Calibrating Data

Scientists often invent measuring technology in order to measure some property of an object. A simple thermometer measures temperature, defined in terms of the Celsius scale, as a displacement of a column of mercury (in millimeters).

This example shows a common problem in measurement. It is often the case that the scale of interest (degrees) is very different than the scale upon which the measurement is based (millimeters). To translate between these scales you need to carry out a process called calibration.

An instrument has been created that measures temperature by moving a marker through a specific number of millimeters. The scale was calibrated by measuring the temperature of several bodies of known temperature, measured in Celsius degrees. Suppose that you created a Calibration Table in which you measured how a specific temperature causes a specific displacement. The measurements indicate that at T=10 C, the marker moved to an indicator of x=10 millimeters. At T=30 C, it moved to x=15 mm. At T=50C it moved to x=20mm and at T=70C it moved to x=25 mm.

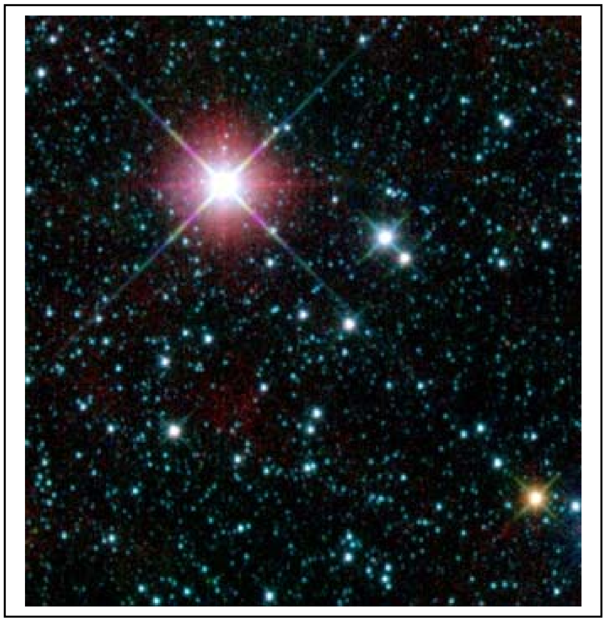
Problem 1 - With temperature on the horizontal axis, graph the data to form a Calibration Curve for the instrument.

Problem 2 - Determine the best-fit linear equation for the data in the form y=mx+b.

Problem 3 - What is the Zero-Point (x=0) for the calibration?

Problem 4 - What is the Calibration Constant (M) for the data, and what are the units for the Calibration Constant?

Problem 5 - If the instrument indicates x=5mm, what is the temperature being



Astronomers build instruments to photograph distant stars, galaxies and nebulae, such as the NASA WISE satellite image shown to the left. The measuring units that are provided by the instrument do not, by themselves, indicate the proper units required for measuring some aspect of a distant object being imaged.

A process of 'calibration' must be followed to relate the measuring units to the physical units of the distant object being studied.

A CCD camera has been built that consists of 16 million pixels in a square format of 4096 x 4096 pixels. The intensity of the starlight falling upon a pixel as it passes through the optics of the telescope is registered in each pixel as a 20-bit digital word. Each of the 2^{20} = 1,048,576 levels indicated by the data word (abbreviated as DN) can be related to a physical brightness level in the distant astronomical body through the calibration process.

The astronomer uses this telescope+camera system to image 5 different stars of known brightness, and records the number of DN units that are measured by an individual pixel centered on the star. The Calibration Data Table is as follows:

Star	Brightness (picoWatts/m^2/nm)	DN value
Polaris	4	40,000
Regulus	10	100,000
Spica	16	160,000
Arcturus	40	400,000
Sirius	80	800,000

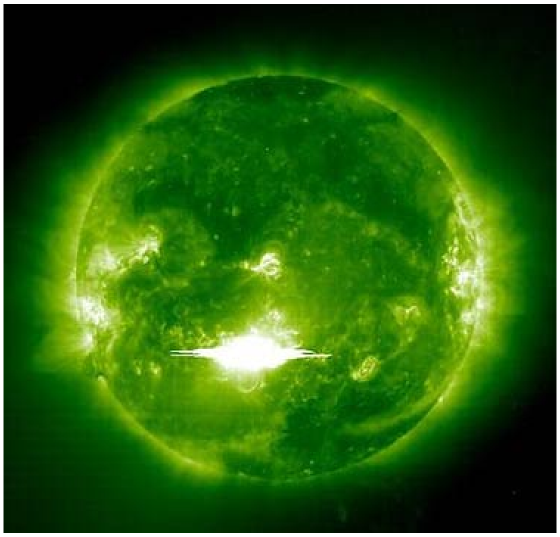
Problem 1 - With the DN values on the horizontal axis, graph the calibration curve for the data.

Problem 2 - What is the best-fit linear equation of the form B = mX + b, where B is the brightness and X is the DN value?

Problem 3 - What is; A) the Zero-Point of the scale (B(0)) in the correct physical units? B) the Calibration Constant (M)

Problem 4 - The star 36 Ophichi is measured to be x= 12,000 DN on the CCD image. What is the brightness of this star in the correct physical units?

Light Intensity and Pixel 'DNs'



Once the image has been transmitted to Earth and translated back into its original numerical format as an array of numbers, the numbers have to be converted into units that actually describe how much light was detected by the CCD. Without this important step, called calibration, an astronomer will not be able to relate the numbers that make up the image to physically important properties of the object being studied. Here's an example:

At the distance of a satellite from the Sun, the total amount of sunlight power is known to be 1000 watts/meter^2. Since this energy is spread out over the sun's entire electromagnetic spectrum, it is convenient to indicate the spectral irradiance of the sun, B. At visible wavelengths (500 nm), this spectral irradiance is about B(500) = 2.0 watts/meter^2/nm.

Problem 1 - A 50 nm, narrow-band filter is used on the satellite's imager that only passes radiation between wavelengths of 500 nm and 550 nm. What is the sunlight power delivered to the surface of the CCD if P = B x bandwidth?

Problem 2 - The surface area of the CCD chip is 1 cm^2. It is a 16 megapixel array. What is the surface area of one pixel in meters^2?

Problem 3 - How much power is falling on one CCD pixel based on your answers to Problem 1 and 2?

Problem 4 - The measured value of a pixel in the CCD is based on a 16-bit data word which has a maximum value of DN=65,536. After flat-fielding, a single pixel centered on the Sun registers a value of DN=63,000. In terms of actual solar power, what is the conversion constant that converts DN values into solar power values of watts for this CCD array?

Problem 5 - A pixel measures a faint detail on the sun with a pixel value of 50,000 DN units. What is the corresponding solar power incident on the pixel?

The goal is to convert the grayscale units (256 levels) into increments in terms of the physical brightness unit of Lux.

1 Lux = 1 Lumen/meter^2

= 0.0015 watts/meter^2 at 550 nm

Object	Lux
Sun (-26.7m)	130,000
Full Moon (-12.5m)	0.267
Venus at Brightest (-4.3)	0.000139
Sirius (-1.4m)	0.0000098
Faint Star (+6m)	0.0000000105

We have determined the diameter of the moon, Dp, in pixels, the total area, N, in pixels, the total area, A, in arcseconds^2, and the average moon brightness in DNs/pixel, Bp, in DNs, Example from above image:

Dp = 34 pixels N = 3,630 pixels, A = 707 arcseconds^2 Bp = 138 DNs/pixel

We move to the next step which is to relate the DN values to a physical light brightness unit.

Problem 1 – From the average DN per pixel and the moon area in pixels, what is T, the total number of DNs for all the moon pixels combined?

Problem 2 – From the above table, what is the total flux, F, of light from the full moon in A) Lux and B) watts/meter^2?

Determing the three calibration constants:

Problem 3 – What is the calibration factor for this camera A) Ca = F/(AT) in watts/meter^2/arcsec^2? ; B) Cp=F/(NT) in watts/meter^2/pixel? and C) Cl=Fl/N in Lux/Dn/Pixel?

Problem 4 – You measure a star image as a total of 1500 DN in a total of 6 pixels. What is its brightness in A) watts/meter^2? B) Lux?

Common digital cameras use CCD chips whose pixels count the arriving photons. The counts are converted into a 256-level grayscale representation that is used in the storage of the image as a gif or jpeg file. We can use the calibration and photography information to determine how many photons correspond to a change by 1 DN in the 256-DN grayscale number.

This moon image was taken by a Nikon d3000 camera with a focal length of 200 mm, at F/32, with ISO=100 and an exposure speed of 1/25 sec.

We have determined the diameter of the moon, Dp, in pixels, the total area, N, in pixels, the total area, A, in arcseconds^2, and the average moon brightness in DNs/pixel, Bp:

Dp = 34 pixels **A = 707 arcseconds^2**
N = 3,630 pixels, **Bp = 138 DNs/pixel**

We have also determined for this lunar image the various calibration constants

Ca = 1.1x10^{-12} watts/DN/meter^2/arcsec^2
Cp = 2.2x10^{-13} watts/DN/meter^2/pixel.
Cl = 1.5x10^{-10} Lux/Dn/pixel

Problem 1 – The lens diameter is determined from its focal length L, and f-stop f, according to D = L/f. What is the area of the lens, in square meters, used to create the above photo of the Moon?

Problem 2 – The energy of a single photon of light at visible wavelengths (550 nm) is about Ep= 3.7x10^{-19} Joules. If 1 watt = 1 Joule/ 1 second, to two significant figures, what was the rate, F, at which photons were falling onto one pixel on the disk of the full moon through a lens with an area of A?

Problem 3 – During the time that the exposure was being made, how many photons entered a single pixel?

Problem 4 – For this lunar image, how many photons correspond to 1 DN to one significant figure?