Order-of-Magnitude Estimation
How big is a massive star? (Level 2)

The Question

What fraction of the stellar mass of the Milky Way Galaxy is in a star that can explode in a supernova?

Background

Our Galaxy, the Milky Way, is big. It is made up of a few hundred billion stars, clouds of gas and dust, a supermassive black hole, and some unknown substance called dark matter. The sun is one of the many stars, and in fact is a somewhat "typical star". Some stars are more massive, some are less so. Most stars will end their lifetime as a white dwarf, or the hot remnant of the stellar core. But more massive stars (about ten times more massive than the Sun) can collapse on themselves and explode in a spectacular supernova.

Guiding Questions

Here are some things you may need to consider:

- How many stars are in the Galaxy?
- What is the mass of the Sun?
- What is the mass of all the stars in the Galaxy?

The Solution

The Sun has a mass of 2×10^{30} kg. Since the Sun is a typical star, we can say that on average stars have the same mass as the Sun (more massive and less massive stars will cancel out — this isn't strictly true, but within an OoM). Therefore, we just multiply the number of stars (approximately 200 billion) in the galaxy by the mass of the Sun to get the total stellar mass:

$$M_{\text{stellar}} = 2 \times 10^{11} \times 2 \times 10^{30} = 4 \times 10^{41} \text{ kg} \tag{1}$$

A star with a mass about ten times the mass of the sun can go supernova:

$$M_{\text{SN}} = 10 \times 2 \times 10^{30} = 2 \times 10^{31} \text{ kg} \tag{2}$$

Therefore, the fraction of Galactic stellar mass in a single massive star that can explode as a supernova is:

$$f = \frac{M_{\rm SN}}{M_{\rm stellar}} = \frac{2 \times 10^{31}}{4 \times 10^{41}} = 5 \times 10^{-11} \tag{3}$$

To convert this to a percentage, we multiply by 100 and find that a single massive star is 0.000000005% of the total stellar mass of the Galaxy.

Education Standards

This OoM Estimation problems meets the following standards in **bold**:
Next Generation Science Standards (NGSS)*:*

- Physical Sciences
  - Matter & Its Interactions
  - Motion and Stability: Forces and Interactions
  - Energy
  - Waves and Their Applications in Technologies for Information Transfer
- Life Sciences
  - From Molecules to Organisms: Structures and Processes
  - Ecosystems: Interactions, Energy, and Dynamics
  - Heredity: Inheritance and Variation of Traits
  - Biological Evolution: Unity and Diversity
- Earth and Space Sciences
  - **Earth's Place in the Universe**
  - Earth's Systems
  - Earth and Human Activity
- Engineering, Technology, and Applications of Science
  - Engineering Design

Common Core Standards (CSS)*:*

- **Counting & Cardinality**
- **Operations & Algebraic Thinking**
- **Numbers & Operations in Base Ten**
- **Number & Operations — Fractions**
- **Measurement & Data**
- Geometry
- **Ratios & Proportional Relationships**
- The Number System
- **Expressions & Equations**
- Functions
- Statistics & Probability