Analysis of Astronomical Eruptions

Isaac Burmingham
Janek Turk

Introduction

For our final project, we decided we wanted to avoid the COVID popularity and focus on projects that were related to our areas of specialty. We both have backgrounds in Physics, so we decided to try to find some interesting datasets that pertained to this. The first dataset we are using contains fireball & bolide data, and the second contains supernovae data. We have uploaded these and used a Github repository which can be found here to easily work together and divide work. Our primary research goal is to investigate each of these important scientific phenomena individually by examining their properties, and then jointly, how do these high-velocity, highly energetic explosions from each compare, and what do they tell us about the Universe.

Dataset Descriptions

Isaac's dataset is from the NASA JPL Center of Near Earth Objects Studies (CNEOS). This dataset contains fireball and bolide data events from 1988 to 2020. Fireballs and bolides are astronomical terms for very bright meteors, which are large enough to be seen over a wide area. A fireball typically reaches a visual magnitude of about -3 or brighter (roughly the same brightness as Venus). Fireballs that explode in the Earth's atmosphere are referred to as bolides. The primary goal here was to investigate the relationships between basic meteor properties such as mass and energy, and velocity and energy, as well as plot a world map of where these fireballs have been located.

Janek's dataset comes from the The Open Supernova Catalog (OSC). Supernovae occur when the mass of the gaseous layers of a star become too great for the metallic core of the star to support. The resultant shift in weight causes the star to initially collapse in upon itself. Once the acceleration of the outermost regions has been overcome by the pushback from the core, the star ejects the outermost layers in a massive explosion. Due to the unpredictability of these events, much of the data collected is concerning the aftermath detail rather than the initial explosion.

Supernovae come in all shapes and sizes. Stars are understood to form from large gaseous clouds drawn together by gravity until enough pressure exists to initiate nuclear fusion. Jupiter is a case of a gas cloud that never reached the pressure necessary for fusion. After millions of years, the pressure inside the core will grow to push the outer gaseous layers out upwords of the distance of an astronomical unit, AU. This gas eventually grows in pressure and the resultant collapse to the core signals the initial supernova. The remnants of a supernova vary between a white dwarf, neutron star, or a blackhole. The outcome being dependent on the weight of the star. Our sun and any star with a magnitude of its weight should result in a white dwarf. Where any star greater in mass than 10x our sun should result in either a neutron star or blackhole. Not enough is known to easily differentiate between those two results.

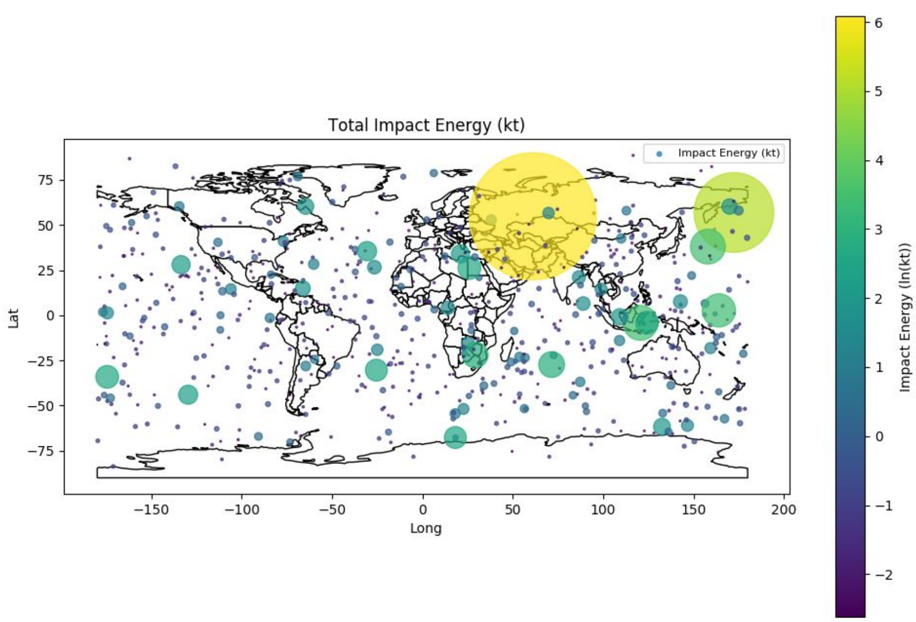
Multiple sources have measured various components of supernova remnants over the last 50 years. OSC has provided a single repository to house the detail of all supernovae experiments and data collection. Beyond providing a comprehensive warehouse, OSC provides an open API for easy access. Unfortunately, there are some limitations to what is provided via the API versus the information provided on the web portal. Each of these limitations will be expanded upon in a description of how the data was collected.

Fireballs & Bolides Analysis

The data from CNEOS can be found here. The dataset has fields for Peak Brightness, position, altitude, velocity, radiated energy and calculated impact energy of classified fireballs & bolides from 1988 to present day. In order to analyze this dataset, I used the Pandas package. The first plot was a recreation of the world map on the data page which used GeoPandas, and the other plots were examinations of relationships of the properties of the fireballs.

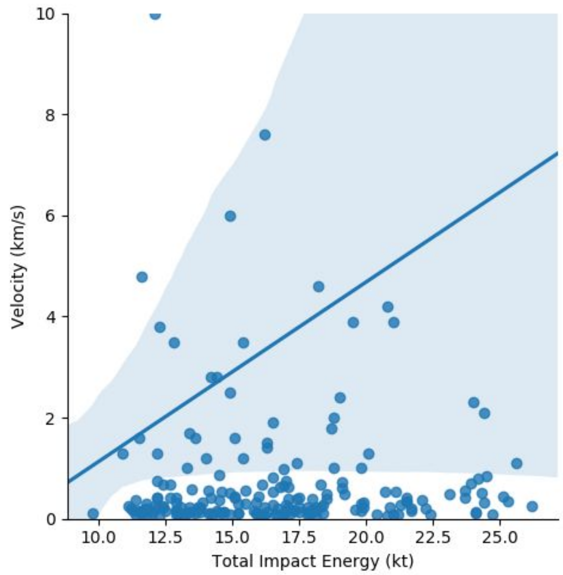
World Plot

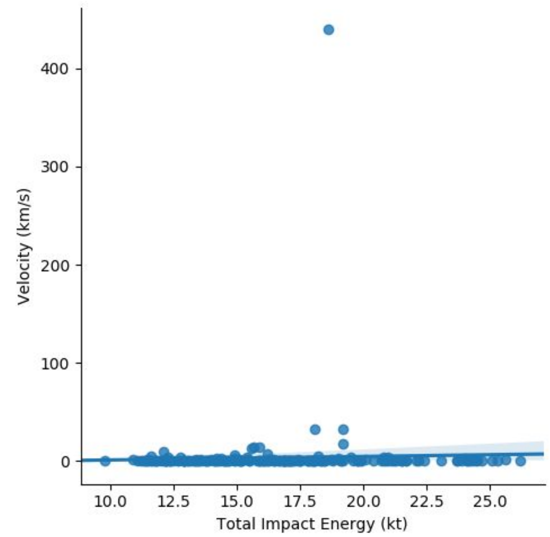
Fireballs and bolides enter the Earth's atmosphere at high speeds, causing the objects to break up in the Earth's atmosphere, either making a bright streak in the sky, or exploding. With the instruments that NASA uses to detect these events, we can determine where these objects are. Using GeoPandas, we can pull a base map for the plot, and then plot latitude and longitude over the map, while using different attributes to produce the scaled points. The points and scale colors are scaled to Impact Energy, to examine if there is any specific distribution between where these objects fall with respect to how bright or large the explosion was. The Impact Energy field is an estimated quantity of energy of how large of the energy output of such an impact would be. As you can see, it is fairly evenly distributed, and we have two large fireballs over Russia. The largest one can be identified as the Chelyabinsk meteor, which was a superbolide which became brighter than the sun.



Velocity Plot

As these objects enter the atmosphere, they enter at very high speeds. This plot was to examine the relationship between velocity, and the total impact energy. There were a couple high outliers, which skewed the data. Using the standard deviation, we tried to cut the data to eliminate these, but they were still some in the data. Below are two plots, with different x-axis ranges to see the true relationship between velocity and energy. We expect a positive relation, based on the basic energy principles.





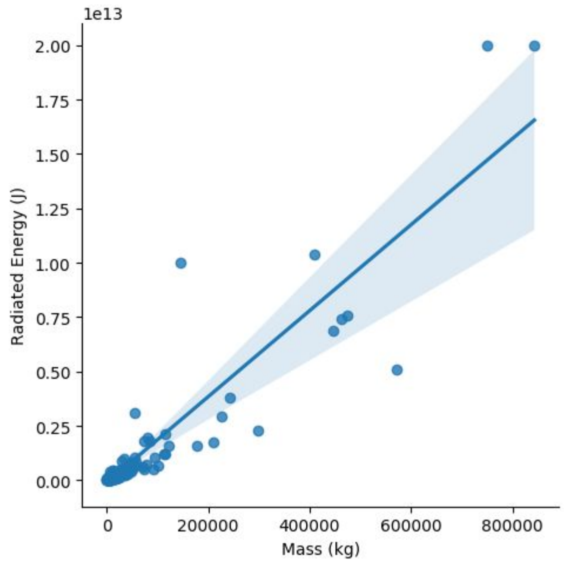
Using the lmplot in the Seaborn package, we were able to plot the scatters, along with a regression line with approximated error. Obviously, there is a high distribution that are much lower, as most of the fireballs have a velocity of < 2 km/s. But, we still see the positive correlation between velocity and energy that we expected.

Mass Plot

In order for these objects to have this much velocity and have this much energy, they must be large, massive objects. Using the following equation, which is derived from kinetic energy, we were able to calculate mass of each fireball object.

$$m = \frac{2E}{v^2}$$

The energy we used to calculate the mass was the impact energy, we plotted the relationship between the mass of the object, with it's radiated energy. Which as the equation implies, should also produce a positive relationship, which we can see is true below.



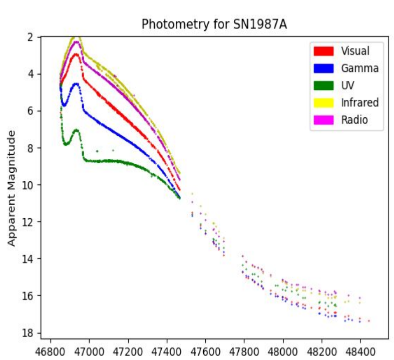
As you can see, these can be very massive objects, and the more massive the are, the more energy they give off when they enter the atmosphere.

Supernovae Analysis

The analysis of a supernova was completed on the object SN1987A, where the number indicates the year the object was discovered. All data collected was acquired through the website [The Open Supernova Catalog](). The page concerning object SN1987A can be found here, [SN1987A](). The plots generated are recreations of the graphs presented on the page for the supernova.

Photometry Plot

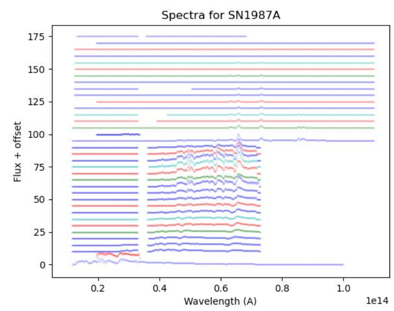
The spectrum of light is separated into about a dozen different sections. Each section is named according to how we utilize the bandwidth. One such example is radio waves, which are used for radio communication. When talking about photometric measurement, we are measuring the brightness or intensity of a light source in a given spectrum. For the visible spectrum of light, the source is typically measured through a refractive telescope where CCD imaging measures the light gathered.



Brightness is an inverted log scale, which implies that as the magnitude of brightness increases the luminosity is decreasing at an exponential rate. Apparent magnitude (measured on the left hand side of the graph) is the measure of brightness relative to the Earth. In contract, Absolute magnitude (measured on the left hand side of the graph) is the measure of the brightness the object is actually emitting. In reference to the Earth, the apparent magnitude of the object is quite dim. However, comparing the values for the absolute brightness, it is apparent that this is a very bright object that is simply very far away.

Spectra Plot

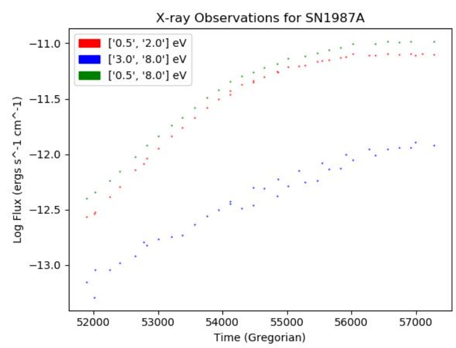
At the turn of the century Dr. Einstein discovered that materials emit a photon at particular wavelengths called the photoelectric effect. Inversely, materials can be resolved by matching wavelength patterns to the intensities found at varying wavelengths. Typically a transparent printout of an unknown source is laid over the top of known materials.



The spectra plot is that of flux intensity over a wavelength range. The intensities are scaled and each plot is given an incrementing offset to avoid them laying over each other. Each line is a separate measurement of the supernova.

X-Ray Plot

Similar to the spectral analysis, x-ray emission readings give the activity in an object. Heavy materials such as iron will emit x-ray radiation. The number of interactions occurring should result in a greater amount of energy radiated. Our instruments measure within a band of energy (eV), the different bands are plotted as described by the legend. The plot below gives the measurements as in inverse log scale. As with the magnitude of light, a positive slope corresponds to a loss of energy radiated over time. Such is the case with supernova SN1987A, the data is plateauing at constant values.

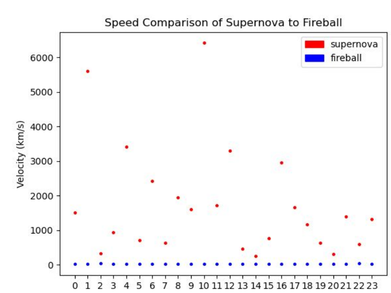


Joined Datasets

We chose to compare these astronomical objects by velocity, energy, and brightness.

Velocity Comparison

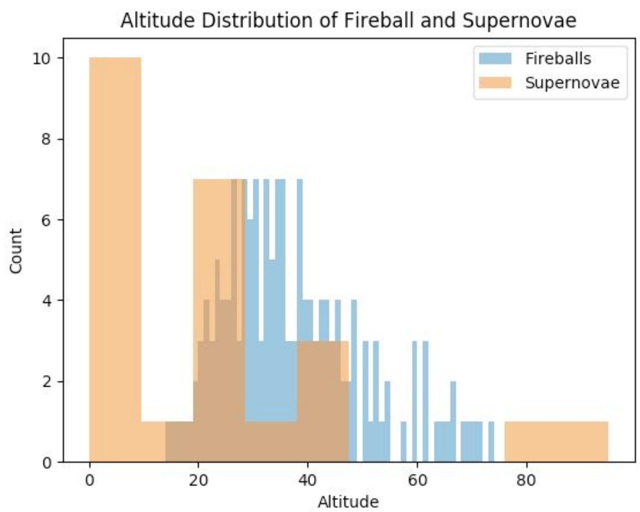
When comparing velocities, it is important to define the reference frame we are using to describe an object. For supernovae, the original star is most typically the center of some solar system existing in a galaxy much like our Milky Way. So the speed given is the travel speed of the resultant object through it's galaxy, which is typically measured in respect to the speed of our sun. The speed for our fireball incidence is the impact speed on it's descent into the atmosphere. Both systems are primarily driven by the force of gravity. The supernova has the excess energy from the molecular reactions occurring within itself. The equation for gravity depends on the mass of both objects affected. Thus supernovae are not only pulled by a larger object but are also a larger object themself. The



range of fireball velocities is limited by the size of the original asteroid as the impact of the earth is the same for all instances.

Altitude/Distance Comparison

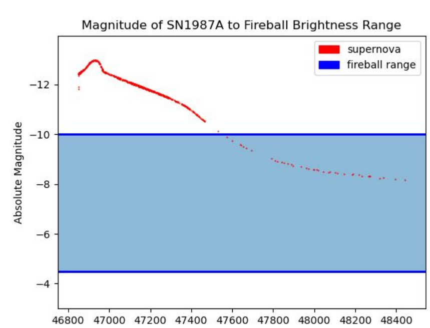
Next, we wanted to compare the distribution of the altitude of the fireball objects, to the distribution of the distances of the supernovae. In order to do this, we used the altitude field that was given in the fireball dataset, and then pulled the comoving distance for each supernova and then used a histogram to plot both histograms over each other.



Units were ignored here since the altitude of the fireballs were in km, while the supernovae were in megaparsecs, so they would not be in the same range. As you can see, there is fewer supernovae data points, so the distribution is not as full as the fireball set. It is interesting to note that the fireball distribution looks almost normal, while the skewed left.

Brightness Comparison

The brightness of a fireball is described as a meteor having an absolute magnitude greater than Venus. Venus has a brightness magnitude of -4.5. Most fireballs do not exceed a brightness of -10 due to the size of the objects. I've compared this range to the brightness of supernova SN1987A. The graph below shows that the initial blast was around 1000 times the brightness. We do not see an object of such intensity because of the vast distance, however, adjusting for distance and redshift parallax, we can estimate the actual brightness. The supernova object dwindles, but is still on the upper half of the fireball range. The reason the brightness holds roughly constant is due to the reactions occurring after the initial blast. New stars might have formed due to the distribution of matter.



Conclusion

Astronomical objects range from space dust to super black holes. The vastness of space is best described by Dr. Sagan's quote as he describes the Earth as a pale blue dot. At our level of experience, the Earth is a complex interconnected ecology spreading thousands of miles comprising what we call life. However those distances and interactions are miniscule compared to the intricacy of our own solar system. This is an unknown that has driven humanity toward exploring space since before society existed.

In our paper, we look at comparing two reactive objects viewable from Earth, fireballs and supernovae. Fireballs are much more crucial to life on Earth as they pose a relatively serious threat to human life. Agencies around the world look to monitor asteroids which are likely to fall under the pull of Earth's gravitation. With some billion asteroids orbiting outside of Mars, we are both protected from outside objects, but also liable to have life put out if one large enough falls. Supernovae are typically studied with the intent of answering questions concerning the early stages of the universe, solar systems and the nature of atomic interactions. They provide insight that we would otherwise have to wait thousands of life times for answers.

These objects are very distinct in their nature, however our scientific process allows us to view them under the same criteria. Which can be used to correlate data and possibly find breakthroughs in energy, material or any field applicable. It is up to curious scientists to ask questions others would not in the pursuit of discovering something that might change everyone's life.

Addendum

Isaac Code

```
usage: fireball.py [-h] [-he] [-o <outfile>] [-p {map,velocity,mass}]
                   <command>

Analyze NASA Fireball data

positional arguments:
  <command>             command to execute

optional arguments:
  -h, --help            show this help message and exit
  -he, --header         get the first 5 rows of the DataFrame
  -o <outfile>, --ofile <outfile>
                        file to write to, default is standard output
  -p {map,velocity,mass}, --plot {map,velocity,mass}
                        Plot the output with by either the map, velocity or
                        mass
```

The script is run by compiling fireball.py. The script has a command argument called 'print'. This will print out the dataset to the file if specified, or to stdout. It also has 3 other arguments: -he, -o, -p.

- To print out the help description, call with '-h' option
- To print the header of the dataset, call the '-he' option
- To print to a csv file, call the '-o' option and specify the filename
- To print the plots, call the '-p' option, and then call either 'map', 'velocity' or 'mass' for each respective plot

Janek Code

```
Anaconda Prompt (anaconda3)

(base) C:\Users\janek\Documents\Python Scripts\3006 Final Project\Janek Portion\Scripts>python main.py -h
Building argument parser
Parsing arguments
usage: main.py [-h] [-p] [-s] [-x]

Plot data on supernova

optional arguments:
  -h, --help        show this help message and exit
  -p, -photometry   plot photometry data
  -s, -spectra      plot spectral data
  -x, -xray         plot xray data
```

The script is ran by compiling the script main.py. This script has no command arguments. It has 4 option arguments: -h, -p, -s, -x.

- To print out the help description shown above, call the script with '-h' option set
- To print out the photometry plot, call the script with '-p' option set
- To print out the spectra plot, call the script with '-s' option set

- To print out the x-ray plot, call the script with '-x' option set

Combined Code

```
usage: main.py [-h] [-v] [-b] [-a]

Plot data on supernova

optional arguments:
  -h, --help       show this help message and exit
  -v, -velocity    plot velocity scatter plot
  -b, -brightness  plot brightness comparison plot
  -a, -altitude    plot altitude distribution of fireballs and Supernovae
```

The script is ran by compiling the script main.py. This script has no command arguments. It has 4 option arguments: -h, -v, -a, -b.

- To print out the help description shown above, call the script with '-h' option set
- To print out the comparative velocity plot, call the script with '-v' option set
- To print out the comparative altitude distribution plot, call the script with '-a' option set
- To print out the comparative brightness plot, call the script with '-b' option set