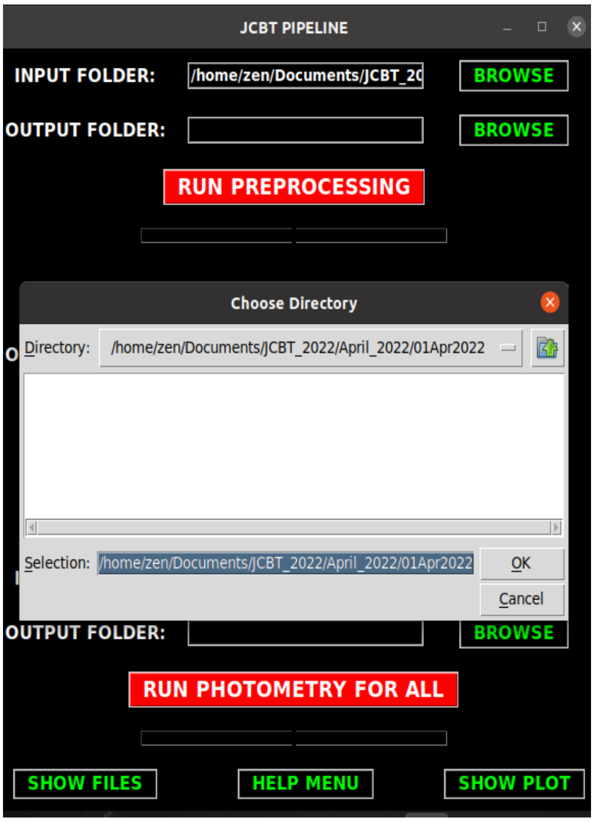
- Preprocessing part
- Photometry for individual frames
- Photometry for all frames



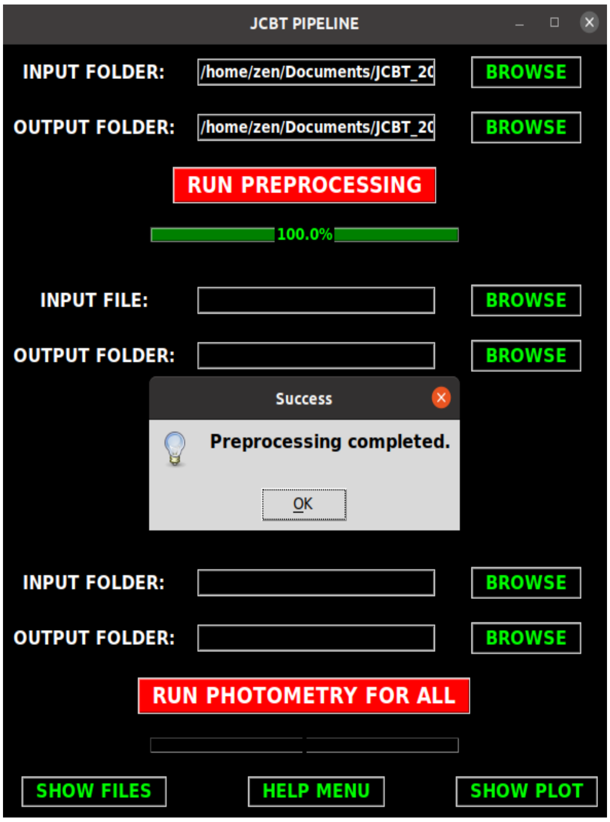
JCBT PIPELINE INTERFACE

SCREENSHOT-8

The pipeline can be easily opened by typing 'pipeline.py' in the terminal as the directory of the code is added to the system's PATH. Thus the pipeline provides detailed progress updates in the terminal, displaying each step and action as they occur . The **preprocessing part** contains two fields, input folder and output folder. We have to specify the directory containing the raw frames for the input field as well as the directory to which the output files must be generated . We can do this simply by clicking the the browse button. By clicking the run preprocessing button the image processing happens .This includes the bias correction ,flatfielding etc which are described in the preprocessing part .The progress of the preprocessing is indicated by a bar below the run preprocessing button .After the preprocessing is completed ,a dialog box appears showing that the process is completed .If it encounters any error the code terminates the process and shows the error in the dialog box .If the process is completed successfully the calibrated file i.e the .tbf file will created in the output directory.

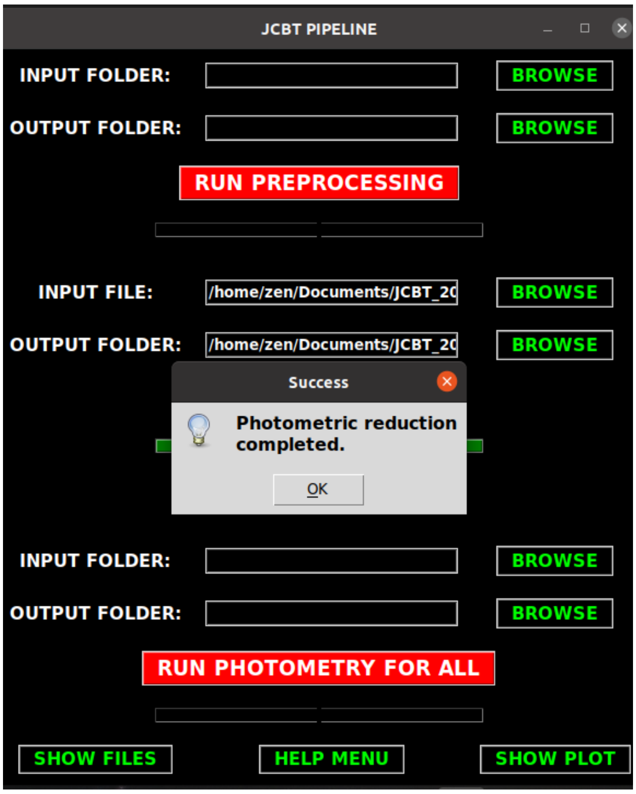


Choosing Directory for the input and output fields

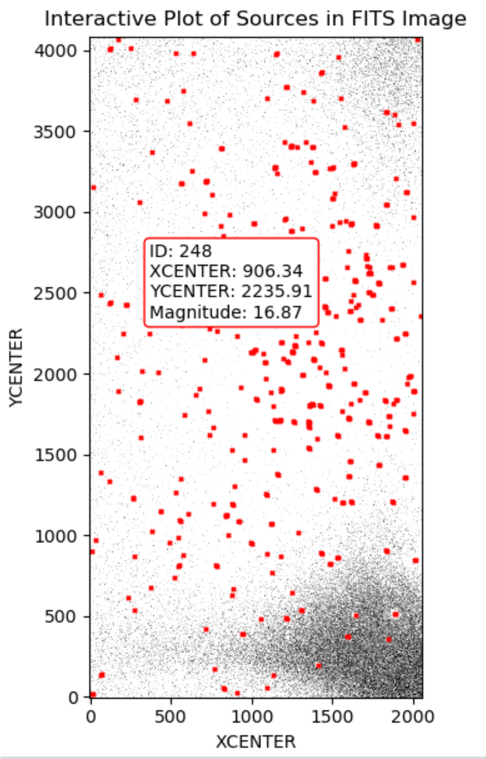


Preprocessing

Now we have two options for doing photometry ,for individual frames and for all frames. The second section in the pipeline interface is the photometry for individual frames here in the input field we select the particular calibrated frame of our interest and also the output file directory is also provided. On running the photometry ,the photometric processes such as the source detection, Aperture photometry and PSF photometry is executed in the IRAF in background. The progress updates are shown in the terminal. If any error occurs it will be shown in the terminal same as in the case of preprocessing. After photometry is done, it would generate the photometry output files such as the .coo file (Source Detection),.mag file (Aperture Photometry), and the files after the PSF photometry (.als,.arj,.psf,.pst) files . A log file is generated which would list each steps happening while running photometry. The pipeline also generates a median fwhm file where the median of fwhm of the sources is recorded. There is a 'show map' button which when clicked , generates a graphical representation of the photometry for each frame. This includes all sources along with their coordinates and magnitudes.

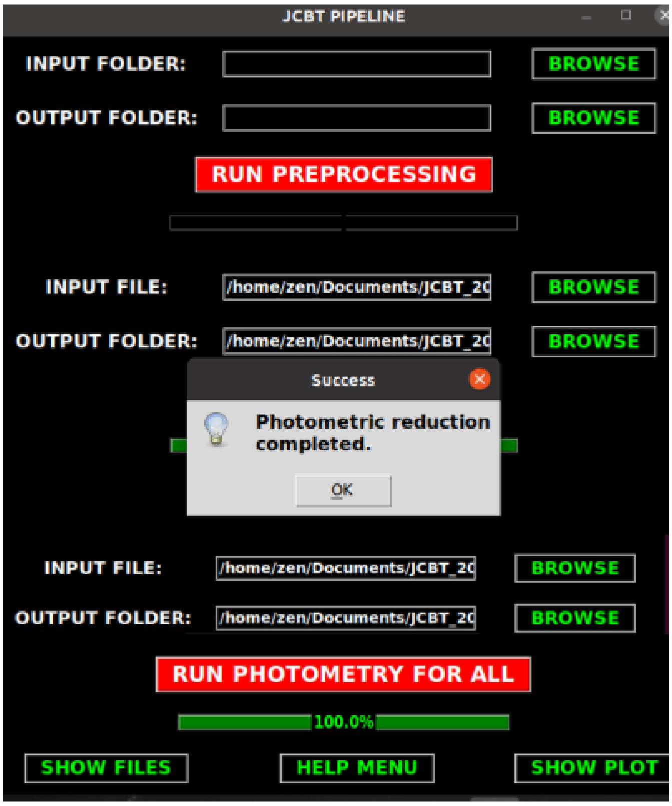


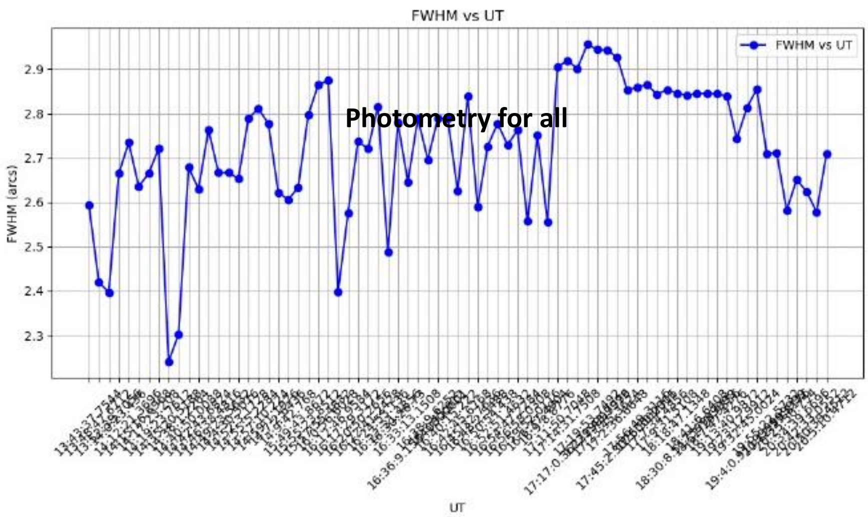
Photometry Completed



The Interactive plot that is generated on clicking 'show map'

The third section is the photometry for all. In this section we provide the directory to the calibrated frames. Running photometry would execute photometric processes for all tbf files in the directory. Each frames undergoes photometry and results are shown in the terminal. Here also a median fwhm file is created where the fwhm values of each frames are listed. The 'show files' button would direct the user to go into the output directory. The 'show plot' would generate a FWHM v/s UT graph for the particular day using the matplotlib python package. Here the code would analyse the median fwhm file and extract the fwhm values which is then used for plotting. This plot can be used for further analysis.





FWHM V/S UT Plot generated on clicking 'Show Plot'

CHAPTER-3
SUMMARY

3.1. OBSERVATIONS

Photometry can be considered a form of "low resolution" spectroscopy. Despite this, we can derive a wealth of information from reduced photometric data. This data allows us to understand a range of phenomena, from the atmospheric conditions of our planet to the study of exoplanets.

In the context of exoplanet detection, photometric reduction is essential for identifying the minute changes in a star's brightness caused by a transiting exoplanet. Through precise calibration and reduction, these tiny variations can be detected and analysed, providing valuable insights into the presence and characteristics of exoplanets.

UT vs FWHM plot

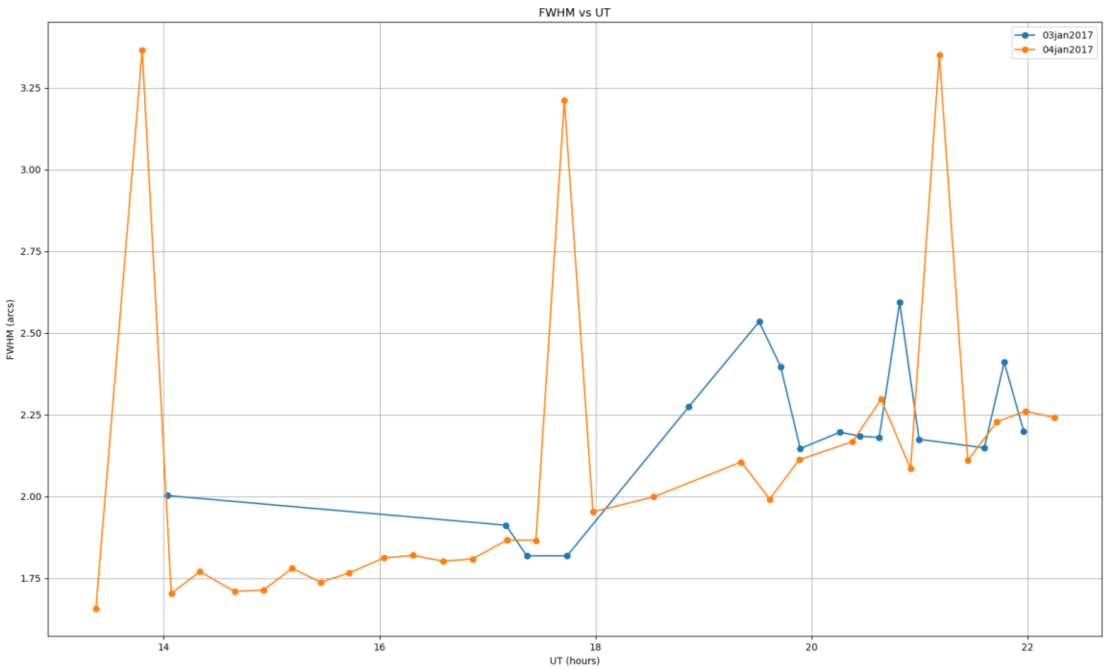
After the photometric reduction using the pipeline, the full width half maximum and observation time (UT) values are extracted from the median_fwhm txt file that is generated post reduction and the header list of various objects, using necessary python code. Using these fwhm and ut values of various months in which observations are made, various fwhm vs ut plots are made for corresponding months using appropriate python code. This can also be done using the 'show plot' option in the pipeline interface.
Several observations are made from these plots regarding the observations and atmospheric conditions of the sky, on a monthly basis.

FWHM: It is a measurement of a star's full width at half of its maximum amplitude value (intensity). Small fwhm value in the observation of a star means more observable good atmospheric condition and the sharper the visibility and the resolution of the star. Large fwhm value corresponds to less observable bad atmospheric condition in which the seeing of the star will be bad with less sharpness and resolution. The Y-axis of the plots indicates the fwhm values in arc seconds.

UNIVERSAL TIME (UT): It is the time standard used in astronomical observations and is based on earth's rotation. It is the same everywhere on the earth. Universal time of observation in hours is taken as X-axis.
The legend on the left side of each plot represents the dates and months on which the observations are made on.

These plots represent variation of fwhm values with observation time. Each date of the months on which are taken are indicated in the graph with different colours and marker distinctively. A peak in the plots represents a high value of fwhm in the corresponding universal time and decline represents low fwhm value. These indicates the quality of the observation taken and in turn an idea about the quality of the atmospheric condition.

JANUARY 2017



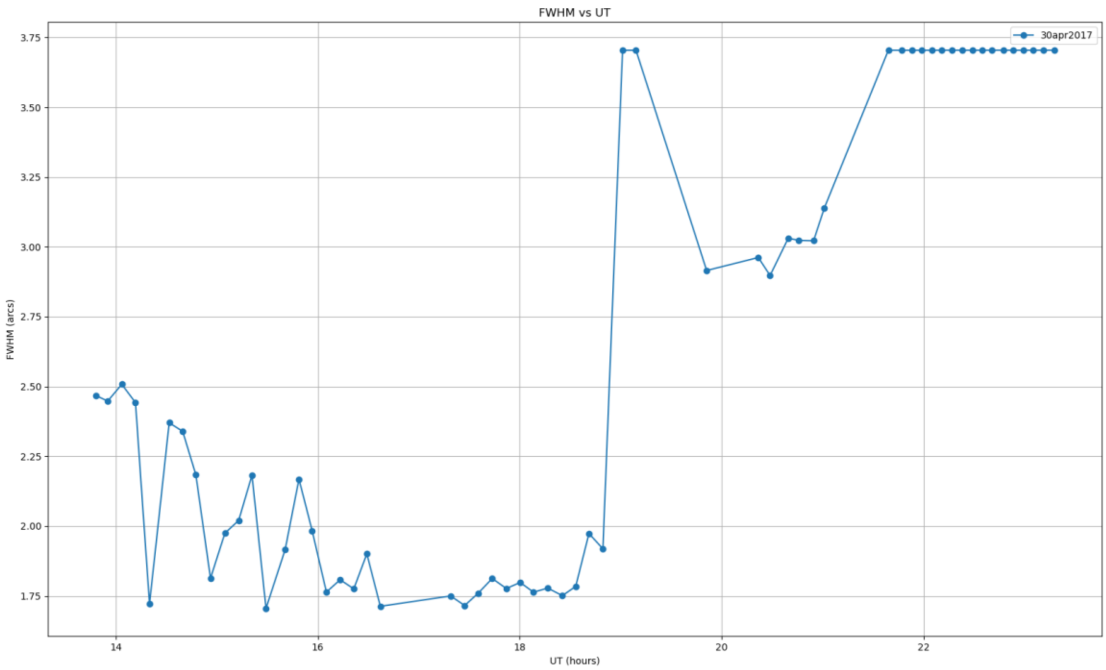
The plot of FWHM versus UT for January 3, 2017, and January 4, 2017, reveals insights into atmospheric conditions and sky seeing quality.

On January 3, the FWHM values are relatively stable, ranging between 1.75 and 2.75 arcseconds, indicating moderate and generally consistent atmospheric conditions, with occasional peaks suggesting brief periods of poorer seeing.

In contrast, January 4 shows highly variable FWHM values, with frequent sharp peaks reaching up to 3.25 arcseconds, signifying unstable atmospheric conditions and poorer overall seeing quality. This variability impacts the reliability of the observational data, making January 3 more suitable for high-precision studies like exoplanet transits.

Meanwhile, January 4's data, though less stable, can still be useful for studies requiring less precision. Robust photometric reduction and careful consideration of atmospheric effects are essential for both nights to ensure accurate scientific analysis.

APRIL 2017

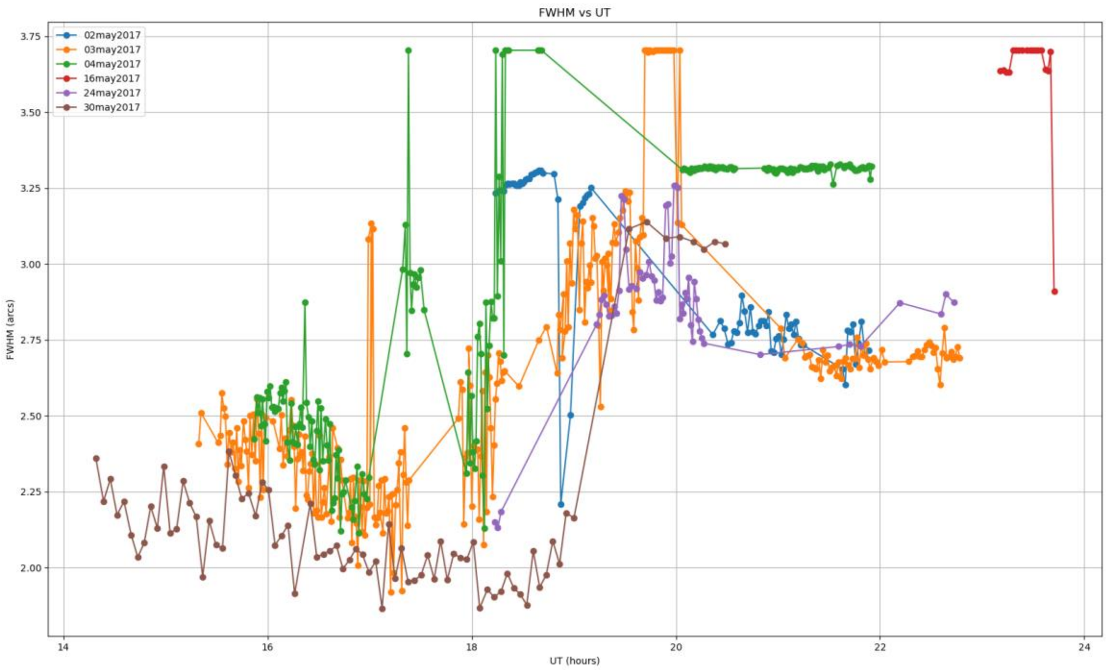


The plot of FWHM versus UT for April 30, 2017, shows significant variations in atmospheric conditions and sky seeing quality throughout the night. Initially, from 14:00 to 18:00 UT, the FWHM values range from approximately 1.75 to 2.50 arcseconds, indicating relatively stable and good seeing conditions with minor fluctuations. However, after 18:00 UT, the FWHM values begin to increase sharply, peaking at over 3.75 arcseconds around 21:00 UT and remaining high until the end of the observation period. This substantial increase in FWHM indicates a marked deterioration in atmospheric conditions, likely due to turbulence or other environmental factors that adversely affect seeing quality.

1. Early Stability: The stable FWHM values in the early hours suggest favourable conditions for high-precision observations, with minimal atmospheric distortion.
2. Deterioration: The sharp rise in FWHM values post-18:00 UT points to worsening atmospheric conditions, making this period less ideal for detailed photometric studies.
3. Impact on Data Quality: The high FWHM values towards the end of the observation period imply that data collected during this time may require more extensive reduction and correction to mitigate the effects of poor seeing.

Overall, the initial stable period offers a good opportunity for precise measurements, while the later part of the night is more challenging for accurate data collection due to degraded atmospheric conditions.

MAY 2017



Date-specific Analysis:

- 02 May 2017 (Brown Line): This date shows relatively stable and low FWHM values between 2.0 to 2.5 arcseconds, indicating good seeing conditions for most of the observation period.
- 03 May 2017 (Blue Line): This date shows significant fluctuations, with FWHM values ranging from around 2.0 to 3.5 arcseconds, suggesting highly variable seeing conditions.
- 04 May 2017 (Green Line): The FWHM values fluctuate widely from 2.5 to over 3.5 arcseconds, indicating poor and unstable atmospheric conditions.
- 16 May 2017 (Red Line): Initially stable with FWHM around 2.5 arcseconds, there is a sharp increase to above 3.5 arcseconds later in the observation period, indicating a deterioration in seeing quality.
- 24 May 2017 (Orange Line): This date shows a mix of conditions, with FWHM values ranging from 2.25 to 3.5 arcseconds, indicating variable atmospheric conditions.
- 30 May 2017 (Purple Line): The FWHM values stay within a narrow range of around 2.5 to 3.0 arcseconds, suggesting relatively stable but average seeing conditions.

Stability vs. Variability: Dates like 02 May and 30 May show more stable conditions, which are preferable for precise astronomical observations, whereas dates like 03 May and 04 May show high variability, making them less ideal.

In summary, May 2017 presented a mix of atmospheric conditions, with some nights offering good seeing quality and others showing significant variability.

3.2. CONCLUSION

The introduction of the JCBT pipeline to the field of astronomy has revolutionized the data reduction process, making observations faster and more enjoyable. Although still in its developmental stage, the pipeline already produces data that rivals the quality obtained through traditional methods, demonstrating its potential superiority. Once fully developed, this software will significantly simplify the complex and time-consuming data reduction process, allowing scientists to focus more on analysis and observation.

The reduction process includes source detection, aperture photometry, and the creation of PSF models, ultimately determining the instrumental magnitudes for the observed stellar sources. By employing both manual methods and the automated pipeline, I transformed raw data into valuable, high-quality photometric data. The instrumental magnitudes derived from this process can be converted into apparent magnitudes, facilitating further scientific studies. The reduced data is crucial for a wide range of analyses, including investigating atmospheric characteristics, variations in light profiles of celestial sources, and other astrophysical phenomena.

During my two-month internship at the Vainu Bappu Observatory, I reduced astronomical data from 2017 and 2023 using the JCBT pipeline. This period was filled with challenges, including numerous errors when converting raw image frames to ".als" text files. We diligently reported these issues and contributed to the addition of extra narrowband and broadband filters to the pipeline.

This hands-on experience not only enhanced my technical skills but also underscored the collaborative nature of scientific advancement. The knowledge and insights gained during this internship will undoubtedly contribute to my future endeavors in astronomical research, allowing me to be part of the ongoing evolution in data reduction techniques.

REFERENCES

1. **HANDBOOK OF CCD ASTRONOMY,** SECOND EDITION BY STEVE B HOWELL, NATIONAL OPTICAL ASTRONOMY OBSERVATYORY AND WIYN OBSERVATORY.
2. **A USER'S GUIDE TO STELLAR CCD PHOTOMETRY WITH IRAF** BY PHILIP MASSEY, LINDEY E DAVIS, NOAO
3. **A REFERENCE GUIDE TO IRAF /DAOPHOT PACKAGE** BY LINDSEY E DAVIS
4. **IRAF MANUAL** BY THIJS COENEN
5. **THE HANDBOOK OF ASTRONOMICAL IMAGE PROCESSING,** SECOND EDITION BY RICHARD BERRY, JAMES BURNELL
6. **AN INTRODUCTION TO ASTRONOMICAL PHOTOMETRY USING CCDS**, BY W ROMANISHIN, UNIVERSITY OF OKHALOMA
7. https://www.teledynedalsa.com/en/learn/knowledge-center/ccd-vs-cmos/
8. https://cosmicvarta.in/vainu_bappu_telescope_town_gourav
9. https://sites.google.com/cfa.harvard.edu/saoimageds9
10. https://www.iiap.res.in/