Laboratory of Astronomy I

CCD Part

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Main Targets

- Learn how to use a telescope and a software for astronomical observation
- Perform astronomical observation
- Process acquired data

- Exercise 1:
  Building an Astronomical image
- Exercise 2:
  Building the Hertzsprung-Russel diagram

EXERCISE 1

Building an Astronomical Image

Courtesy of NASA: Astronomy Picture of the Day. Link: http://apod.nasa.gov/apod/ap160917.html

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Table of Contents: Exercise 1

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Table of Contents: Exercise 1

- **The instruments:**
  - The telescope used
  - Basic notions on CCD

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The Telescope: ZimLAT

- ZimLAT: Zimmerwald Laser and Astrometric Telescope.
- Characteristics:
  - Ritchey – Chretién
  - Diameter: 1m
  - Focal Length: ~1.2, 4, 4, 8 m
  - Field of View: ~26'x 26'
  - Mount: Alt-Azimuth
- CCD Camera:
  - 2064 x 2048 [15 µm]
  - Resolution: ~0.7"/Pixel
  - Back-Illuminated
  - Johnson-Cousins photometric system: B, V, R, I
- For CCD and SLR Observations

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Basic Notions 1 of 2

- Charge Coupled Device (CCD):
  - Constituted by semiconductor elements → pixels
  - Photons excite electrons within pixel
  - Read out of pixels and Signal Amplification
  - Digitalization of Signal by mean of Analog-Digital Converter (ADC)
  - Software interpretation of signal and image construction

Basic Notions 2 of 2

- There aren't perfect CCD cameras:
  - Different sensitivity of pixels
  - Dead and hot pixels
  - Different gain of different parts of chip

- Pixel sensitive to other sources of energy:
  - Cosmic rays
  - Thermal noise

⇒ Images Standard Reduction ⇒ Calibration Measurements

Table of Contents: Exercise 1

- **Calibration Measurements**
  - Bias
  - Dark
  - Flat Fields

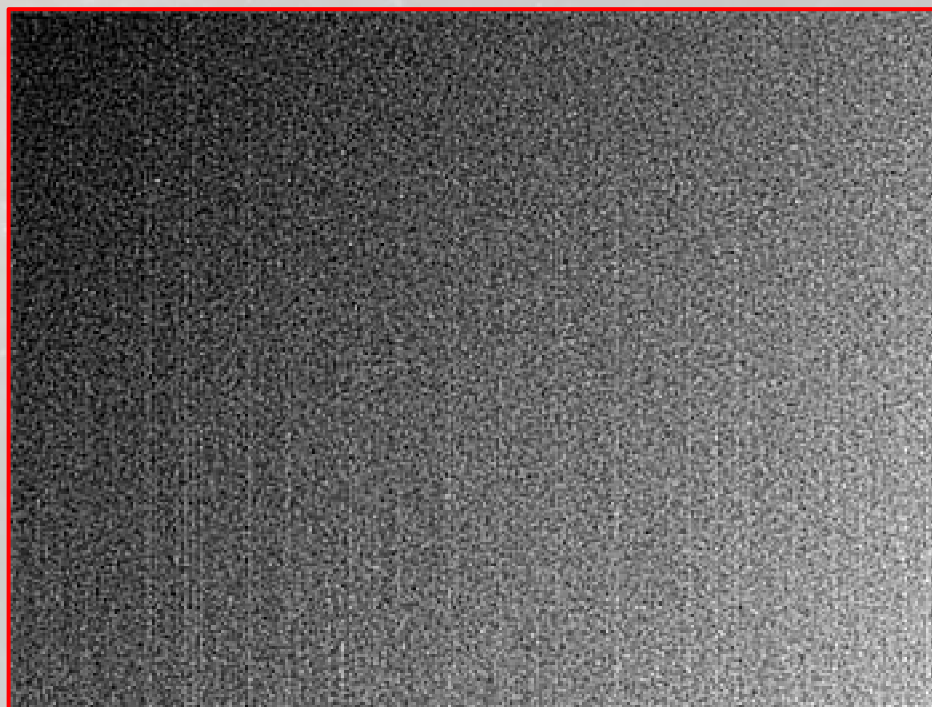
Calibration Measurements: Bias Frame

BIAS:

measure of the "No Signal" noise level of the detector.

- Is used to characterize the CCD camera's pixel-to-pixel variation in zero-point.
- Dark frames contain the same bias as a light frame, dark-subtracted images are already bias-subtracted.

- Bias frame can be used to scale a dark frame.
- A bias frame is, ideally, an exposure of zero length (the shortest possible exposure time, usually 0.01-0.1sec.).
- The camera should be at the same temperature as the dark/light frames.
- How many: more than 3 and combined with statistical methods.



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Calibration Measurements: Dark Frame

DARK FRAMES:

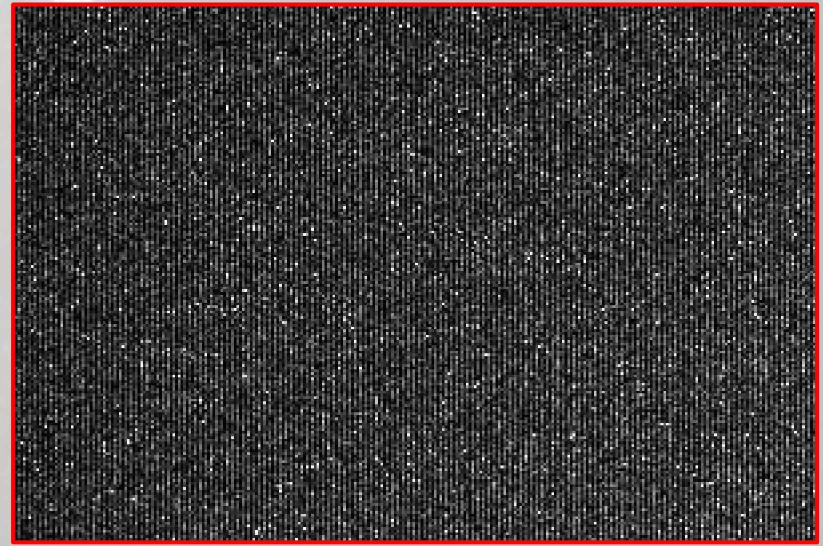
measures the thermal noise of the CCD-camera.

- The noise in a CCD image is dependent on the temperature of the camera.
- The thermal noise accumulated on the image is proportional to the exposure time.
- It works by taking a picture with shutter closed of the same exposure time as the light frame.
- Dark frame scaling.
- How many: “more is better”, more than 5 and combined with statistical methods.

The noise characteristics of a camera are dependent on:

- exposure time,
- temperature,
- binning.

Dark frames must be equivalent to the regular light frames in every respect.



Calibration Measurements: Flat Field

FLAT FIELDS:

is used to determine the variation in the pixel-to-pixel sensitivity.

Are used to remove image artefacts due to the optical systems as:

- Vignetting
- Obstructions
- Reflections
- Shadows from out of focus dust
- Gradient in the CCD-chip

To obtain them a homogeneous source of light is needed.

Take images with the 35-50% of the saturation value of the CCD.

Hot to acquire a FF:

- Flat Box
- Dome Flat
- Sky Flat

- How many: “more is better”, more than 10 and combined with statistical methods.

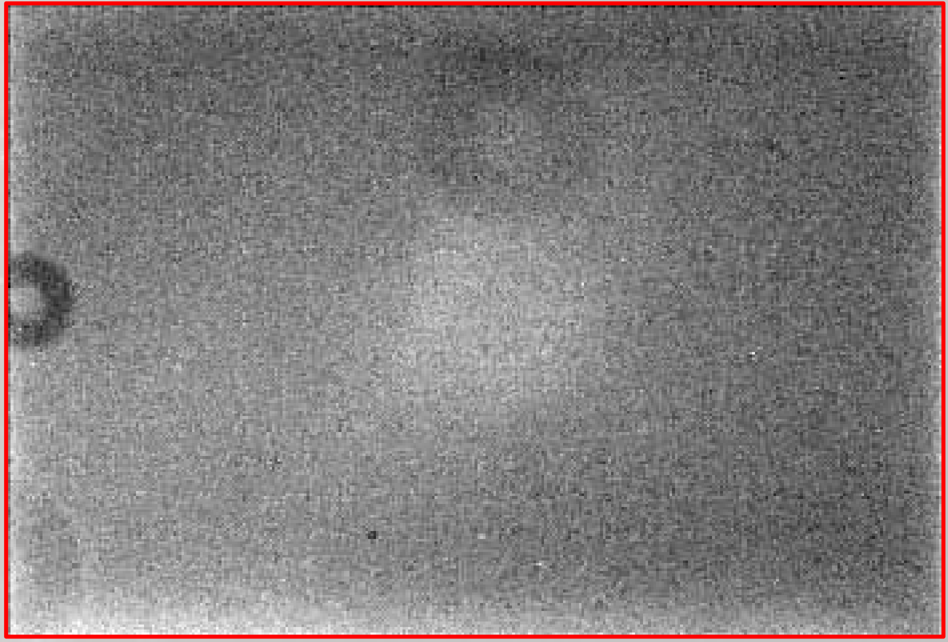


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Table of Contents: Exercise 1

- Object Selection
  - Object characteristics
  - Visibility Check

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Object Selection

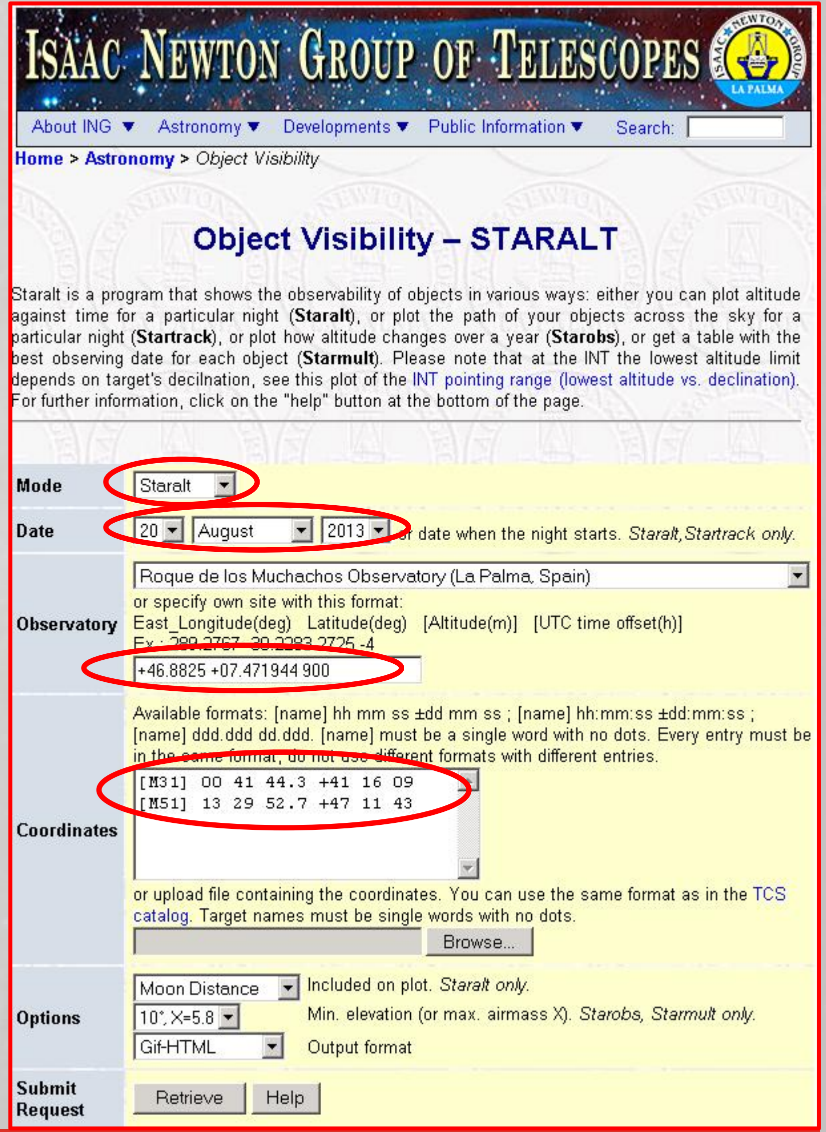
- Rotation of the Earth
- Mask angle of 20°
- ZimLAT Field Of View: 26’ x 26’
- Dimension and Magnitude of the object
- Distance from Moon

- DON’T CHOOSE ANY PLANET OR STAR!!!!!

- Advice: Use Messier catalogue but check with other ones: http://en.wikipedia.org/wiki/Category:Messier_objects

Visibility Condition 1 of 2

- Verify that the object will be visible from the observatory during the observation night.
- Use: http://catserver.ing.iac.es/staralt/index.php
- Zimmerwald coordinates: 46.8772° N, 7.4652° E, Height 951.2 m
- Pay attention to time format (UT)



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Visibility Condition 2 of 2

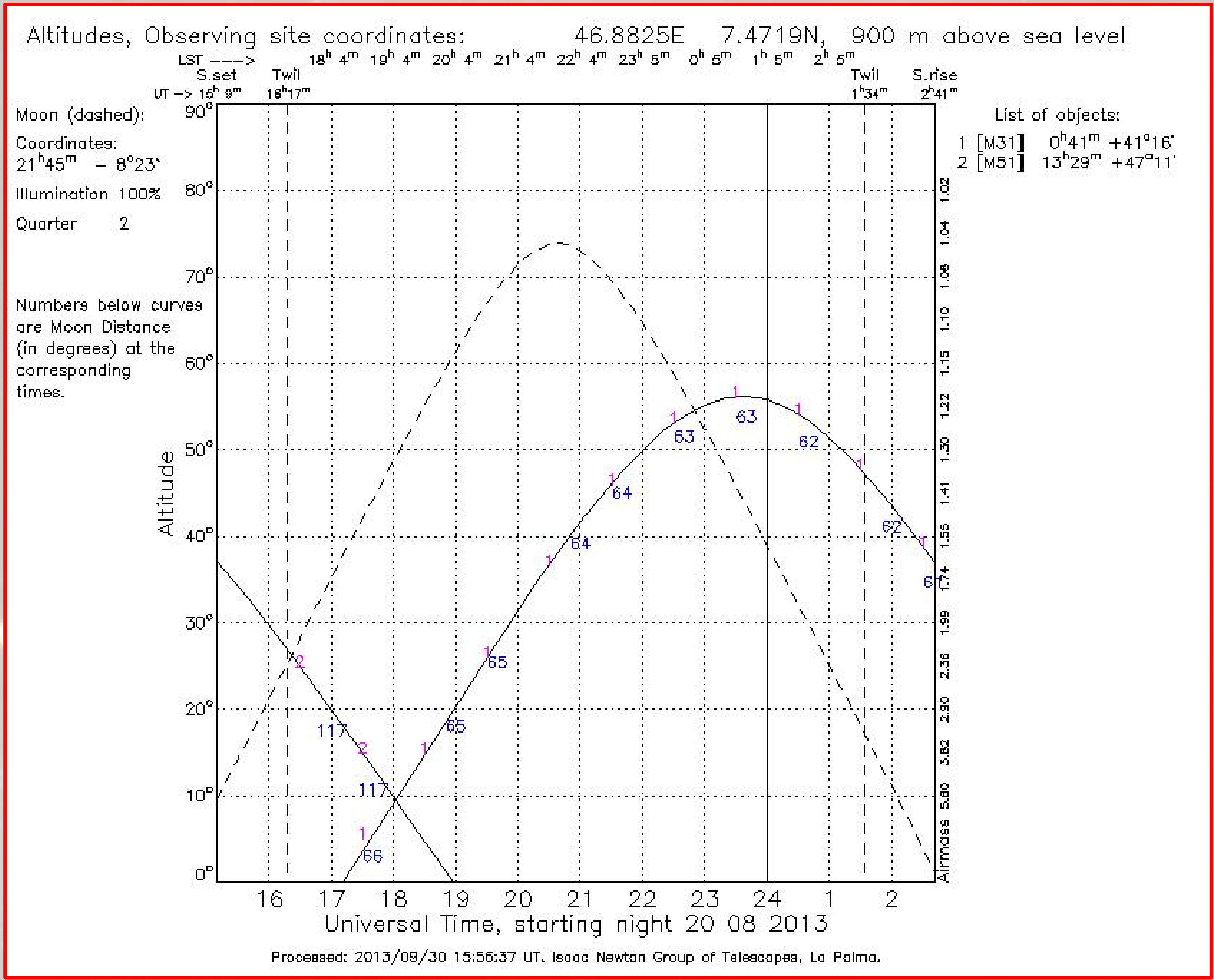

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Table of Contents: Exercise 1

- Data Acquisition
  - Number of exposures
  - Astrometric data reduction
  - Determination of the exposure time

Number of Exposures

How many exposures we need?

- 1 x Bias
- 1 x Dark
- 1 x [B–filter, V–filter, R–filter]
- 1 x without filter

Are these enough?

NO because of external error sources

Solution?

Statistical methods combining series of exposures

Master frames

- Several methods to average pixel values:
  - Arithmetic mean
  - Median

- Example pixel values: 13, 15, 16, 17, 92
  - Arithmetic mean = 30.6
  - Median = 16

- The outlier is neglected using the median method.

⇒ Value closer to reality.

Standard reduction

Image calibration using master frame

$$Cal = \frac{Raw - Bias_M - (Dark_M - Bias_M) \cdot \frac{T_R}{T_D}}{\left[Flat_M - Bias_M - (Dark_M - Bias_M) \cdot \frac{T_F}{T_D}\right]_{normalized}}$$

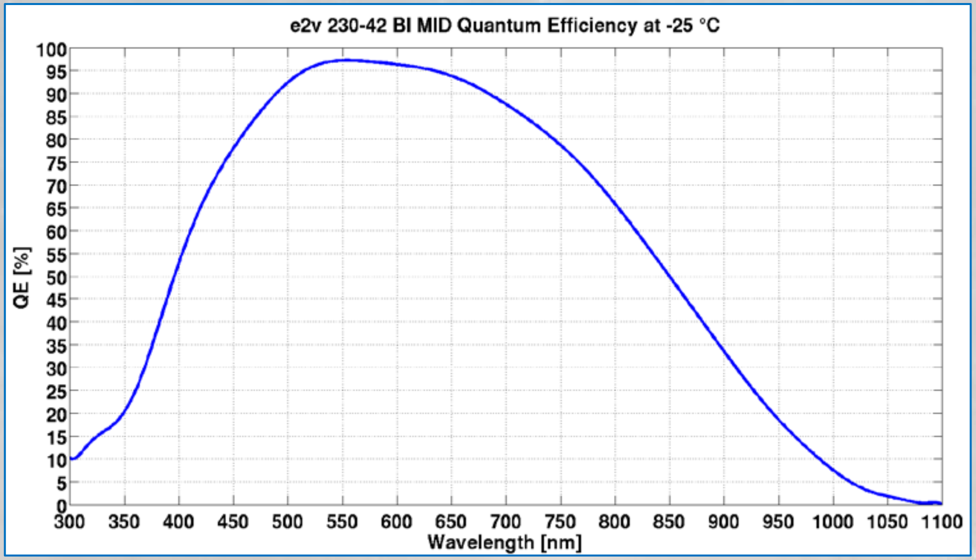
If flat field is not available

$$Cal = Raw - Bias_M - (Dark_M - Bias_M) \cdot \frac{T_R}{T_D}$$

Dark Current = $(Dark_M - Bias_M)$

Cal = calibrated value; *Raw* = raw value; *BiasM* = bias master value; *DarkM* = dark master value; *FlatM* = flat field master value; *TR* = exposure time of raw images; *TD* = exposure time of dark; *TF* = exposure time of flat field.

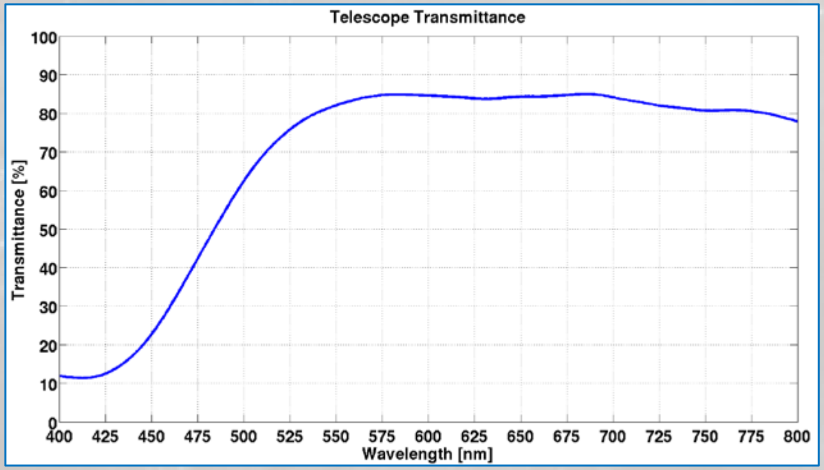
Observation: Exposure Time Determination

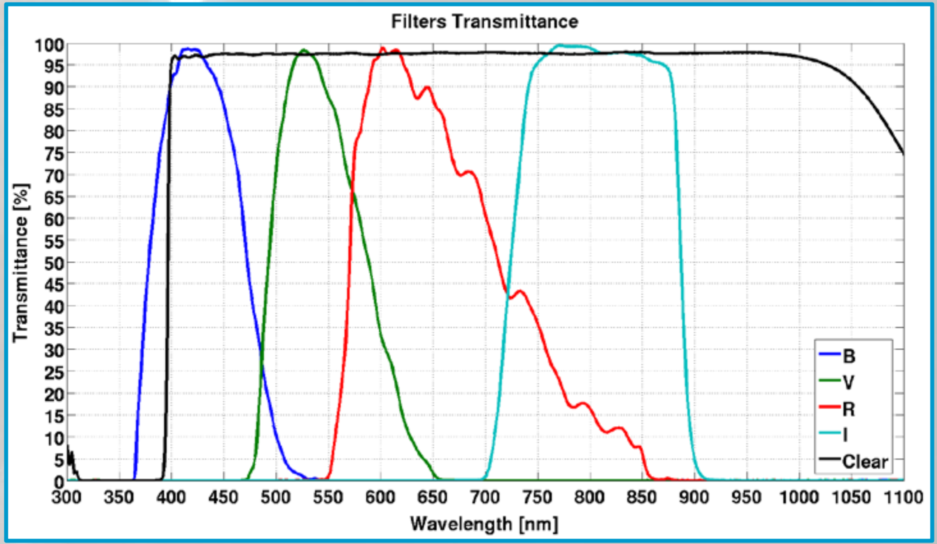


We want to have the same amount of signal in all passbands

How we can balance it?

What do we need?





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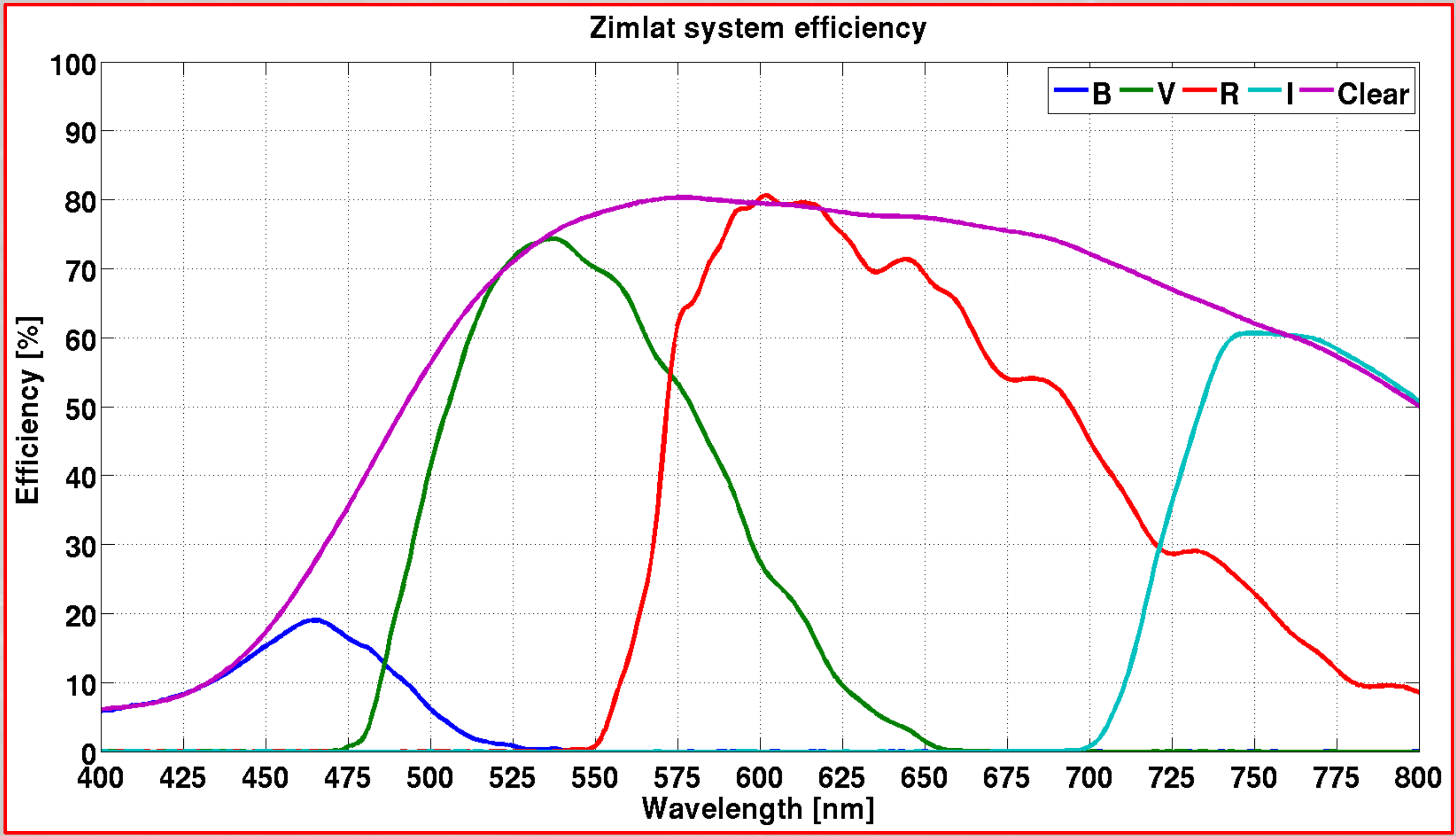
Observation: Exposure Time Determination

System Efficiency



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Observation: Exposure Time Determination

- Determine empirically the exposure time for B-filter
- Determine the other exposure time using:

$$t_X = \frac{\int_{\lambda B_s}^{\lambda B_e} T_{TB} \cdot T_B \cdot Q_B d\lambda}{\int_{\lambda X_s}^{\lambda X_e} T_{TX} \cdot T_X \cdot Q_X d\lambda} t_B$$

$$t_{bias} = 0 \text{ sec}$$

$$t_{dark} \simeq t_B$$

t = exposure time related to each filter; T_T = trasmittance of the telescope system at a certain wavelength; t_{dark} = dark exposure time and t_{bias} = bias exposure time.

WARNING: depending of the series number and the number of images per series performing all the observation could require time.

Filter	Integrated Efficiency
B	1265
V	6932
R	11189
I	4559
C	23606

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Observation: Name Format

Recommended format name: [Object]ddmmyyyyiijj.fts

- [Object] = Object name
- ddmmyyyy = day, month, and year of the observation
- ii = series number;
- jj = images number of series;

WARNING: take note of relation between series and kind of exposure.

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Table of Contents: Exercise 1

- Processing
  - The software
  - The workflow
  - Results

MaximDL

- Processing software;
- Create calibration master frame;
- Create scientific exposure master frame and perform automatically the standard reduction;
- Build colour image;
- Modify the reciprocal influence between colour channels.

30 days free trial version downloadable on the web; otherwise a computer with this software is at your disposal, but for this ask the laboratory supervisor.

Workflow

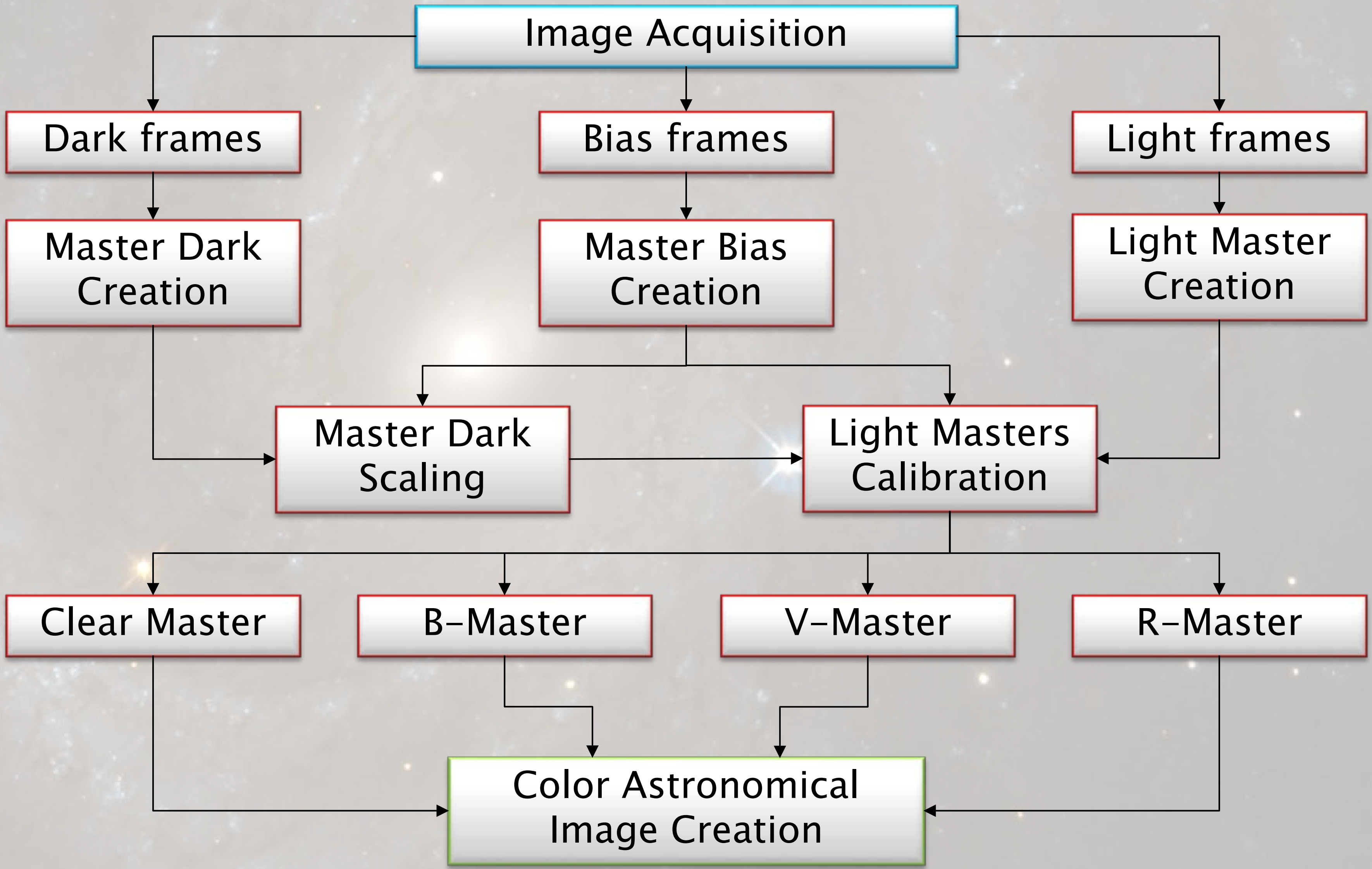
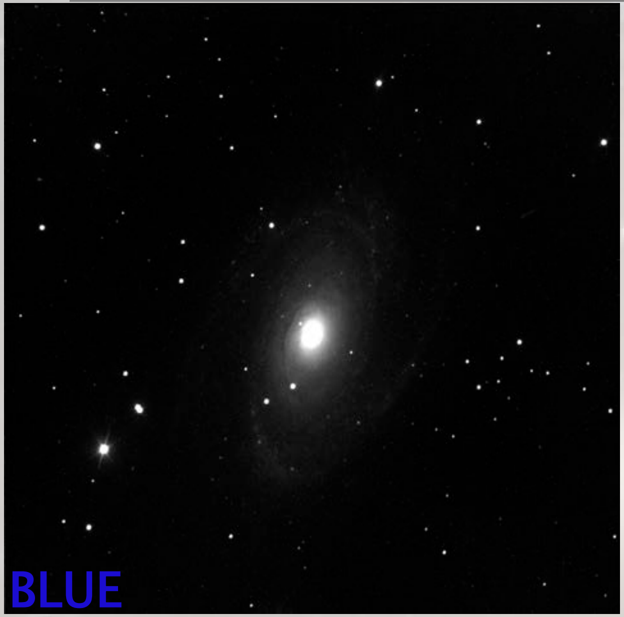
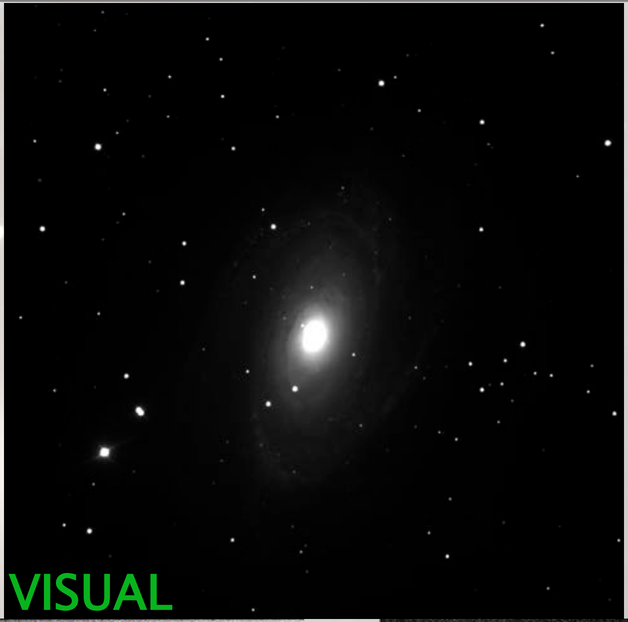
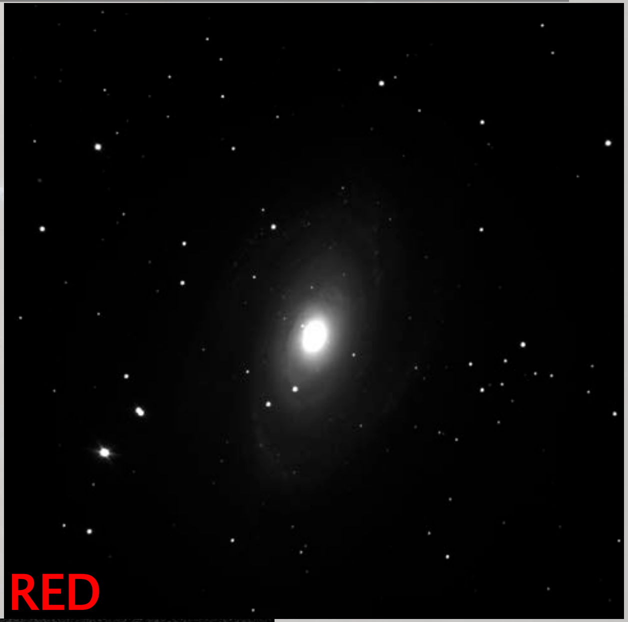


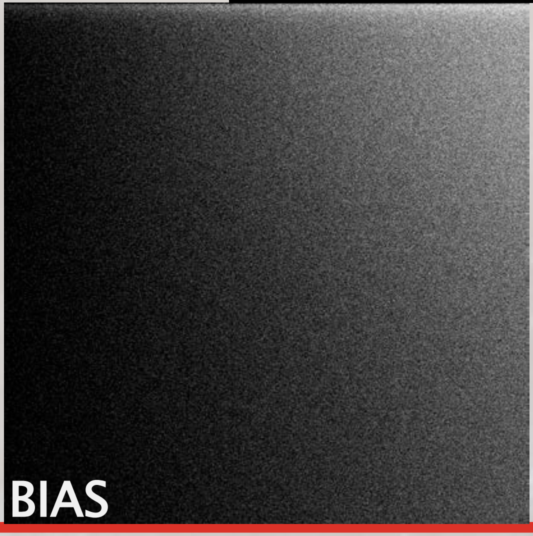
Image Acquisition
Dark frames
Bias frames
Light frames
Master Dark Creation
Master Bias Creation
Light Master Creation
Master Dark Scaling
Light Masters Calibration
Clear Master
B-Master
V-Master
R-Master
Color Astronomical Image Creation

Results 1 of 2









Results 2 of 2

EXERCISE 1: Complement

Old-fashioned Astronomer

ZimSpot

What are we going to do?

1. Verify the visibility of the chosen objects
2. Find objects in the sky

In an analogical way

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Table of Contents: Complement to Exercise 1

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The Telescope: ZimSpot

- ZimSpot: Zimmerwald Student Practicum and Observer Telescope.

- Characteristics:
  - Newtonian
  - Diameter: 25 cm
  - Focal Length:1.6 m
  - Focal Ratio: f/6.3
  - Field of View: depend on the eyepiece
  - Mount: Dobsonian (Alt-Azimuth)

- Eyepieces:
  - TeleVue Ethos 13 mm
  - TeleVue Ethos 8 mm
  - EWO 30 mm
  - Plössl 10 mm
  - Plössl 25 mm

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Eyepieces Characteristics

- **Focal length**
  important for the determination of the magnification and the field of view
- **Field of view**
  function of the field stop, focal length and barrel size
- **Eye Relief**
  is the distance from the last surface of an eyepiece at which the user's eye can obtain the full viewing angle
- **Exit Pupil**
  is the width of the cone of light that is available to the viewer at the exact eye relief distance

Eyepiece	Ethos 13mm	Ethos 8mm	EWO 30mm	Plössl 10mm	Plössl 25mm
Model #	ETH-13.0	ETH-08.0	-	EAP-11.0	EAP-25.0
Focal Len. [mm]	13	8	30	10	25
Barrel size [in.]	2'' & 1.25''	2'' & 1.25''	2''	1.25''	1.25''
App. FOV [°]	100	100	69	50	50
Eye Relief [mm]	15	15	-	8	17
Weight [g]	589	431	-	62	122
Field Stop [mm]	22.3	13.9	-	9.1	21.2

ZimSpot important features

The scale (s) of the image formed in the focal plane is:

$$s = f \tan u$$

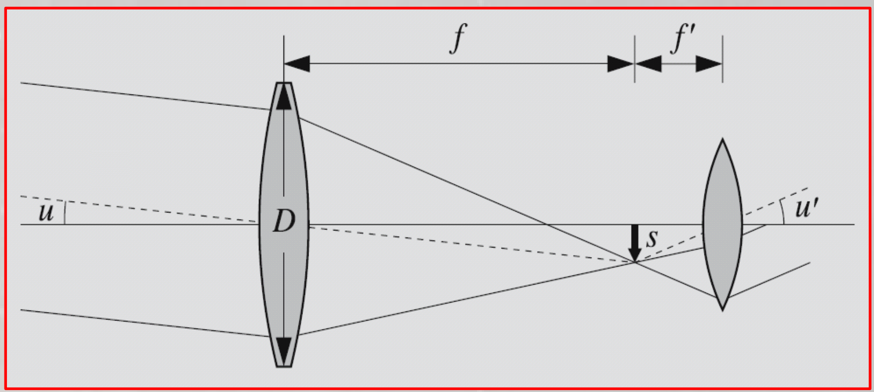
Applying the same relation for the eyepiece, we can determine the magnification (ω) of the telescope

$$\omega = \frac{u'}{u} \approx \frac{f}{f'}$$

The resolution of the telescope (θ) is

$$\sin\theta = 1.22\frac{\lambda}{D}$$

u angle of the object, f, f' focal length of the telescope and the eyepiece, u' angle of the object see from the eyepiece, 1.22 constant given by the shape of the objective, λ wavelength of the incoming radiation, D is the aperture of the telescope and e is the resolution of the human eye.



The telescope resolution together with the characteristics of the human eye determine the magnification limits.

The maximum magnification that is worth using in telescopic observation is

$$\omega_{max} = \frac{e}{\theta} \approx \frac{D}{0.001}\,[\mathrm{m}]$$

The minimum magnification is obtained from the condition that the diameter of the exit pupil (L) of the telescope must be smaller or equal to the pupil of the eye (d).

$$L = \frac{f'D}{f} = \frac{D}{\omega} \Longrightarrow \omega_{min} \geq \frac{D}{d}$$

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ZimSpot important features

The Field of View (FOV) describes the area of a target that can be seen on the chip of a CCD-camera or when looking through a telescope

For a lens focused at the infinite, without distortion

$$\alpha = 2\tan^{-1}\frac{d}{2f}$$

Actual/True field of view (TFOV): the angular size of the amount of sky that can be seen through an eyepiece when used with a particular telescope, producing a specific magnification.

If the AFOV is known and it is less than 60°, a good approximation for the TFOV is:

$$TFOV = \frac{AFOV}{\omega}\ [\text{rad}]$$

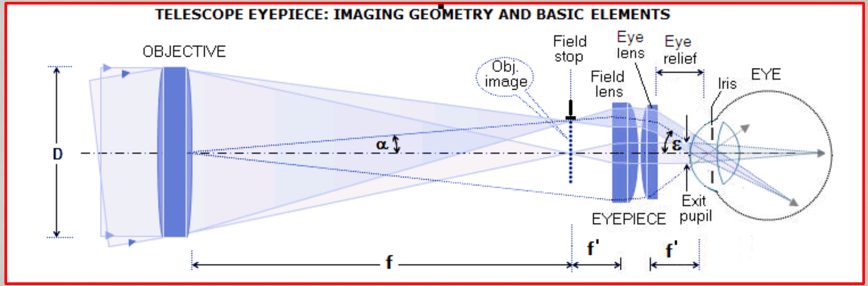
Otherwise the ISO 14132-1:2002 determines the Angle of View (AOV) starting from the Apparent Angle of View (AAOV)

$$\tan\frac{AAOV}{2} = \omega\tan\frac{AOV}{2} \quad \text{where} \quad AAOV = 2\tan^{-1}\frac{f_s}{2f'}$$

d is the CCD-chip dimension or field stop f_s is the diameter of the field stop

Apparent field of view (AFOV): it is a measure of the angular size of the image viewed through the eyepiece.

This is constant for any given eyepiece of fixed focal length, and may be used to calculate what the *actual* field of view will be when the eyepiece is used with a given telescope.



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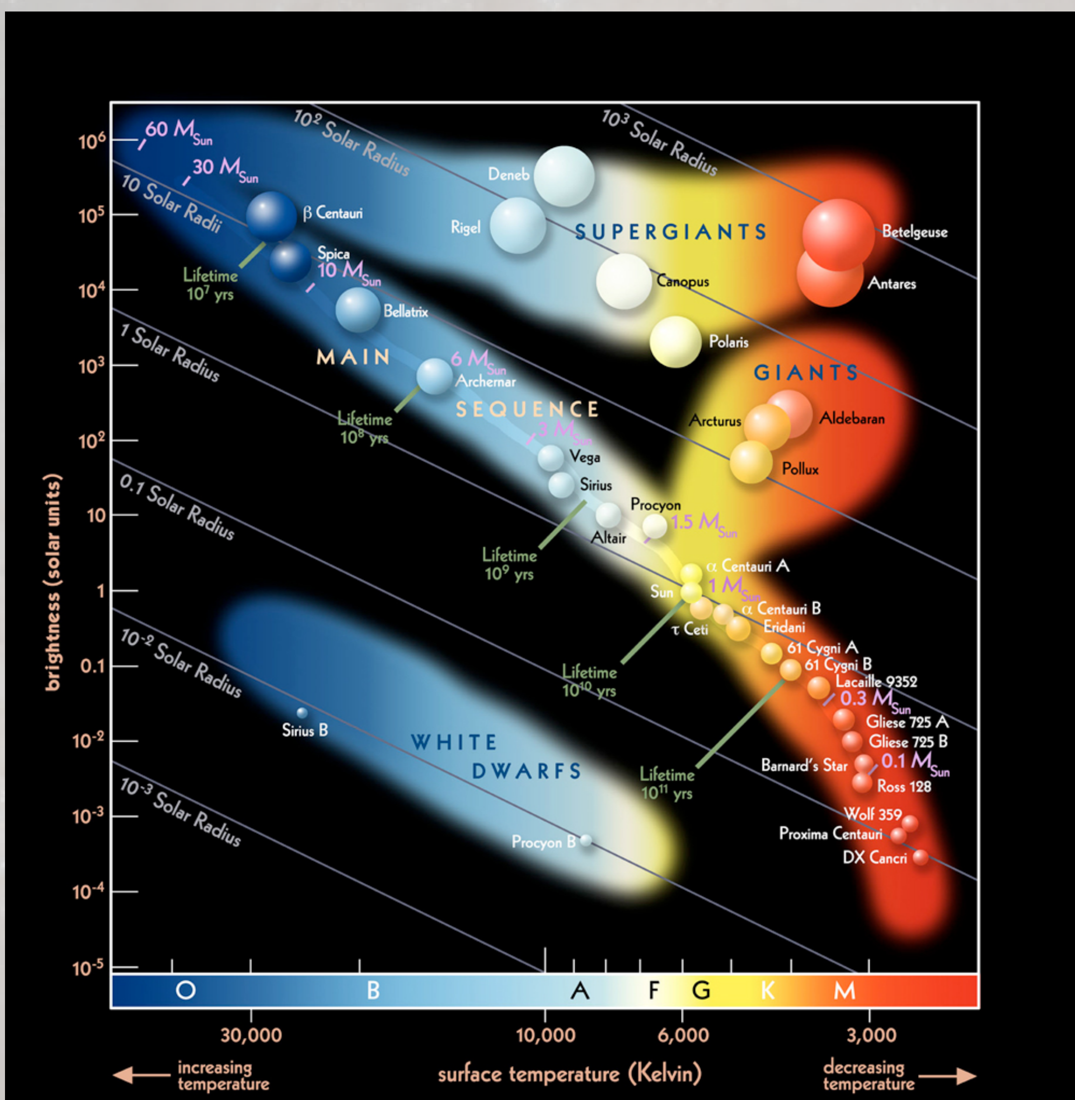
EXERCISE 2



Building the Hertzsprung–Russel diagram

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Table of Contents: Exercise 2

The Telescope: ZimSmart

- ZimSmart: Zimmerwald Small Apertur Robotic Telescope.

Used for the discovery of space debris in GEO, follow-ups of bright LEO objects and for streak-photometry.

- Characteristics:
  - Newtonian, hyperbolic primary and field corrector
  - Diameter: 20 cm
  - Focal Length:58 cm
  - Focal Ratio: f/2.8
  - Field of View: 3.6°x3.6°
  - Mount: German-equatorial

- CCD-camera:
  - 4096 x 4096 [9 µm]
  - Resolution: 3.16”/Pixel
  - Front-illuminated
  - Johnson-Cousins photometric system: B, V, R, I

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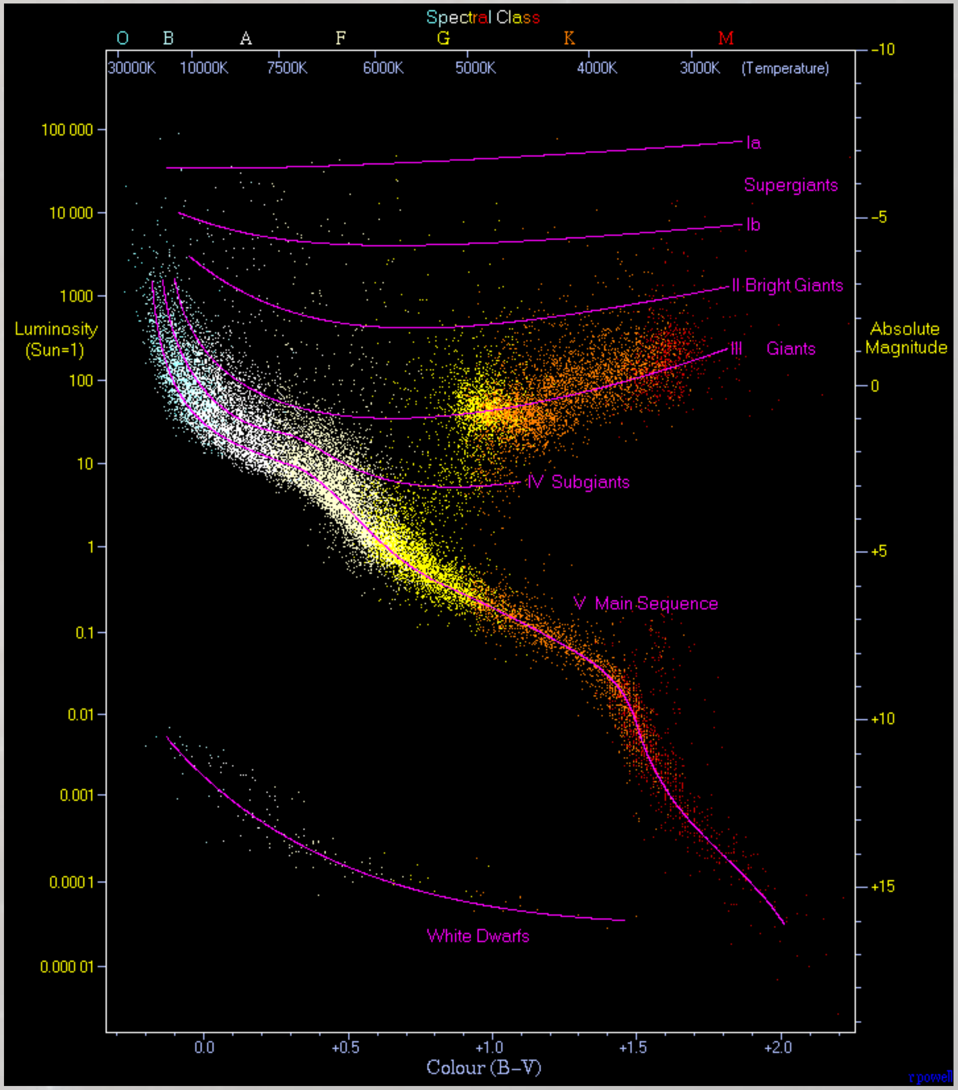
The Hertzsprung-Russel Diagramm

- Despite different temperature, size and luminosity the stars belong to particular region of the diagram
- Important for stellar evolution
- Capability to determine
  - Distances
  - Dimensions
  - Temperature
  - Masses

  of the stars
- HR is Spectral Class Vs Luminosity
- Color Vs Magnitude



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The Target

Build the HR diagram for an open cluster

- Calibrate the images
- Create the master frames
- Perform the aperture photometry analysis
- Determine the magnitude of the stars in the cluster
- Build the HR diagram

The Processing

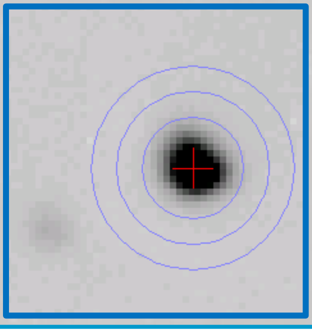
Tools to be used:

- **MaximDL**
  analogously to exercise 1, needed to calibrate/manipulate the images and create masterframes
- **AstroImageJ**
  used to evaluate the flux of the stars
- **Star Catalogue: Landolt or Simbad**
  set the zero point for the magnitude evaluation
- **MatLab**
  magnitude determination and results display

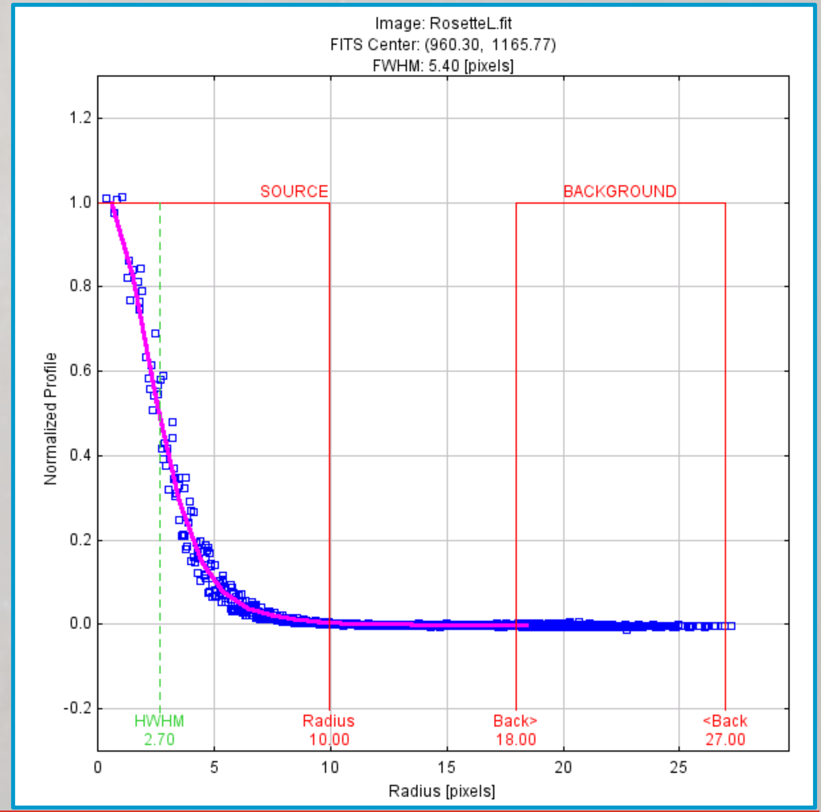
Ps: MatLab is just a suggestion you can use any other software.

Aperture Photometry

A star is a point source, but due to the atmosphere, the light on a CCD is spread over a number of pixels



To extract the brightness of a star from the image, we must first sum the star's contribution over all illuminated pixels illuminated and subtract the contribution from the sky background



Need to select a good size for the aperture!!!

A good choice for the radius of an aperture is about 1.5 or 2.0 times the FWHM

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Magnitude Determination

The Apparent magnitude is the measure of the observed flux of a celestial object as seen from the Earth

$$M = -2.5 \, \log_{10} F + K$$

M is the magnitude to determine

F if the flux measured by the image

K is the zero-point of the magnitude scale

K has to be determined !!!

Use a reference star, close to the observed object to neglect extinction differences, whose magnitude is well known and available on the web.

The Landolt catalogue can be used for this purpose and can be found on the web at the following link.

http://james.as.arizona.edu/~psmith/61inch/ATLAS/atlasinfo.html

Magnitude Determination

Hints on how to use the Landolt star catalogue which deals with color indices

$$M_B - M_V = -2.5\log_{10}\left(\frac{F_B}{F_V}\right) + K_B - K_V$$

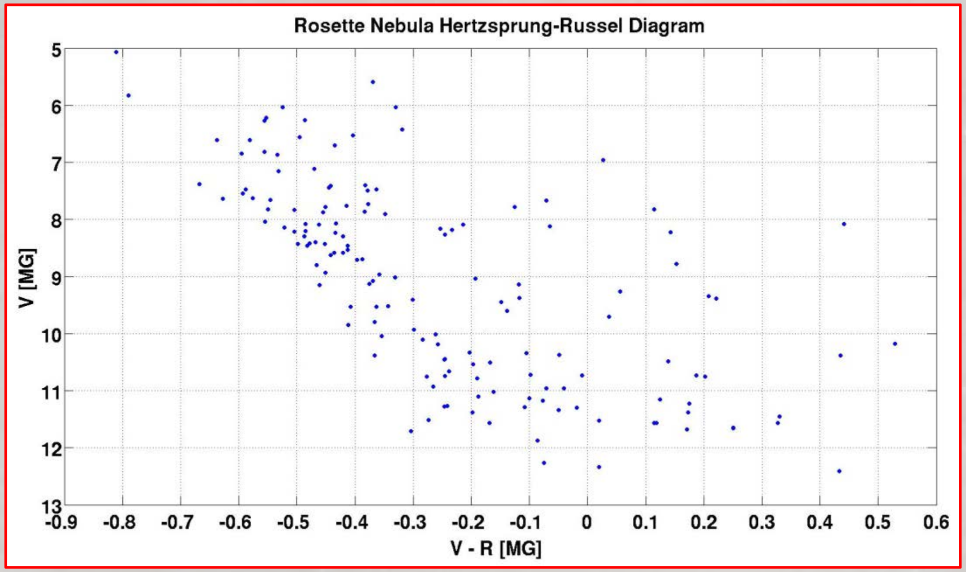
Since the zero-points are the same for same observation conditions, we can solve for them and we will obtain that:

$$K_B - K_V = M_B - M_V + 2.5\log_{10}\left(\frac{F_B}{F_V}\right)$$

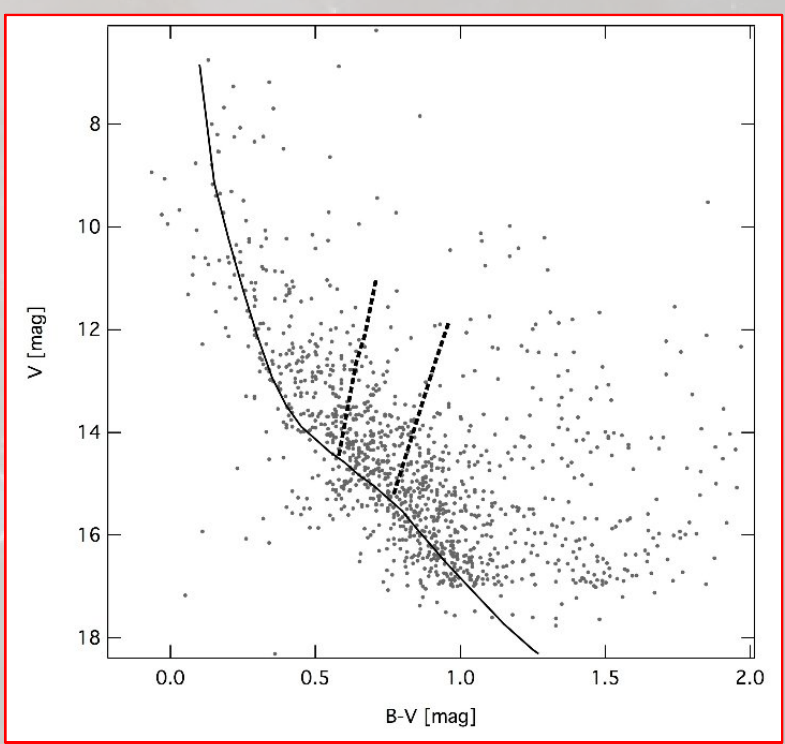
Now, you can build your own HR diagram !!!

Results

Obtained diagram for NGC-2244



Reference diagram for NGC-2244



Considerations:

- Good shape approximation
- Difference in the magnitude (V)
- Difference in the color index (V–R) Vs (B–V)

Possible explanations?

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Important Remarks

- Image Processing:
  - The only pixel values that can be manipulated are the one in the dark frames
  - The light/scientific exposure must be properly calibrated but no scaling of these values is allowed!
  - The images provided for the Hertzsprung-Russel diagram are intentionally of the same exposure time: No scaling is Needed!
- Astronomical Image Creation
  - Find in the web how your chosen object will appear in the visual spectrum
  - Remember what you will see by naked eye
  - Compose your colour image so that is as close as possible to the reference one, to do it, act on the weight matrix
  - Show the results obtained with and without the tuning of the colour weights and give a scientific explanation of your results.
- Old-fashioned Astronomer
  - You will be asked to find objects in the sky… Write in the report which one did you found, which one not and why.
- Hertzsprung-Russel
  - More stars you choose, better will result the diagram (at least 200).
  - Find in the web the diagram for the chosen open cluster
  - Compare the reference diagram with yours highlight the difference and give a scientific explanation of your results.
  - What are the conclusions on the observed cluster that you can deduce from your diagram?
- Aperture Photometry
  - Do not use overexposed stars!!! (many pixel with ADU value = 65536)

Final Report

- Max. 3 students per group.
- Write the report .pdf or a .doc file in English.
- Describe in the report all the activities performed and why.
- Beside the report, write the answers to all questions found in the introduction document.
- Show your master frames and final image in report.
- Put all your images in a CD (both .fts and .jpeg) and refer them in the report with their file name, this is valid also for the HR diagram.
- Put in the cd also the obtained HR diagram and the text file used to determine the magnitude of the stars.
- Before semester end
- Doodle
  - Pay attention to the weather
  - Only one group per observation night
  - At latest the day before

Material Download

The Script, the slides and the images can be downloaded from:

ftp://ftp.unibe.ch/aiub/users/astropra/

Have Fun!!!