**Origins of Heavy Elements: The r-Process**

Sheldon Wasik

**Abstract**

**1. Introduction**

There are 94 naturally occurring elements in the universe, many of which make up our everyday life. The most common, hydrogen and helium, came about billions of years ago from the Big Bang. The remaining elements, also called metals, are created by stars. (cite <https://physicstoday.scitation.org/doi/10.1063/PT.3.3815> ???) Most of the lower mass elements (A < 26) are created in massive star’s cores by the process of nuclear fusion (should I find a cite???). Examples of these elements are oxygen, which we need every day to breathe, and carbon, which is in a variety of essential items. As we move down and across the periodic table, the elements start to become more massive. About half of these high mass elements (A > 26) are created via the slow neutron-capture process, or s-process. This process occurs over thousands of years and occurs in massive stars that are very luminous but cool in retrospect (AGB stars) (cite <https://arxiv.org/pdf/1810.01788.pdf>). The s-process is a large area of study in the nuclear astrophysics’ world but is a topic for another paper. This paper is going to focus on the remaining region of nucleosynthesis, the r-process.

The rapid neutron-capture process, or r-process, makes up the remaining half of high mass elements. All the sources of the r-process are not entirely known but is an active area of research. With the help of observed distributions of elements in the known universe, as well as computational advances, we can however determine the most likely prospects. To do this, countless studies in the nuclear astrophysics field about the r-process are brought together in this paper. The findings are laid out as following. In section 2, this paper is going to walk through the physics of the r-process, as well as the necessary environment for this to take place. Section 3 is going to present the observational data of heavy elements created by the r-process. Recent and on-going theoretical models that display high mass element distributions will be laid out in Section 4. Ultimately, Section 5 will combine all these ideas together and propose the most likely candidates of the r-process.

**2. Rapid Neutron-Capture Process**

**2.1 Reactions**

The r-process can best be explained by rapid, consecutive neutron captures. Neutron capture is where a nucleus of an atom takes in a free neutron:

AX + 1n → A+1X’ (1)

Note that we see a conservation of nucleons, charge, and leptons. Neutron capture can happen due to the neutral charge of a neutron; therefore, it will not be repelled by the positive nucleus. The quicker neutrons are captured by a nucleus, the greater the mass will be of the resulting nucleus. This is because of the properties of a neutron, which will decay into a proton, electron, and an antineutrino in about 15 minutes. This type of decay is known as beta minus decay:

ZX → Z+1X’ + e− + ve (2)

Until the neutrons start decaying into protons, the atomic number of the element’s nucleus capturing the free neutrons stays the same, while its mass number is increasing. The mass number continues growing until rapid neutron capture is no longer achievable, most of the time due to the neutron density decreasing (discussed in Section 2.2). The resulting nucleus thus has a large mass number relative to the atomic number, as the protons have remained constant. These values cause the “new” nucleus to be extremely unstable.

Unstable nuclei will spontaneously decay into stable nuclei by weak interactions. When there are vastly more neutrons than protons, beta minus decay occurs (described above). This results in the neutron rich nuclei to “create” protons in exchange for neutrons, thus creating a new element. An example of this is platinum decaying into gold, something we have all learned to love and appreciate:

78Pt → 79Au + e− + ve (3)

Note, once again, that there is conservation, and we see a release of an electron and an antineutrino. This spontaneous decay occurs over and over until the limit of the neutron drip line is reached (cite???). This results in a variety of new elements from different masses instead of the same elements over and over.

**2.2 r-Process Environment**

Like stated before, rapid neutron capture can only occur in very specific environments.

* About 100 captures/sec
* 10^24 free neutrons/cm^3 at 1GK
* Atomic numbers in abundance peaks (Section 3)

**3. Observational Element Distribution**

**4. Theoretical Studies**

**5. Likely r-Process Sites**