Colonization of the Milky Way

The distances between the stars are huge. However, our galaxy has existed for more than ten billion years, so does the time or the distance win? An easy way to see that the time is triumphant is to note that a speed of 30 km/s, comparable to the fastest spacecraft our still-young civilization has launched, is about 1/10,000 times the speed of light. Our galaxy is about 100,000 light years across, so even at a slow rate the time to cross the galaxy is about $100,000 \times 10,000 = 10^9$ years, or one billion years. This is short compared to the more than ten billion year age of the galaxy, so the amount of time is more than enough.

You may object that I have surely left out important considerations. Two obvious ones are:

- We've emphasized that if rocky planets are needed for life to develop, heavy elements are essential. Perhaps it is only now that these elements are in sufficient abundance, so much more ancient civilizations do not exist.

- Our time calculation assumes a straight-line journey, but this is a ridiculous oversimplification. There are a few hundred billion stars in our galaxy, which at an average separation of a few light years means that the total distance traveled is around a trillion light years, which could not be traveled by light let alone slow spacecraft in the ~ 14 billion year history of the universe. This is like the Santa Claus problem: going around the world on Christmas Eve is possible, but not visiting billions of houses.

These difficulties are only apparent. For the first, note that a billion years is short compared to the age of the galaxy, and even relatively short compared to the 4.6 billion year age of our Sun. Yes, it is true that a billion years before the Sun formed the average fraction of heavy elements in the universe was less than when our Sun emerged. However, local variations are much more prominent than a mere billion year difference. For example, the larger number of stars per volume closer to our galactic center means that the environment is richer in heavy elements there. In addition, the time it took on Earth to produce an intelligent civilization might have been longer by a billion years than elsewhere. This is a minor issue.

The second is a bit less obvious and requires a necessarily uncertain assumption about the desire of aliens to explore or conquer. Yes, no single ship or contingent of aliens could visit all of our stars in a reasonable time. But think of the following strategy, which again points out the power of exponentials.

Suppose that our aliens send out a ship to the nearest star to them, and this takes 100,000 years to get there. When they arrive, they take 1,000 years to acclimate, breed, and fully settle in. That's a long time; it is for example greater than the time from the

Norman Conquest of England (1066 AD) to now. However, it barely adds to the 100,000 years of travel. After that time, both the original world and the new world send out ships to different stars, taking 100,000 years, and these two new colonies also take 1,000 years to get their local affairs in order. At the end of that period, the four worlds send exploratory ships out, and so on.

This is exponential growth again. After 100,000 years the aliens have two worlds. After 200,000 years, they have four; after 300,000 years eight, and so on. The number of worlds they have can be described by the equation

$$N = 2^{t/100,000 \text{ years}} . \tag{1}$$

This would say that after just 10 million years, the total number of stars they would have would be $2^{100} \approx 10^{30}$, which is actually a hundred million times the total number of stars in the visible universe. Clearly this can't be; the resolution is that after a short time the various colonies would run into each other. The net result is that the bottleneck really is how long it takes to get from one star to another. If a species had a strong planet grab instinct it could easily occupy every single planetary system in our entire galaxy within a billion years.

They wouldn't even have to do it themselves. Another possibility would be to send self-replicating machines that make copies of themselves from the local resources of any system they found.

Incidentally, this argument does *not* work when we consider the distances between galaxies. For example, the nearest big galaxy to ours is the Andromeda galaxy, some 2.2 million light years away. At 30 km/s, the trip would take 22 billion years, i.e., longer than the universe has existed. Civilizations that span a single galaxy are in principle possible with nearly-current technology, given enough time, but ones that range over many galaxies would require significant advances in propulsion.