# The Real Starry Sky

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When you look up on a clear night, you are seeing a very unrepresentative sample of the kinds of stars that populate our corner of the Galaxy. Because stars exhibit an incredible range of luminosities, some would be seen with the naked eye only if much closer than Alpha Centauri (the closest star system to the Sun), while others easily blaze across a considerable fraction of the Galaxy's diameter. In what follows, keep in mind that absolute magnitudes quantify the apparent brightness of an object at a standard distance of 10 parsecs, or 32.6 light-years.

The smallest viable star is about 8% of the Sun's mass and glows feebly at absolute magnitude +19. (Our Sun has an absolute of +4.8.) That is 14 magnitudes or 400,000 times dimmer than our Sun. The heaviest stars begin their lives with masses of roughly 100 times that of the Sun, and are the Galaxy's beacons at upwards of absolute magnitude −8, over 160,000 times the solar luminosity. The total range of stellar luminosities, then, occupies a range of 27 magnitudes, or a factor of 60 billion!

Nature does not like to make big stars, and those that are formed live brief lives. Star counts show that as we look to ever fainter stars, their numbers rise dramatically. For the very dimmest stars, the numbers seem to level off then decrease, but the decline may be due to the great difficulty in finding them. If the trend does persist through the lowest masses, the number of these brown dwarfs could be astounding. Contributing greatly to these rising numbers with decreasing mass and brightness is the fact that small stars live incredibly long lives. Where the most massive stars explode as supernovas after a few million years, which is only the blink of an eye in cosmic time, the smallest stars are expected to last for trillions of years, which is many times the current age of the universe.

The naked-eye sky is very strongly biased towards bright stars — mostly B- and A-type main sequence stars. Ironically, none of the most common type of star, M-type dwarfs, is visible without optical aid! We can only truly sample the fainter stellar types in the area immediately around the Sun; much farther and they fade to invisibility. To get anything like a representative sample of the brightest types, their rarity demands that we extend our net to thousands of light-years.

In Table 1, for every five absolute magnitudes, I have indicated the distance, in light-years, at which such a star would be just visible to the unaided eye. To put star counts into perspective, we need to express them in a common unit of volume. A convenient standard is 10,000 cubic parsecs, the volume occupied by a sphere just over 13 parsecs in radius. The tabulated counts are for "normal" stars (main sequence, giants, and supergiants, but not white dwarfs). The counts are presented in one magnitude bins. The first bin, labeled "−6," includes stars between absolute magnitude −6.5 and −5.5. Continuing with this line, we can see that in that magnitude range, we will find 1/10,000 of a star (a strange thing to picture) per 10,000 cubic parsecs ($pc^3$) or 1 star per 100 million $pc^3$. This small fraction of a star is still 2.6 times brighter than the Sun (the whole star would be 26,000 times brighter than our Sun), and that is with only 0.5% of the Sun's mass.

A number of interesting facts can be gleaned from a study of Table 1.

1) Look at the totals. For every 10,000 $pc^3$ we find 1008 stars, giving an average per $pc^3$ of 0.1 stars with a mass of 0.036 solar masses and producing 0.053 times the Sun's luminosity. If we include the expected number of white dwarfs, the mass goes up to 0.065 solar masses per $pc^3$, but the light contribution to the total would be practically negligible.

2) Most stars are intrinsically faint. The maximum numbers occur at an absolute magnitude of around +14, typically K and M dwarfs.

3) Nearly all of the light is emitted by the brightest stars, despite their rarity. Peak emission comes from stars with an absolute magnitude of +1, typically A-type dwarfs and K and M giants.

4) Most stellar mass is contributed by the vast number of dim stars. Whereas virtually all light comes from stars brighter that the Sun (near absolute magnitude +5), the mass is fairly uniformly distributed in the magnitude range from +3 to +15. The dynamics of the galaxy are clearly dominated by stars that are, at best, inconspicuous.

5) The mass-to-light ratio for stellar objects, including white dwarfs, is 1.2 solar masses per solar luminosity (654 ÷ 532 = 1.23). The ratio is greater than one because the bulk of stars are the smaller dwarfs with densities higher than that of the Sun. Density virtually always increases with decreasing luminosity. Main sequence O and M stars have, respectively, 0.03 and 10 times the Sun's density — white dwarfs have nearly a million times the Sun's density. The mass-to-light ratio derived here is surely a lower limit, as many types of objects evade detection. Many objects, (*e.g.*,

faint companions in multiple systems, dead white dwarf and neutron stars, and black holes) will contribute mass but little, if any, light.

In Table 2 we break down the number distribution of stars by spectral type and class. The row labeled "Giants" includes giants, bright giants, and supergiants. The main sequence stars dominate because that is where a star spends 90% of its lifetime, quietly burning hydrogen to helium. Additionally, no star in the universe that has about 80% or less of the Sun's mass (all K and M dwarfs) has yet evolved away from the main sequence. White dwarfs, the cores of dying stars that began their life in the range of 0.8 to about 5 solar masses, contribute significantly to the total number.

Why bother knowing this stuff? As our place in the Galaxy most probably is not unique, we should have a good idea of the overall content of the Galaxy's disk, at least at the Sun's distance from the centre. For amateur astronomers, it is always good to have a quantitative feel for the nature of what we are observing. That is especially so in this case, as the stars are the fundamental framework of what we appreciate aesthetically in our skywatching.

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Table 1

General stellar luminosity function of the solar neighbourhood (per 10,000 $pc^3$)

| Abs. Mag. | # of stars | lum. (Sun =1) | mass (Sun=1) | visibility (l.y.) |
|---|---|---|---|---|
| −6 | 0.0001 | 2.6 | 0.005 | |
| −5 | 0.0006 | 5.1 | 0.02 | 5000 |
| −4 | 0.0029 | 9.4 | 0.06 | |
| −3 | 0.013 | 17 | 0.17 | |
| −2 | 0.05 | 28 | 0.5 | |
| −1 | 0.25 | 54 | 1.6 | |
| 0 | 1 | 96 | 4.0 | 500 |
| 1 | 3 | 111 | 7.4 | |
| 2 | 5 | 64 | 8.7 | |
| 3 | 12 | 66 | 17.3 | |
| 4 | 17 | 36 | 19.4 | |
| 5 | 29 | 25 | 28.1 | 50 |
| 6 | 30 | 10 | 24.7 | |
| 7 | 32 | 4 | 21.3 | |
| 8 | 33 | 1.8 | 21.8 | |
| 9 | 42 | 0.9 | 24.2 | |
| 10 | 70 | 0.6 | 35.0 | 5 |
| 11 | 90 | 0.3 | 36.0 | |
| 12 | 127 | 0.17 | 36.3 | |
| 13 | 102 | 0.055 | 20.8 | |
| 14 | 102 | 0.022 | 16.3 | |
| 15 | 127 | 0.011 | 16.3 | 0.5 |
| 16 | 102 | 0.0035 | 10.5 | |
| 17 | 51 | 0.0007 | 4.3 | |
| 18 | 22 | 0.0001 | 1.6 | |
| 19 | 13 | 0.0000 | 0.7 | |
| Totals: | 1008 | 532 | 356* | |

* 654 including white dwarfs

Table 2

Number density in the solar neighbourhood brighter than absolute magnitude +16 by spectral type and class, per 10,000 $pc^3$

| | Spectral type | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Class | O | B | A | F | G | K | M | Totals |
| Giants | | | | 0.5 | 1.6 | 4 | 0.25 | 6.3 |
| Main sequence | 0.00025 | 1 | 5 | 25 | 63 | 100 | 630 | 800 |
| White dwarfs | | 63 | 100 | 50 | 50 | 25 | | 250 |