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What if a Star was a Grain of Sand?

To help visualize how many stars there are in the galaxy or the universe, stars are often compared to grains of sand. This document takes that analogy and calculates the approximate volumes of the collective stars in our galaxy and the universe… if they were all grains of sand, and you could somehow gather them and throw them into a big box! How big a box would you need?

How big is a grain of sand?

Our total volume calculation, of course, greatly depends on the assumed size of a grain of sand. The Wentworth scale is often used to categorize particle size [1]. Referring to this scale, a "medium sand", typical of what you would find at an average beach, has a diameter of 0.25-0.5 mm. For this calculation, let's assume that d = 0.25mm, or radius (r) = 0.125 mm. Let's simplify the model and assume the sand grains are spherical in shape. This yields the following result:

$$Volume\ grain\ of\ sand = \frac{4}{3}\pi\, r^3 = \frac{4}{3}\pi\, (0.125mm)^3 = 8.18x10^{-3}\, mm^3 = 8.18x10^{-12}\, meter^{\,3}$$

How many stars are there out there?

Galaxies typically have billions (and even trillions) of stars in them. Our own galaxy, the Milky Way, is fairly typical in size, so let's work with it. The Milky Way is estimated to have approximately 200-400 billion stars in it [2]; let's go with the midpoint estimate of 300 billion ($3x10^{11}$) stars.

Now, how many stars are there in the universe? That is an excellent question which has been a moving target for many years. In 1999, a Hubble survey estimated that there are 125 billion galaxies out there [3]. A more recent study, using a super computer simulation, put the number at 500 billion [4]. We do not know the precise answer, of course, so for this exercise let's assume the midpoint of the estimates and go with 300 billion ($3x10^{11}$) galaxies in the universe.

If you assume that the Milky Way is average, and there are 300 billion galaxies out there, then you find:

$$Total\ stars\ in\ universe = (ave.\ galaxy) * (\#\ galaxies) = 3x10^{11} *\ 3x10^{11} = 9x10^{22}\ stars!$$

How well does sand "pack" in a container?

If you throw sand into a container, the total volume it takes up will be a combination of the volume of the grains themselves, plus the voids between them as they pack in some random formation. If you stay with the assumption that the sand grains are uniform and spherical, then we can use a typical "void fraction" for randomly packed, uniform spheres = ~38% [5]. You can then calculate the total volume of sand in the container as follows:

$$Total\ volume\ of\ sand = \frac{(\#grains) * (volume\ per\ grain)}{(1 - void\ fraction)}$$

So how much space do our stars take up?

Let's take our stars and make them the size of typical grains of sand, assume they are uniform and spherical in shape and pack randomly as we pour them into a box. How big will the box need to be?

For the Milky Way, you get the following result:

$$Milky\ Way\ sand\ stars = \frac{(3x10^{11} grains) * (8.18x10^{-12}\, m^{\,3}\ each)}{(1 - 0.38)} = 3.96\, meter^{\,3}$$

So, you would need a box with volume of ~3.96 cubic meters, which translates to a cube ~1.6 meters (~5.2 feet) on each side, filled with grains of sand to represent just our galaxy, the Milky Way!

Expanding this same calculation to the entire universe you get:

$$Universe\ sand\ stars = \frac{(9x10^{22} grains) * (8.18x10^{-12}\ m^{3}\ each)}{(1 - 0.38)} = 1.19x10^{12}\ m^{3} = 1{,}190\ km^{3}$$

So in this case, you would need a box with volume ~1,190 cubic kilometers, which translates to a cube ~10.6 kilometers (~6.6 miles) on a side to contain all of the stars in the universe…if each were a grain of sand!

References

[1] http://en.wikipedia.org/wiki/Particle_size_(grain_size)
[2] http://en.wikipedia.org/wiki/Milky_Way
[3] http://imagine.gsfc.nasa.gov/docs/ask_astro/answers/021127a.html
[4] http://www.universetoday.com/30305/how-many-galaxies-in-the-universe/
[5] http://en.wikipedia.org/wiki/Random_close_pack