INDIAN INSTITUTE OF INFORMATION TECHNOLOGY, ALLAHABAD

C1 Finite Time Assessment (FTA), February 22, 2022.

Computational Astrophysics

B.Tech: (IT & ECE) Elective VI – Semester *QP: PC*

Full Marks - PART A: {1X16} + PART B: {5+6+14+5}=46 (Scaled to 10)

Time - 1hr, Max Time - 2hrs.

CALCULATORS/COMPUTER ALLOWED

Answers should be brief and to the point.

Unnecessary Extra writing will attract negative marks.

This FTA will be of **10marks** out of **30**. The remaining **20 marks** will be for the online assignments that have been submitted. This ratio of 10:20 may be varied in favour of the performance by the students so that the performance of the students could be maximised.

On the Top margin of each paper Students should write their

i) Question No, ii) Roll No, iii) Name and iv) Signature.

These pages should be scanned and uploaded. Please install Adobe Scan to take the pictures of your answer pages for uploading it (Preferably in PDF). Do not Scan at high resolution so that the file size is large and it becomes difficult to upload it from your end.

Do not share your login and password of your IITA e-mail. Any Malpractice of uploading through a single IP no, Uploading someone else's answer Sheet IS A CRIME. THE STUDENT will automatically fail the course.

These are difficult times. Your sincerity towards learning and ethical practice is expected from all of you.

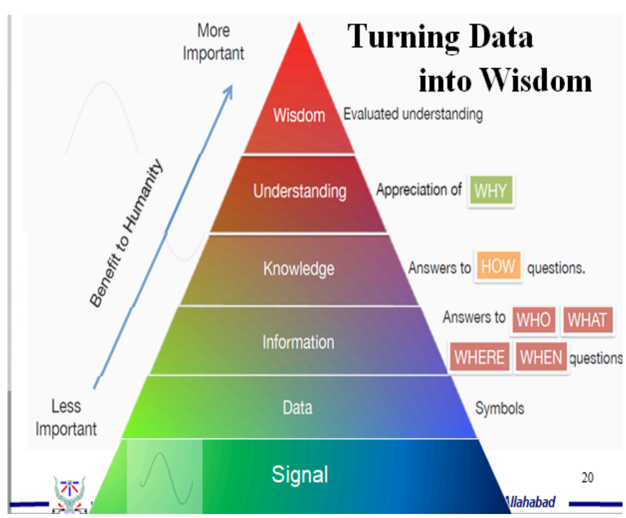
PART-A

Short Question Short Answers (form Class Lectures) [Marks: 16X1=16].

There will be marking the answer should be at least 75% correct to obtain 1 otherwise the marking will be 0.

1. Draw the pyramid showing the different layers of the pyramid moving from **Signal** to **Wisdom** (6Layers).
2. Write beside the pyramid what each layer is, what do they signify and what type of questions do these layers address how **Signal** is converted to **Wisdom**.
3. What condition should be followed during sampling of a Time variant signal? What should be a sampling rate for a signal $10 sin(2 \times 10^6 \cdot t)$ in MHz?

   Nyquist Sampling Theorem demands that there should be minimum 2 sampling per frequency to be detected in the sampled data. The minimum sampling rate for the signal $10 sin(2 \times 10^6 \cdot t)$ should be $4\ MHz$.



4. What are the related field that help in Data Mining and Knowledge Discovery
Machine learning, Visualisation, Statistics and Data Bases
5. What is more theory-based and is focused on testing hypotheses. **Statistics**
6. What is more heuristic and focuses on improving performance of a learning agent and looks at real-time learning. **Machine learning**
7. What integrates theory and heuristics; focuses on the entire process of knowledge discovery, including data cleaning, learning, and integration and visualisation of results.
Data Mining and Knowledge Discovery
8. Knowledge Discovery in Data is the *non-trivial* process of identifying ____________________
***Valid, novel,* potentially *useful* and ultimately *understandable patterns* in data.**

9. Why do we see the pattern in the sky shown in the photograph of the Anglo-Australian Observatory (**Fig. 01**)?
The Pattern is in **Fig. 01** observed because the Camera is fixed on the earth and the earth is rotating w.r.t the stars (**Duranal Rotation**). **Fig. 01** is a long exposure photograph where the stars have relatively rotated around the Southern Pol. The photograph is of the Anglo-Australian Observatory which is in Australia (Southern Hemisphere) so the centre of the circles is the direction of the southern pole axis of the earth's rotation.

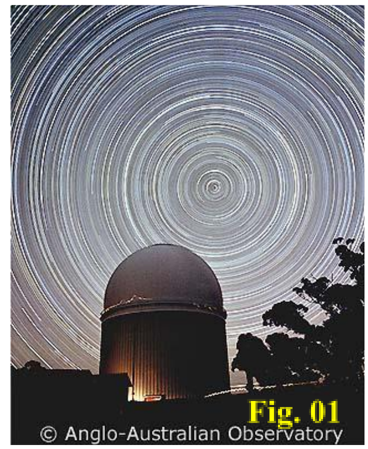


Fig. 01
© Anglo-Australian Observatory

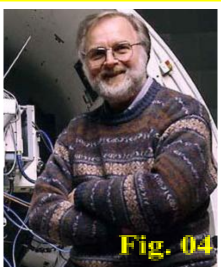


Fig. 04


Fig. 03


Fig. 02

10. In the photograph taken by famous Astro-Photographer David Malin (**Fig. 04**), of the **Halley's Comet** (**Fig. 02**) during its last visit close to earth in 1986, we see streaks (lines) of **Red**, Green and **Blue**; while the Photograph of the Orion Nebula (Fig. 03) by the same photographer does not show these Streaks. Why?
The **Halley's Comet** (**Fig. 02**) was photographed by Astro-Photographer David Malin during its last visit close to earth in 1986. This is a long exposure photograph where the telescope has been guided W.R,T the comet nucleus which is **relatively moving W.R.T. the stars**. This picture is a **composite picture** of 3 Grayscale images Taken **one after the other** through **R (Red,** $\lambda_0 = 6349A^o = 634.9nm$**)**, **V (Green** $\lambda_0 = 5477A^o = 547.7nm$**)** and **B (Blue** $\lambda_0 = 4353A^o = 4353.5nm$**)**. Since it is a composition of 3 Images The stars in each filter are at a different location. Therefore we see streaks (lines) of **Red**, Green and **Blue**; of the relative movement of stars with respect to the comet nucleus. The Photograph of the Orion Nebula **(Fig. 03)** by the same photographer does not show these Streaks since the telescope is tracking the stars to compensate for the earth's rotation ($15 Arcsec/sec\ east\ to\ west\ in\ RA$).

11. In the image of **Comet Hyakutake C/1996 B2**, taken 10 years later in 1996 by Dr Pavan Chakraborty which appeared on the front Cover of ***Current Science*** (*Vol. 79 No. 12 25 June 1996*) (**Fig. 05**) also shows the streaks as seen in **Fig. 02**. However, these streaks do not show as separate **Red**, Green and **Blue**. Why? (*The **Comet Hyakutake C/1996 B2** was travelling very close to the earth, therefore it had a high angular velocity in the sky. An SLR Camera with a 120mm Zoom lens, with Kodak Multi Film in it, was used for taking pictures. The SLR Camera was mounted piggyback on the main 30inch Telescope at the Vainu Bappu Observatory. The Main 30 inch Telescope which had a longer Focal ratio f/13 was used to guide on the comet's nucleus as the comet moved across the sky. Kodak Multi was a colour film with ISO 100 to 1000*).

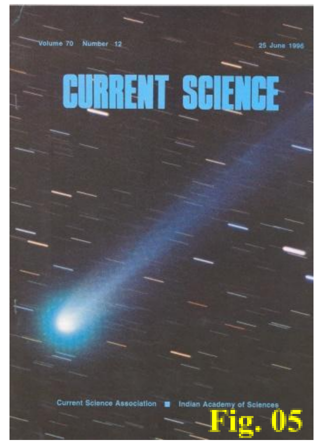


Fig. 05

As mentioned, This image was taken 10years later with a Colour Kodak Multi (ISO:100 to 1000) multi film which simultaneously exposed in all 3 colours in **Red**, Green and **Blue**. It is not a composite of 3 separate images in **Red**, Green and **Blue**. The Streaks do appear since the camera is tracking the Comet Nucleus and the stars are moving wrt the comet.

12. As mentioned in ***Question 11*** *{above}*, **i)** what is the focal Length of the SLR Camera? **ii)** Focal Length of the 30 inch Telescope with focal ratio f/13.

i) Focal Length of the SLR Camera: $120mm$.

ii) Focal Length of the 30 inch Telescope with focal ratio f/13: $13 \times 30 = 390inch = 99,060mm$

iii) Plate Scale = $\frac{1}{f} rad/mm = \frac{(180/\pi)\times 3600}{f} = \frac{206264.806}{f}$.

13. {***Question 11,12 Continued***} Plate Scale of the SLR Camera and 30 inch Telescope in ***arcsec/mm***. (*1 arcsec = 1/3600 of a degree*; $\pi = 3.14159265359 = 180^o$, $1\ inch = 2.54cm$).

For the SLR Camera $Plate\ Scale = \frac{206264.806}{120} = 1718.8734 Arcsec/mm$

For the 30 inch Telescope with focal ratio f/13 $Plate\ Scale = \frac{206264.806}{99060} = 2.0822 Arcsec/mm$

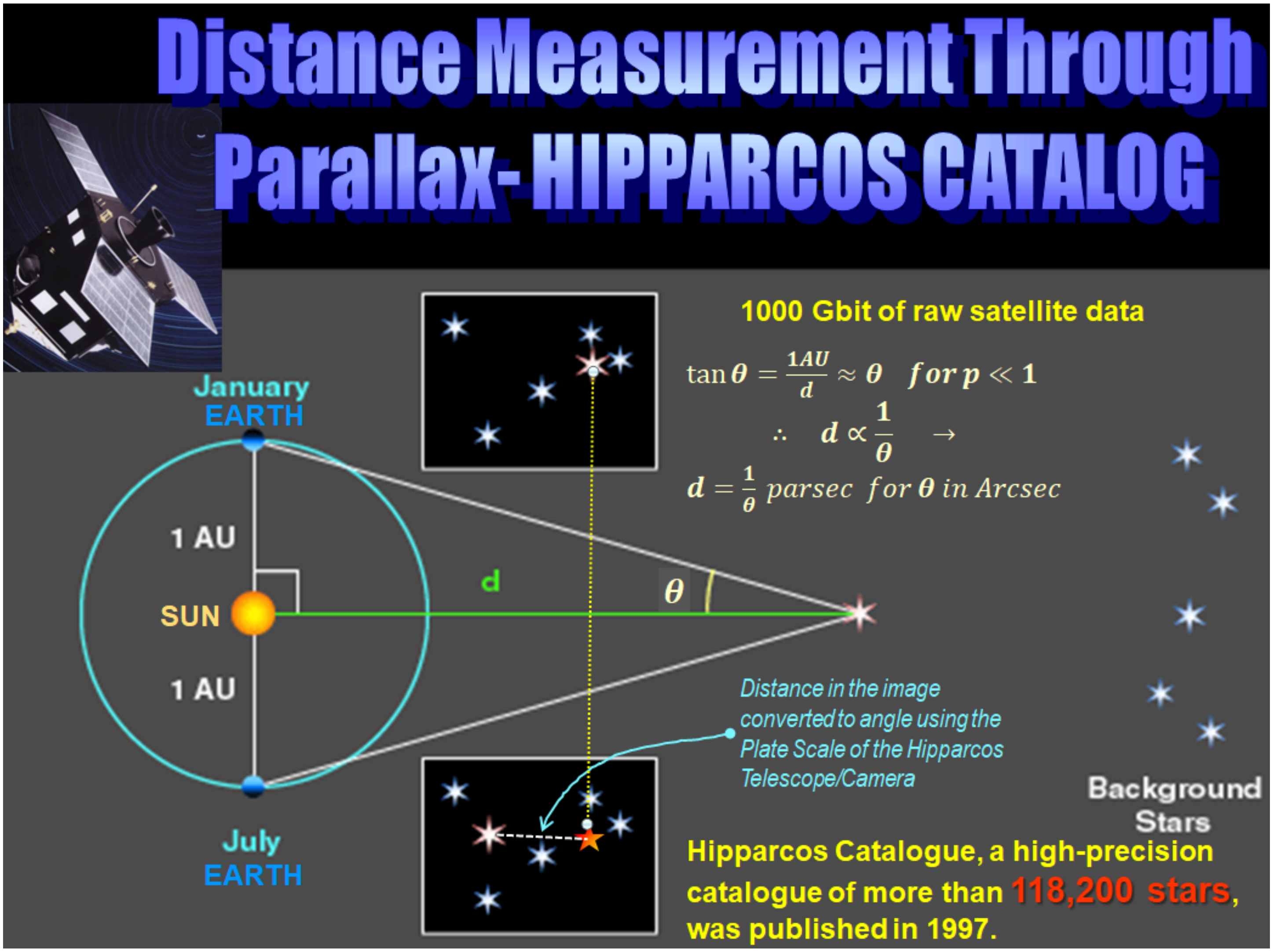
14. Why Adding images after proper alignment, reduces noise while increasing the signal?

If we assume noise to be random with a Normal/Poissonian distribution, it is both positive and negative while the signal is always positive. So if we Add images after proper alignment the **signal will grow** while the noise reduces due to **positive and negative summation** of noise.

15. What is the best and most famous example of the above technique {***Question 14***} of adding images which lead to the discovery of a host of faint extragalactic objects?

The Hubble Deep Field by the Hubble Telescope in Space

16. Hipparcos Catalogue was a high-precision catalogue of distances to the stars in our galaxy (more than 118,200 stars). This Hipparcos catalogue data was made using the Hipparcos Satellite. Images of the same region of the sky were taken 6 months apart and comparing these images the distance the stars were obtained. Draw the diagram and show how from the variation of position of the stars on the 6 months apart images reveals the distance to the stars.



17. From the above drawing {***Question 16***} define the distance unit "***parsec***"?

$\tan\theta = 1AU/d \approx \theta \qquad for\; p \ll 1$

$\therefore \qquad d \propto 1/\theta \quad \rightarrow$

$d = 1/\theta\;$ parsec for θ in Arcsec

18. If $1AU = 1.496 \times 10^{11} m$ and speed of light $c = 299,792,458\, m/s$ in Vacuum; Calculate 1 Parsec and 1 Lightyear in metres. Show the steps of calculation.

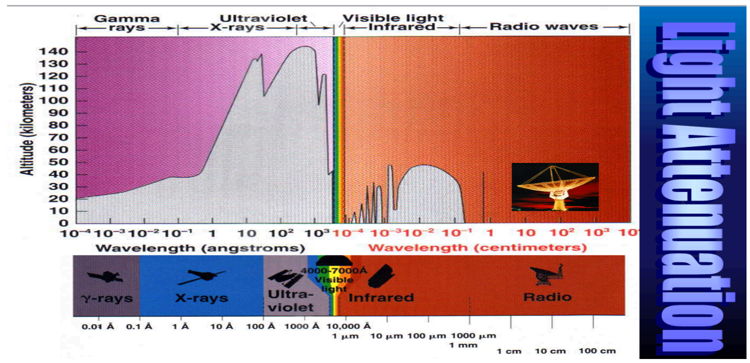
$1\, ly = 299,792,458\, m/s \times 60 \times 60 \times 24 \times 365 = 9.461 \times 10^{15} m$

$$1\, parsec = \frac{1AU = 1.496\times10^{11} m}{1\, Arcsec = \pi/(180\times60\times60)} = \frac{1.496\times10^{11}}{3.1416/(180\times60\times60)} = 3.086 \times 10^{16} m$$

Why is Astronomy known as a "passive" science?

We can't (yet) go to the stars or other galaxies, The Universe must come to us; that is, we obtain information about the astronomical sources through the light emitted by them. No controlled experiment as done in other branches of physics can be done. We can only passively observe. What you see is all you get. So you need to squeeze EVERY last drop of information out of the light we get.

20. The figure to the right shows Attenuation of Light by the earth's atmosphere across the entire electromagnetic spectrum. Why from γ-rays to UV and in IR we require Space based observation while in the Optical and Radio waves we can use ground based observatories. In IR ($10^{-4} \leq \lambda \leq 10^{-3} cm$) why can we still make ground based observations from a dry high altitude observatory?

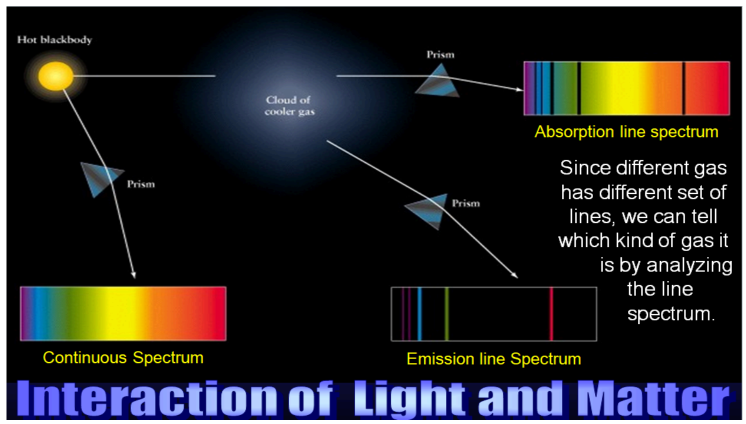


From γ-rays to UV and in IR we require Space based observation because the Attenuation of Light by earth's atmosphere is so high, No EM signal from space reaches the ground based observatories.

In the Optical and Radio waves we can use ground based observatories because the earth's atmosphere allows the EM signals from space to reach the ground based observatories.

In IR ($10^{-4} \leq \lambda \leq 10^{-3} cm$) why can we still make ground based observations from a dry high altitude observatory because the Attenuation is due to absorption of IR by the water molecules in the atmosphere. There are however bands in which the attenuation is low. Ground based observations can be made in these windows.

21. From the figure to the right, explain a)Continuous Spectrum b) Absorption Spectrum and c) Emission Line Spectrum.

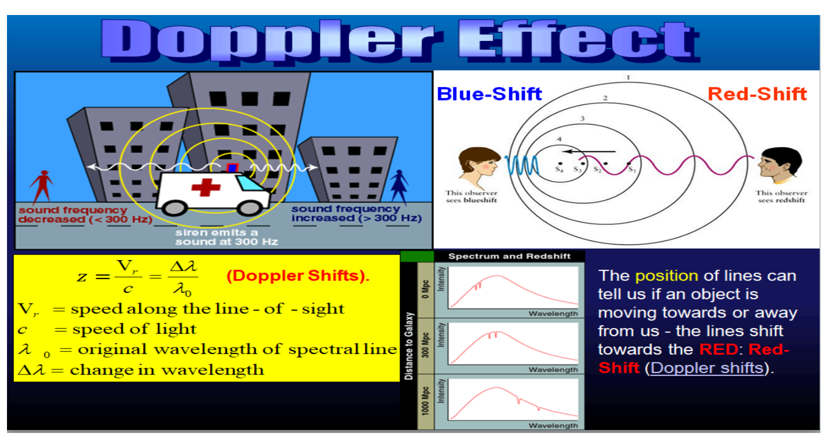


a)Continuous Spectrum: An extremely hot object emits a Black Body Spectrum Associated to the Temperature of the Black Body which is a continuous spectrum.

b) Absorption Spectrum: If light passes through a colder medium, The medium absorbs radiation corresponding to the excitation of the elements that composes the medium. The atoms/molecules in the colder medium absorb the excitation frequency so the radiation seen through the cooler medium has absorption lines, thus the Absorption Spectrum.

c) Emission Line Spectrum: Absorbed energy by the cooler medium excites its atom/molecules to a higher energy level. When these atoms/molecules drop from higher energy back to the lower, it emits lines. These lines are observed from the cloud as the Emission Line Spectrum. The observation should not be in the line of initial radiation.

22. What is the Doppler Effect? Explain Red-Shift and Blue-Shift. How is it measured?



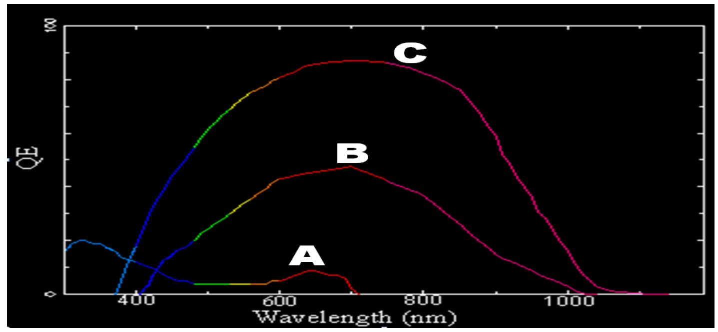
Doppler shift is measure by measuring the wavelength shift $\Delta\lambda$ of the absorption/ emission lines of moving objects. If the object moves towards the observer the lines are shifted towards the **blue** of the spectrum (**BLUESHIFT**) while the object moving away from the observer the line shifts towards the **RED.** (**REDSHIFT**)

23. Edwin Hubble using high resolution spectroscopy observed the redshift of galaxies. From the observations he postulated the Hubble's Law: $v = H_0 \cdot r$, where v is the velocity of the galaxy, r the distance from the observer and $H_0 = \left[1.5 \times 10^{10}\, yr.\right]^{-1}$ is the Hubble constant. What does Hubble's Law signify?

Hubble's Law observationally signifies that the Universe is expanding and further objects are moving faster away from us.

It is the strongest observational proof for the **Big Bang** Theory. How was the velocity v computed/measured by Hubble?

Hubble observed the spectrum from far objects where distance to the object could be known from different methods. He measured the wavelength shift $\Delta\lambda$ of the absorption/ emission lines from which he calculated the doppler shift (Red Shift) z. The vlosity of the object will then be: $v = cz = c \cdot \frac{\Delta\lambda}{\lambda_o}$



24. The figure to the right shows the graph of the Quantum Efficiency (QE) vs Wavelength of 3 Detectors **A**, **B** and **C** with wavelength. Which are the detectors **A**, **B** and **C**?

A: QE of the photographic plate. **B**: Amateur CCD. **C**:Professional CCD

25. Advantages of CCDs over film: Enumerate 4 advantages with reasons.

1. CCDs have a linear response to light. *i.e.* the measured signal is directly proportional to the amount of light which was received. This is not true for film.A linear response means that if the exposure is doubled, then the measurable signal will double. Also, twice the signal means the source is twice as bright.

2. CCDs have a wide dynamic range. Coupled with their linearity they can measure both very faint targets and very bright ones.

3. CCDs are dimensionally stable. The sensing elements (pixels – or picture elements) are laid out in a regular grid formed on the silicon substrate. This makes them excellent for most forms of positional measurement.

4. CCDs are digital and so modern computers can be put to use in processing the images. No more messing about with photographic chemicals or working in the dark.

END of PART A **PART B in the Next page**

PART-B: PROBLEMS

26. a) Write the equation of the CCD imaging data acquired from a Telescope with all its systematic errors. Define each component of the equation.

$$F_{ij}(\lambda, t) = G_0(\lambda)G_{ij}(\lambda)I_{ij}(\lambda, t) + b_{ij} + d_{ij}(T, t)$$

The source Flux is $I_{ij}(\lambda, t)$

b) Explain the acronyms and the terms: ADC, ADU, Bias, Bias Frame, CCD ReadOut Noise, Bleed or Bloom, Dark current, Dark Frame, Exposure, Flat Field.

ADC : Analogue-to-Digital Converter; it converts an analogue voltage to a digital count.

ADU : Analogue-to-Digital Unit; one "count" out of a CCD

Bias : b_{ij} The background level of the CCD fixed +ve count which avoids negative counts due to NOISE in the signal.

Bias Frame : A zero length exposure to show the bias structure of the CCD. The Positive offset + the ReadOut Noise

CCD ReadOut Noise : The accuracy to which the charge in a pixel can be measured. Usually given as e^- RMS. The residual charges that remain while transferring charges from one pixel to another during read out of the CCD.

Bleed or Bloom : When a pixel is overfilled the charge has to go somewhere, usually into ugly streaks.

Dark current $d_{ij}(T, t)$: The rate of build-up due to thermal noise depends on Temperature T and exposure time t

Dark Frame : An exposure to measure the dark current

Exposure : The time the CCD is exposed to light

Flat Field $G_0(\lambda)G_{ij}(\lambda)$: An image of a blank target designed to show imperfections in the CCD and imaging system

c) Why are Professional CCD Cameras are Liquid Nitrogen Cooled to $-110^oC \approx 163^oK$?

The Professional CCD Cameras are Liquid Nitrogen Cooled to $-110^oC \approx 163^oK$. so that the **Dark current** $d_{ij}(T, t)$ is reduced to the level of 1 count in a 30min exposure. This will be much less than photon Noise therefore the dark can be neglected.

d) Assuming that you have complete data from a professional Telescope Explain each step of DATA reduction to remove the systematic errors.

1) Take multiple Bias Frames and median combine them to generate the Master Bias Image.
2) **BIAS CORRECTION:** Subtract the Master Bias from all the i) All Observed Data and ii) All Flat Field images. (Subtract by b_{ij})
3) Combine multiple Flat Frames for each specific FILTER and median combine them to generate the Master Flat Image for each Filter.

4) Normalise Master Flat Image for each Filter.

5) **FLAT FIELDING:** Divide the Bias subtracted Observed Data of a specific Filter with its specific Normalised Master Flat of the same filter (divide by $G_{ij}(\lambda)$

e) Does the reduced image data provide the actual flux or is it proportional to the actual flux?

The reduced image data provides counts which are proportional to the actual flux. Actual flux is determined through photometry using standard candles / standard photometric stars where the flux is known.

[3+(10x1)+1+(2+3)+1=20]