TNU/SAGI Sumer School in Observational Astronomy 2024

# DATA REDUCTION

TUE NGUYEN-VAN
Quy Nhon Observatory, ExploraScience Quy Nhon

NGUYEN DUC NGUYEN
University of Science and Technology of Hanoi (USTH)

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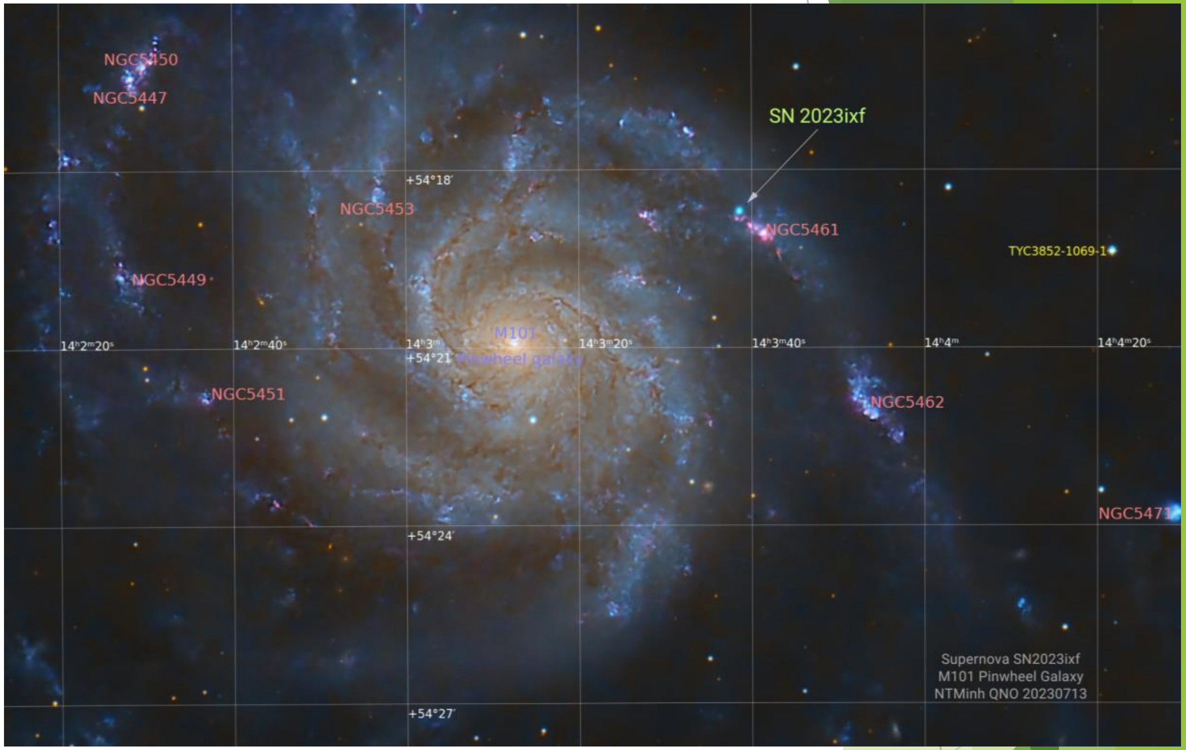
# (1) Introduction

We often want to record an image in a part of the sky
- Discovery (what might be there – an exoplanet/a new supernova?)
- Photometry (measurement of an object's brightness)
- Astrometry (measurement of an object's position/motion)
- … or sometime just to capture a pretty picture.



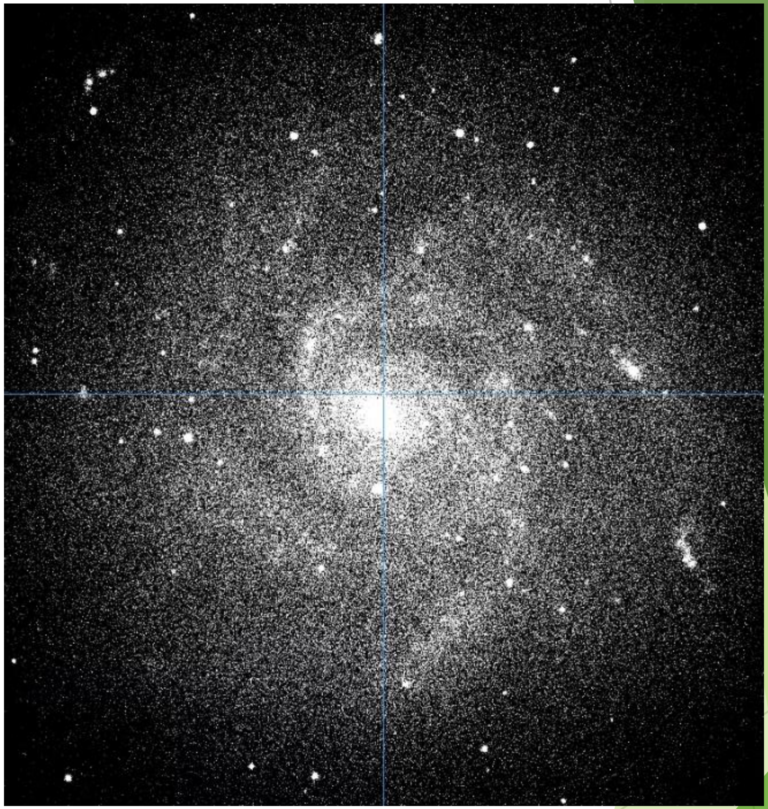

***Messier 101 & Supernova SN2023ixf.***
*From: Quy Nhon Observatory*

# (1) Introduction

A **detector** is placed inside an **instrument** (CCD) behind a telescope; it records a raw image to a computer.

But there are imperfections….

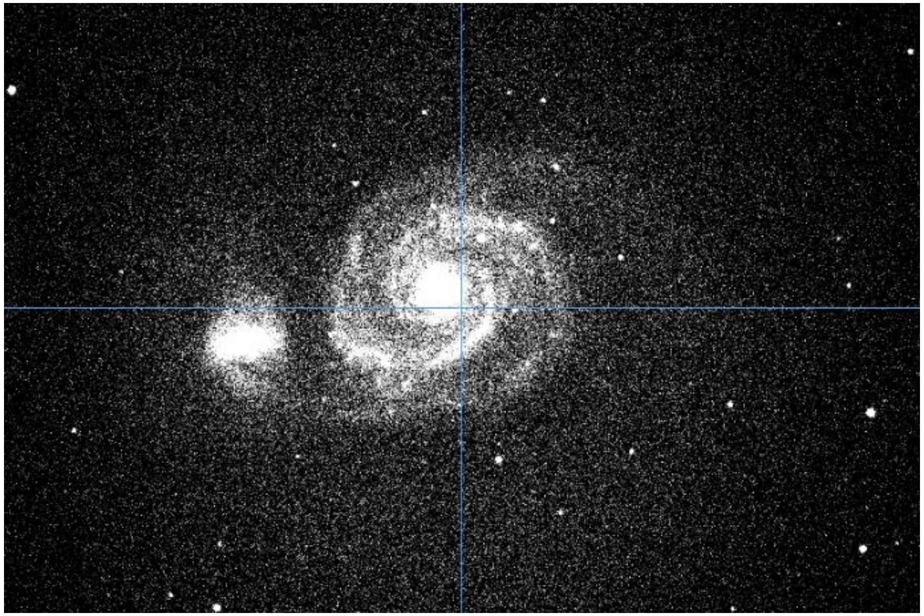
- Raw images are dominated by sky background and instrumental noises/effects.
- Besides, there are a number of issues that affect the sensitivity of the CCD to the light, some of which can be corrected for (vignetting, dust, hot pixels) and some of which cannot (dead pixels)



*Messier 101 (Raw Image)*

# (1) Introduction

From this…….



…..to this


From the original raw image with a lot of noise to the processed image with much less noise and clarity. **How do we get it?**

For example, to measure the photometry of a star, we often use a reference star already in the catalogs. However, a raw image will have a lot of noise/effects, which makes the measurement results no longer accurate, so it won't be easy to use in scientific research.

→ We need "**data reduction**"

# (1) Introduction

## What is the data reduction??

Data reduction techniques seek to reduce effects and noises found in raw data to turn them into usable data for scientific research.

## How to reduce data??

→ In optics, to reduce data we need to calibrate and combine the data.

# (2) Image calibration

- Image calibration is essential for producing high fidelity images by correcting for defects in the camera sensor and optical system. Each sensor has different bias levels, from dark current sensitivity to temperature, and sensitivity to light, all of which can corrupt the intensity expressed in each pixel of the image in a specific way.

- Calibration helps improve the signal-to-noise ratio (SNR).

- The three basic calibration steps are **bias**, **dark**, and **flat-field**.

# (2) Image calibration

*Bias Frame*

## Bias Frame

- Bias is an offset voltage (which translates into some non-zero number of counts) added to every pixel in the image to ensure that when voltages are converted to counts there is never a negative count.
- If bias is not corrected then flat-field calibration will not work correctly.

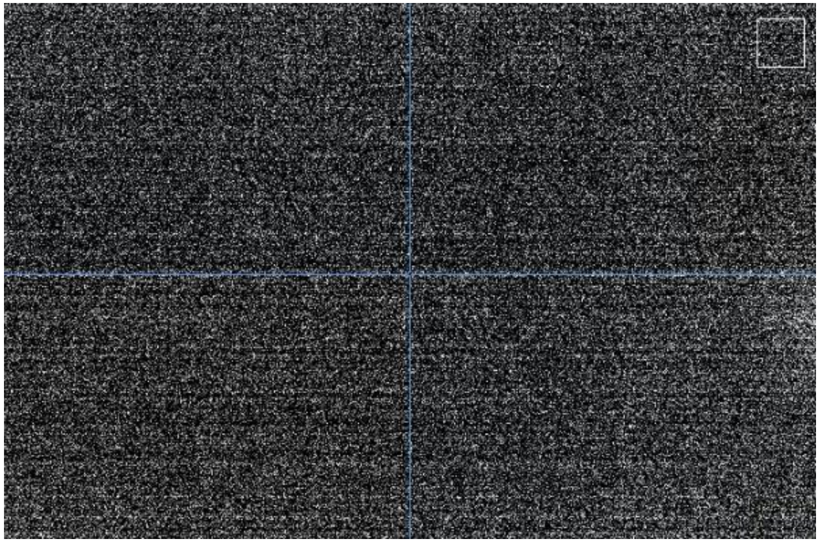
*Side note: The convenience about bias frames is that they can be reused on all images for many months, assuming that the bias for a particular camera remains generally constant over this period of time. Additionally, bias is also included in dark frames, meaning that it is technically possible to perform accurate calibration without using bias frames.

## How to create the Bias frame?

→ Obtain by reading out the CCD with a zero-second exposure. Essentially, a bias frame is a zero-length exposure, or as close to zero-length as possible, with the shutter closed.

→ Then, combine the individually calibrated bias images into a single image. The combined image will have less noise than the individual images, minimizing the noise added to the remaining images when the bias is subtracted.

# (2) Image calibration



*Dark Frame with exposure time 15s and temperature 0ºC*

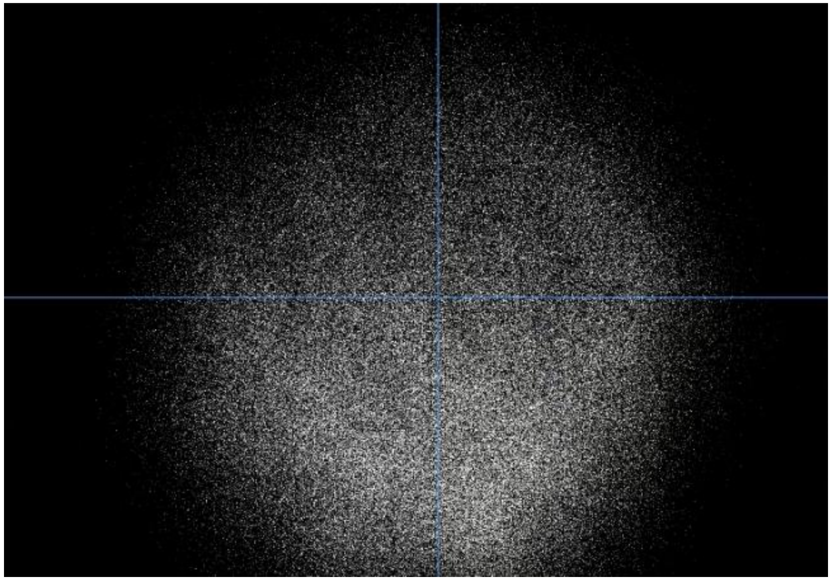
**Dark Frame**

- Dark current depends on the temperature of the sensor. It accumulates at different rates in every pixel.
- Present in every camera sensor which accumulates in the pixels during an exposure.
- A small fraction of pixels are "hot": their dark current is much larger than the rest of the pixels. The location and current of hot pixels is typically stable over long periods of time, which makes it straightforward to remove their effect from science images by subtracting them out.

**How to create the Dark frame?**

→ Exposures taken with the camera shutter closed (dark image), with the same exposure time and temperature as the science images.
→ Then, combine the individually calibrated dark frames into a single combined image.

# (2) Image calibration



*Flat-field Frame*

## Flat-field Frame

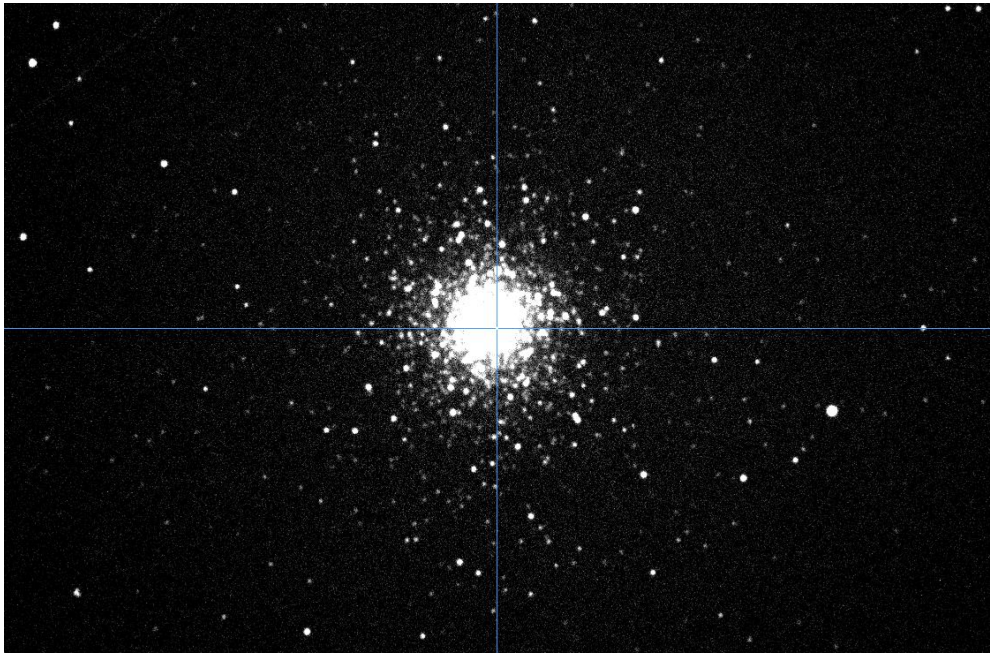
- Not all pixels in a camera have the same sensitivity to light: there are intrinsic differences from pixel-to-pixel. Vignetting, a dimming near the corners of an image caused by the optical system to which the camera is attached, and dust on optical elements such as filters, the glass window covering the CCD, and the CCD chip itself can also block some light.
- Vignetting and dust can reduce the amount of light reaching the CCD chip while pixel-to-pixel sensitivity variations affects the counts read from the chip.

## How to create the Flat-field frame?

→ Exposures of a uniformly illuminated source. (Type of flatfields: Dome, Twilight, Sky,…). Besides, to create a flat-field frame, the optical system is illuminated by a uniform light source and an exposure is taken.

→ Then, combine the individually calibrated flat-field frames into a single combined image.

# (2) Image calibration



*Messier 3 before calibration.*

## Raw Image

The most important image: carries the primary image information.

# (2) Image calibration

At a basic level, we get an expression for the data in a science image:

**Raw Image = Bias + Dark current + Flat * Objects**

→ Image Calibration:

**Objects + Noise = (Raw Image – Dark current – Bias) / Flat**

**Objects + Noise = (Raw Image – Dark current – Bias) / Flat**

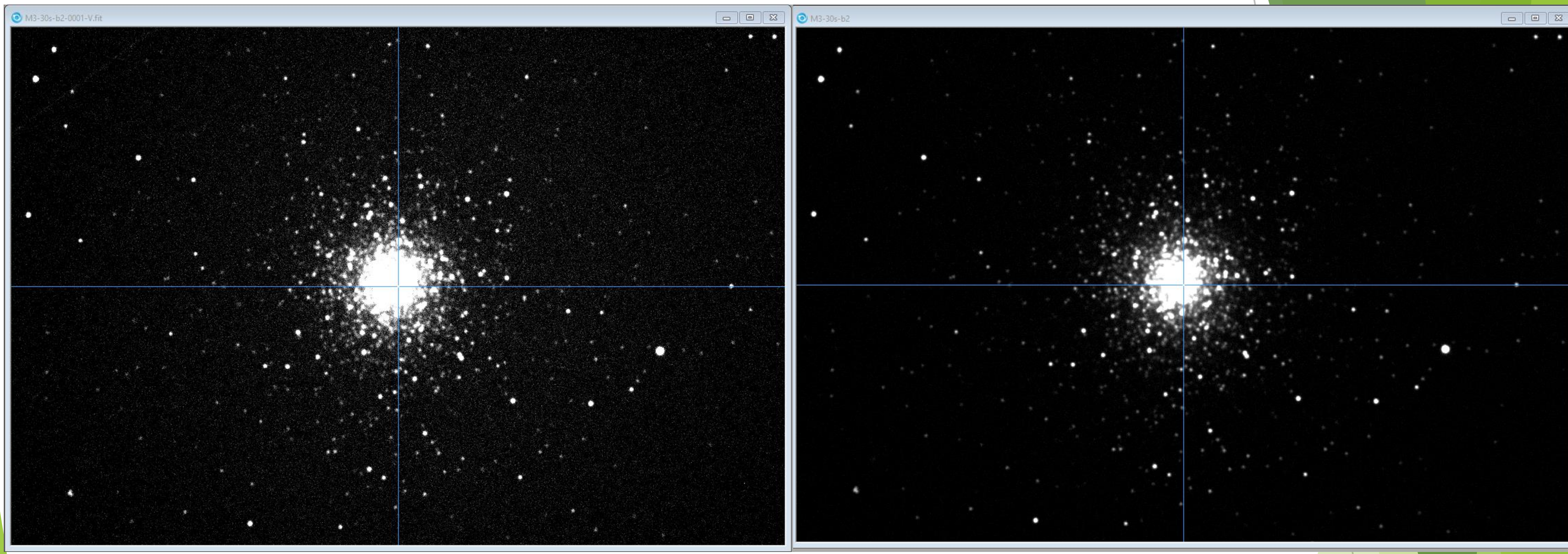
**It is impossible to remove the noise from the raw image because the noise is random.*

The dark current is typically calculated from a dark frame (aka dark image). Such an image has bias and read noise in it as well, so:

**Dark current + noise = (Dark frame – Bias) / Exposure time**

**Once again, note that the noise cannot be removed.*

# (2) Image calibration

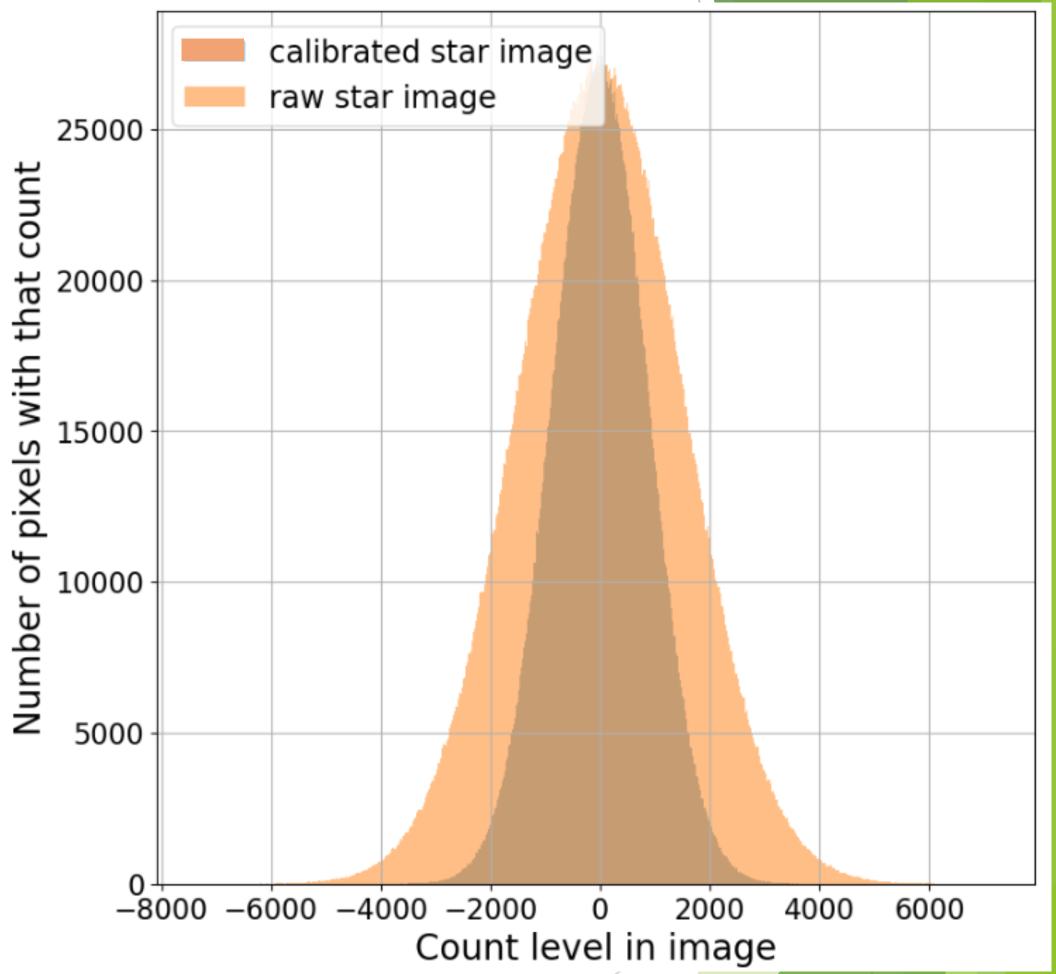



*Messier 3 before and after image calibration.*

The stars are more clearly than in the uncalibrated image.

# (2) Image calibration

For example, the histogram below shows pixel values before and after calibration.
The width of the distribution is a measure of the read noise.
Reducing the image increases the read noise. The reason to takes several calibration images of each type is to reduce the amount of noise in the final calibration image. That will, in turn, keep the noise in the final image as low as possible.



# (3) Image combination

**The final step in data reduction is combining averaging images**

Image combination serves several purposes. Combining images:

- Reduces noise in images
- Can remove transient artifacts like cosmic rays and satellite tracks

*Note: It’s essential that several of each type of calibration image (bias, dark, flat) should be taken. Combining them will reduces the noise in the final images by roughly a factor of $1/\sqrt{N}$, where *N* is the number of images being combined. Using only a single calibration image actually ***increases*** the noise.

# (4) Summary

To get high-fidelity and usable data for scientific research, we need data reduction.

Basic steps to reduce data.

1. Create a single combined image of each type (bias, dark, flat)
2. The image calibration with Bias, Dark, and Flat frames
3. Combine all calibrated frames into one final image.

# (5) Exercise

Let's data reduce the image using calibration and combine techniques. Then, find the magnitude of the object from the image with a reference star.
(Using MaxIm DL 6 software)

**Step 1**
Open all raw image.
The image calibration with bias, dark, and flat-field frames.

**Step 2**
Combine all calibrated images.

**Step 3**
Using tools on MaxIm DL 6 measure the magnitude of the object from the reference star.

# THANK YOU FOR LISTENING