The universe is a BIG place…but it also has some very small ingredients! Astronomers and physicists often find linear plotting scales very cumbersome to use because the quantities you would most like to graph differ by powers of 10 in size, temperature or mass. Log-Log graphs are commonly used to see the 'big picture'. Instead of a linear scale '1 kilometer, 2 kilometers 3 kilometers etc' a Logarithmic scale is used where '1' represents $10^1$, '2' represents $10^2$ …'20' represents $10^{20}$ etc. A calculator easily lets you determine the Log of any decimal number. Just enter the number, n, and hit the 'log' key to get m = log(n). Then just plot a point with 'm' as the coordinate number!

Below we will work with a Log(m) log(r) graph where m is the mass of an object in kilograms, and r is its size in meters.

**Problem 1** - Plot some or all of the objects listed in the table below on a LogLog graph with the 'x' axis being Log(M) and 'y' being Log(R).

**Problem 2** - Draw a line that represents all objects that have a density of A) nuclear matter ($4 \times 10^{17}$ kg/m$^3$), and B) water (1000 kg/m$^3$).

**Problem 3** - Black holes are defined by the simple formula R = 3.0 M, where r is the radius in kilometers, and M is the mass in multiples of the sun's mass (1 M = $2.0 \times 10^{30}$ kilograms). Shade-in the region of the LogLog plot that represents the condition that no object of a given mass may have a radius <u>smaller</u> than that of a black hole.

**Problem 4** - The lowest density achievable in our universe is set by the density of the cosmic fireball radiation field of $4 \times 10^{-31}$ kg/m$^3$. Draw a line that identifies the locus of objects with this density, and shade the region that excludes densities <u>lower</u> than this.

| | Object | R (meters) | M (kg) |
|---|---|---|---|
| 1 | You | 2.0 | 60 |
| 2 | Mosquito | $2x10^{-3}$ | $2x10^{-6}$ |
| 3 | Proton | $2x10^{-15}$ | $2x10^{-27}$ |
| 4 | Electron | $4x10^{-18}$ | $1x10^{-30}$ |
| 5 | Z boson | $1x10^{-18}$ | $2x10^{-25}$ |
| 6 | Earth | $6x10^{6}$ | $6x10^{24}$ |
| 7 | Sun | $1x10^{9}$ | $2x10^{30}$ |
| 8 | Jupiter | $4x10^{8}$ | $2x10^{27}$ |
| 9 | Betelgeuse | $8x10^{11}$ | $6x10^{31}$ |
| 10 | Milky Way galaxy | $1x10^{21}$ | $5x10^{41}$ |
| 11 | Uranium atom | $2x10^{-14}$ | $4x10^{-25}$ |
| 12 | Solar system | $1x10^{13}$ | $2x10^{30}$ |
| 13 | Ameba | $6x10^{-5}$ | $1x10^{-12}$ |
| 14 | 100-watt bulb | $5x10^{-2}$ | $5x10^{-2}$ |
| 15 | Sirius B white dwarf. | $6x10^{6}$ | $2x10^{30}$ |
| 16 | Orion nebula | $3x10^{18}$ | $2x10^{34}$ |
| 17 | Neutron star | $4x10^{4}$ | $4x10^{30}$ |
| 18 | Binary star system | $1x10^{13}$ | $4x10^{30}$ |
| 19 | Globular cluster M13 | $1x10^{18}$ | $2x10^{35}$ |
| 20 | Cluster of galaxies | $5x10^{23}$ | $5x10^{44}$ |
| 21 | Entire visible universe | $2x10^{26}$ | $2x10^{54}$ |

The figure below shows the various items plotted, and excluded regions cross-hatched. Students may color or shade-in the permitted region. This wedge represents all of the known objects and systems in our universe; a domain that spans a range of 85 orders of magnitude ($10^{85}$) in mass and 47 orders of magnitude ($10^{47}$) in size!

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**Inquiry**: Can you or your students come up with more examples of objects or system that occupy some of the seemingly 'barren' regions of the permitted area?