# POWERS OF TEN — SCIENTIFIC NOTATION

Typically, astronomy requires very large and very small numbers. To handle these we require convenient notation, specifically the standard scientific notation that uses "powers of ten."

Positive exponents tell you how many zeros follow the one:

$10^0 = 1$ $\quad 10^1 = 10$ $\quad 10^2 = 100$ $\quad 10^3 = 1000$ etc.

Negative exponents indicate values less than one:

$10^{-1} = 0.1$ $\quad 10^{-2} = 0.01$ $\quad 10^{-3} = 0.001$ $\quad 10^{-4} = 0.0001$ etc.

note that in general $10^{-x} = 1/10^x$ (ie $\frac{1}{10^x}$)

Special prefixes indicate 'how many':

| Number | Prefix | Letter | Meaning | Example |
|---|---|---|---|---|
| $10^3$ | kilo | k | thousand | kilogram (kg), kilometer (km) |
| $10^6$ | mega | M | million | megaparsec (Mpc) |
| $10^9$ | giga | G | billion | gigayear (Gyr) |
| $10^{-3}$ | milli | m | thousandth | millimeter (mm), milliamp (mA) |
| $10^{-6}$ | micro | $\mu$ | millionth | microsecond ($\mu$s) |
| $10^{-9}$ | nano | n | billionth | nanometer (nm) |

Multiplication and division are easy with scientific notation. Since $10^3$ means $10 \times 10 \times 10$ and $10^2$ means $10 \times 10$ then $10^3 \times 10^2$ is equal to $10^5$, or $10 \times 10 \times 10 \times 10 \times 10$. In general:

multiplication: $10^a \times 10^b = 10^{a+b}$ : eg $(2.2 \times 10^3) \times (5.5 \times 10^4) = 12.1 \times 10^7 = 1.21 \times 10^8$

division: $10^a \div 10^b = 10^{a-b}$ : eg $(4.6 \times 10^{12}) \div (2.0 \times 10^3) = 2.3 \times 10^9$

exponentiation: $(10^a)^b = 10^{a \times b}$ : eg $(3.8 \times 10^{-3})^3 = 54.9 \times 10^{-9} = 5.49 \times 10^{-8}$

recall : square root of $x$ is $x^{\frac{1}{2}}$; cube root of $x$ is $x^{\frac{1}{3}}$; n$^{th}$ root of $x$ is $x^{\frac{1}{n}}$

## UNITS

In this course we will be using the *metric system* for our system of units, specifically the 'mks' (meter, kilogram, second) system. In addition, we will often use 'natural' units, such as light-year, parsec, or solar mass. It is important that you have a familiarity with these terms.

[1] **Time:** The basic unit of time is the second (s), with bigger groupings of minute, hour, day (86,000 s), and year ($3.17 \times 10^7$ s).

[2] **Length:** The units of length are *meters*, *centimeters* (*centi*- meaning one hundredth of a meter, about equal to half an inch), and the *kilometers* (*kilo*- means one thousand, hence one

thousand meters, about equal to six-tenths, 0.6, of a mile).
Several special units of length are also used in astronomy:

i. The *Astronomical Unit, A.U.:* This is defined as the distance between the Earth and the Sun, and is about equal to $1.5 \times 10^{13}$ cm.

ii. The *Light Year:* This is defined to be the distance that light travels in one year, and is about equal to $9.5 \times 10^{17}$ cm.

iii. The *Parsec:* This is about 3.25 ly and is used as a convenient measure of distances between stars.

[3] **Velocity:** Standard units of velocity are meters per second (m/s or m $s^{-1}$). For astronomers a more natural choice is often kilometers per second, 1 km/s $\sim$ 2200 miles per hour. For example, the velocity of light is 300,000 km/s.

[4] **Mass:** The unit of mass is the kilogram (kg). For astronomers, we may also use units of Earth Mass ($M_\oplus = 5.97 \times 10^{24}$kg) or Solar Mass ($M_\odot = 1.99 \times 10^{30}$kg). Note that 1 gm is defined to be the mass of one cubic centimeter of water, and 1 kg = $10^3$ gm.

[5] **Density:** This is the amount of mass present in a chosen unit of volume. For example, the density of water is 1000 kg/$m^3$ (also 1 gm/$cm^3$ or 1 gm $cm^{-3}$). We will often discuss the density of various things. For example, air has a much lower density than water, while rock has a higher density.

[6] **Temperature:** Scientists usually measure temperature in *degrees Kelvin*, or occasionally in degrees Centigrade. These have the same 'size' units, but the Kelvin scale starts with zero at 'absolute zero' where all molecules are stationary (about $-273$ C). The Centigrade scale starts with zero at the freezing point of water (+273 K) and can have both positive and negative values. We will avoid Fahrenheit which has smaller size units (about half as big) and a rather arbitrary zero point.

[7] **Angular Measure:** As the name implies these are units for the measurements of angles. There are 360 *degrees* in a full circle, 60 *minutes* of arc in one degree, and 60 *seconds* of arc (one arc-second) in every minute. Examples: The big dipper is about 20 degrees across on the sky; the moon is 30 arc minutes across; the eye can barely distinguish two objects separated by one arc-minute. An arc-second is about the size of a dime seen at a distance of two kilometers.

[8] **Energy:** The unit of energy is the *Joule*. The Joule is the energy you get from dropping 1 kg (eg a bag of sugar) from a height of about 0.1m (about 4 inches). The more familiar unit, the *watt*, is actually a unit of **power** which is a rate of energy production or release per second. 1 watt is equal to 1 Joule per second. So a 100 watt light bulb consumes 100 Joules of energy every second. In astronomy, a natural unit of power is the luminosity of the Sun, 1 $L_\odot = 3.9 \times 10^{26}$ watt $= 3.9 \times 10^{33}$ erg/s.