Stellar Collisions: A Visual Odyssey of Asteroids on Earth's Canvas

Tinu Thomas
Kings College London

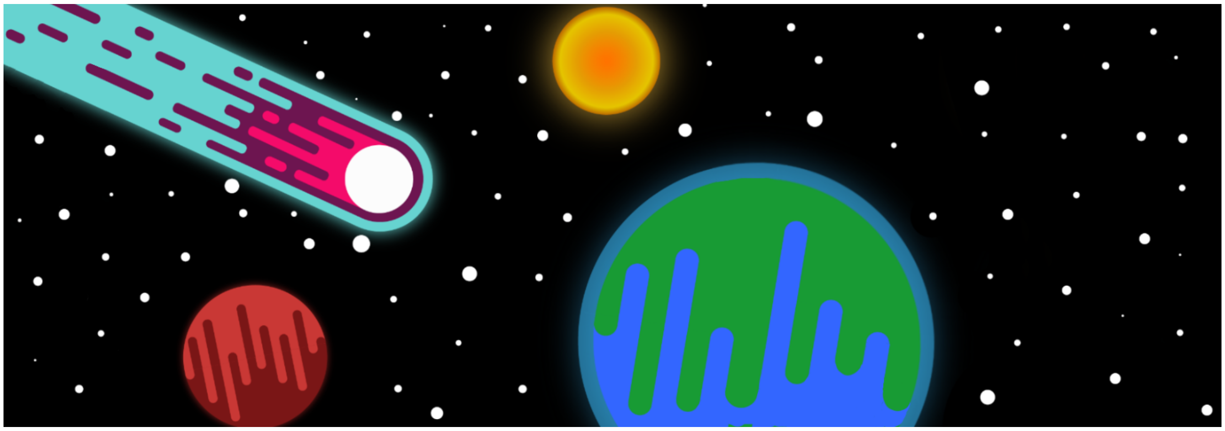

Figure 1: An abstract illustration of an asteroid striking past celestial bodies [41].

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Introduction

In the vast cosmic expanse, celestial phenomena such as asteroids and meteors have captivated human imagination for millennia, their enigmatic dance etching a trail of awe and scientific inquiry. The night sky, a canvas adorned with the shimmering brilliance of countless stars, bears witness to the fleeting yet luminous spectacle of meteors streaking across the celestial tapestry.
Let us embark on a journey to unravel the mysteries of these celestial travellers. At the heart of our exploration lies asteroids, ancient remnants of the early solar system, often referred to as building blocks of planets. These rocky bodies, ranging in size from mere meters to hundreds of kilometres in diameter, orbits the Sun in a perpetual cosmic waltz, predominantly congregating within the asteroid belt between Mars and Jupiter [6].
Now, let us meet their ethereal counterparts - the meteors. These luminous apparitions paint the night sky with their fiery descent, captivating observers with their ephemeral beauty. But what distinguishes a meteor from it's rocky kin? When an asteroid ventures too close to Earth and plunges through our atmosphere, it undergoes a metamorphosis, blazing across the sky as a meteor. Should any fragments survive the fiery descent and land upon our planet's surface, they earn the title of meteorite - a tangible relic of our cosmic heritage [12].
But make no mistake; amidst the awe-inspiring spectacle, lies a sobering reality: these celestial enigmas harbour the potential cataclysmic upheaval. Recall, if you will, the fateful collision that altered the course of Earth's history - the asteroid impact that extinguished the reign of the dinosaurs. This harrowing tale serves as a stark reminder of the peril posed by these wandering giants, capable of reshaping entire ecosystems in the blink of an eye [1].
To understand the physics behind these celestial phenomena is to grasp the essence of our cosmic ballet. From the gravitational tango that shapes asteroid trajectories to the fiery spectacle of meteor entry, each event is a testament to the intricate dance of celestial mechanics.
As we embark on this odyssey of discovery, let us gaze upon the heavens with newfound reverence, for within its depths lie in the stories of our past, present and perhaps, our future. The study of asteroids and meteors transcends mere scientific inquiry, offering a gateway to unravelling the mysteries of our cosmic origins and the intricate mechanisms that govern the universe.

1 Part 1 : Analytics

1.1 Exploratory Research Questions Proposed

Q1 : Explore the distribution patterns of asteroids within the solar system. What insights can be gleaned regarding the spatial arrangement and clustering of asteroids?
Recent research and astronomical observations have revealed the distribution patterns of asteroids in the solar system, with gravitational interactions, collisions, and dynamical resonances identified as key factors shaping their arrangement [30]. Utilising the Asteroid dataset [2] from Kaggle, this study explores the spatial organisation of asteroids and its implications for celestial mechanics.

Q2 : How do the interrelations among albedo, diameter, absolute magnitude, eccentricity, inclination and semi-major axis among asteroids offer insights into their composition, size distribution and orbital characteristics?
The examination of Asteroid Dataset [2] elucidates the interrela-

tion among asteroid characteristics across various asteroid classes. While certain classes display notable correlations, others exhibit more intricate patterns, suggesting diverse underlying mechanisms [27]. This study helps to deepen our understanding of asteroid characteristics and their classification complexities.

Q3 : Analyse how have the global spatial distribution and characteristics of meteorite falls evolved over successive years, are there discernible trends in their occurrence over time?
Analysing the global spatial distribution and characteristics of meteorite falls reveals evolving trends over successive years, including spatial clustering and regional variability. The frequency of meteor falls showcases temporal fluctuations, offering insights into rhythmic pulse of cosmic impacts and their implications for Earth's geological and atmospheric process [39]. Through meticulous analysis of Meteorite Strike Dataset [34], our study endeavours to address these inquiries.

1.2 Data Types and Datasets

In exploring asteroids within the solar system, researchers will rely on astronomical and orbital data [11]. The datasets used for this study include the ***Asteroid Dataset*** [2], containing information crucial for discerning distribution patters and the ***Meteor Strike Dataset*** [34] offers different parameters useful for observing the spatial distribution and fall rate of meteorites over time. These datasets house observational and numerical data, vital for empirical analysis and statistical modelling to address research questions effectively.

1.2.1 Asteroid Dataset

Research questions 1 and 2 relies on the Asteroid Dataset [2] available on Kaggle. The dataset under consideration presents a comprehensive array of parameters essential for exploring the distribution patterns of asteroid within the solar system [26]. With variables ranging from object identification to orbital characteristics and physical properties, this dataset offers a robust foundation for analysing the spatial arrangement and clustering of asteroid. The inclusion of parameters like perihelion distance, aphelion distance, epoch, inclination, semi-major axis and asteroid class facilitates the elucidation of orbital dynamics, potentially revealing gravitational resonance and clustering phenomena [29].
The dataset contains the attributes such as absolute magnitude (H), eccentricity (e), semi-major axis (a), inclination (i) , asteroid diameter (diameter), and geometric albedo (albedo), which are pivotal for investigating the interrelations between asteroid characteristics across different classes. These attributes provide a rich source of information for examining variations in these relations within distinct classes, thereby making the dataset an appropriate resource for addressing the research question at hand.
This dataset's comprehensiveness distinguishes it from others, as it incorporates crucial attributes necessary for through spatial analysis, unlike other datasets that may lack essential orbital or physical parameters [9]. However, challenges such as data incompleteness or inaccuracies in certain measurement may affect the precision of analyses, necessitating rigorous data validation procedures [13].
Moreover, the dataset is provided in CSV format, it facilitates straightforward data manipulation and integration with analytical tools, further enhancing its utility for addressing research inquiries concerning asteroid distributions.

1.2.2 Meteor Strike Dataset

In order to visualise the global spatial distribution and temporal frequency of meteorite falls comprehensively, the meticulous recordings of temporal data alongside precise location coordinates emerges as indispensable variables of significance. We are leveraging on the Meteor Strike Dataset [34] available on GitHub for the analysis. With attributes including meteorite mass, location coordinates, fall type, and year of occurrence, this dataset provides a comprehensive foundation for temporal and spatial analysis [25]. The precise location data facilitates mapping meteorite falls across regions, identifying spatial patterns and temporal trends. The temporal dimension, represented by the year of occurrence, enables examination of meteorite fall evolution, revealing potential environmental or astronomical influences.
Unlike datasets focused on broader astronomical events, the granularity of this dataset allows for targeted analyses specifically tailored to meteor falls, enhancing accuracy and relevance of findings. However challenges may arise from data incompleteness or inaccuracies particularly regarding historical meteorite falls where documentation maybe limited [14].
Presented in JSON format, this dataset offers advantages in terms of flexibility and ease of integration with modern web-based analytical tools and programming languages [8]. The hierarchical structure of JSON allows for efficient storage and retrieval of data, facilitating fluid data manipulation and analysis. Moreover the human-readable nature facilitates data interpretation and sharing, enhancing collaboration and reproducibility in scientific research endeavours.

1.3 Correlation

The ***Asteroid Dataset*** [2] and ***Meteorite Strike Dataset*** [34] provide valuable insights into celestial bodies and their interactions. The asteroid dataset includes parameters like orbital and physical parameters which contribute to understanding asteroid characteristics and behaviours. Additionally, the meteorite strike dataset, although seemingly distinct, correlates with the asteroid dataset in a significant way. Meteorites are often born from asteroid fragments, indicating a relationship between meteorite falls and asteroid events. While the datasets provide abundant resources to work with, they may encounter uncertainties in measurement, which could affect their reliability; however, acknowledging these challenges facilitates the adoption of appropriate methodologies to ensure robust analyses. Thus despite potential limitations, the datasets collectively offer valuable insights in to celestial dynamic and interactions, enhancing our understanding of the universe's complexities.

2 Part 2 : Design and Discussion

In the domain of data visualisation, various concepts converge to create compelling and informative representations of data. These elements are crucial for elucidating complex information clearly and engaging viewers effectively. They can be categorised into four main areas:

- **Colour** : Colour is pivotal for conveying information, differentiating categories, and evoking perceptions. A well-chosen colour scheme enhances clarity, aiding data interpretation. Colours represent quantitative values, highlighting specific data points, facilitating effective communication.
- **Shape** : Shape serves as a visual cue to represent different categories or attributes within the data, aiding pattern recognition and comparison. Assigning distinct shapes to data points or groups enhances visualisation's effectiveness in conveying information.
- **Size** : Size is instrumental in indicating magnitude or importance within visualisations. Varying the size of data points or graphical elements effectively highlights trends, patterns, or outliers, enhancing audience understanding.
- **Aesthetics** : Aesthetics encompass design principles such as layout, typography, and white-space, enhancing visual appeal and user experience. Aesthetically pleasing visualisations are more engaging and memorable, effectively conveying information and insights.

These concepts are fundamental to creating effective and impactful visualisations, enabling clear communication of data to the audience. In this exploration, we examine the significance of colour, shape, size, and aesthetics, showcasing their roles through illustrative examples.

2.1 Exploring Asteroid Distribution Patterns and Spatial Clustering within the Solar System

To effectively encapsulate the first research question, we opt for the utilisation of an interactive 3D scatter plot as our primary visualisation tool (see Figure 2). A scatter plot, a cornerstone technique in statistical graphics, is adept at elucidating the relationship between variables by positioning individual data points on a Cartesian plane [15]. The rationale behind selecting the scatter plot lies in its inherent capability to vividly portray the spatial distribution - in our case, the asteroids. Each data point within the scatter plot represents an asteroid, with its position signifying its celestial coordinates within the solar system. This choice in underpinned by the scatter plot's capacity to accommodate multivariate data, thereby enabling the integration of various classes of asteroids into a cohesive visual representation.

In implementing the scatter plot visualisation, we propose leveraging distinct geometric shapes and meticulously chosen colour palette to bolster clarity and facilitate interpretation [10] Each asteroid will be represented by a round/circular shape; the selection of colours will adhere to principles of perceptual uniformity and contrast, effectively distinguishing between asteroid classes [18]. This approach ensures inclusivity and legibility across diverse audience by accommodating users with carious type of colour vision deficiencies. The choice of round/circular shape for representation ensures consistency and ease of interpretation, minimising visual clutter and focusing on spatial distribution. The scale of the scatter plot was determined by considering the range and distribution of variables to accurately represent the data without distortion.

To enhance user interaction and exploration, the incorporation of features such as dynamic selection of asteroid classes directly from the legend and detailed tool-tips providing pertinent information about selected classes is undertaken. When hovered over, the asteroid representation colour will darken and a tool-tip will display relevant information. Additionally, users will have the ability to zoom, pan, perform orbital and turntable rotations for better exploration. They will also be able to download the selected distribution as PNG. Moreover, an option to toggle the visibility of tool-tips is included to provide users with flexibility in their viewing preferences.

Potential challenges such as data overlap are addressed using techniques like transparency and jittering to enhance visibility.

2.2 Investigating the Interrelations Between Asteroid Characteristics Across Different Asteroid Classes

In addressing the research question concerning the interrelations among albedo, diameter, absolute magnitude, eccentricity, inclination and semi-major axis of asteroids, the selection of an appropriate visualisation method is pivotal. The utilisation of a parallel coordinates plot (see Figure 3) is advocated for its capacity to concurrently compare the primary characteristics of asteroids [32]. Colour selection serves as a vital component for facilitating comprehension and interpretation within the visualisation. Employing a categorical colour scheme aids in distinguishing various class categories, thereby offering insights into their inherent properties [28]. Furthermore, the parallel coordinates plot's straightforward design, with straight lines connecting each axis, ensures clarity and ease of interpretation [21]. Moreover, the determination of scale of each axis is essential to accommodate the extensive range of values exhibited by asteroids, Linear scaling methods are employed based on the distribution of data points, thus adverting the disproportionate representation of characteristics [16].

Through this visualisation, we can discern intricate patterns and correlations among asteroid characteristics, thereby inferring valuable insights into their composition, size distribution, and orbital characteristics. By exploring these relationships, researchers can gain profound insights into asteroid properties [43]. For instance, correlation between albedo and diameter may suggest disparities in surface composition, while correlation between eccentricity and inclination could elucidate the dynamical of asteroid families [33].

Additionally, integrating interactive features such as tool-tips, filtering option to select specific class of asteroids, zoom and pan functionalities, and linked view (scatter plot matrix (SPLOM) & box plot) enriches the visualisation, rendering it more engaging and conducive to comprehensive analysis [32, 28, 21]. Through incorporation of these interactive elements, the visualisation not only serves as an informative toll but also fosters an immersive user experience, encouraging active exploration and interpretation of asteroid properties.

2.3 Analysing the Evolution of Global Spatial Distribution and Characteristics of Meteorite Falls Over Successive Years

For our inquiry into meteorite spatial distribution and temporal trends, our visualisation design adheres to principles of clarity, interactivity, and informativeness, aligning with best practices in data visualisation [17, 20]. For this analysis, we are proposing two visualisation, in which the first one illustrates the distribution of meteorites across the glob (see Figure 4) and the second one portrays the temporal trends of the fall (see Figure 5). The design rationale encompasses thoughtful consideration of colour selection, shape representation, and scale determination to optimise data comprehension [7, 42].

Our primary visualisation method entails a dynamic world map illustrating meteorite landings, allowing users to interact via zooming, panning, and hover-over functionality to access detailed information such as meteorite name, fall year, mass, and class. Colour coding was employed to denote meteorites, aiding rapid identification and interpretation [36].The interface furnishes users with two adjustable sliders facilitating the selection of a specified temporal range for the observation of meteorite falls within the designated time-frame. Moreover, supplementary functionalities, including the option to reset the visualisation's zoom level and to download the displayed visualisation in PNG format, are provided to enhance user experience and analytical capabilities. Circles were chosen as the shape for representing meteorite ladings on the map, with sizes proportional to meteorite sizes, facilitation intuitive comparison [44]. The logarithmic scale was adopted to accommodate the wide range of meteorite sizes wile maintaining visibility and preventing visual cutter [35].

The secondary visualisation, which allows as to illustrate the meteor fall rate over the year comprises of line graph, facilitating observation of temporal trends. The straightforward visualisation is augmented with animation functionality to elucidate the temporal evolution of meteorite falls and a date selection feature enabling users to focus on specific time intervals [38].

By adhering to established principles of data visualisation and incorporating user-centric interactive features, our visualisations offer comprehensive insights into meteorite spatial distribution and temporal dynamics, fostering deeper analysis and understanding of the dataset [40].

3 Part 3 : Implementation

The meteorite strike dataset [34] is obtained from a JSON file hosted on GitHub. The data includes information such as the meteorite's name, class, mass, year, and coordinates. The world map data is fetched from the world-atlas library. The meteorite data is then processed to extract the necessary information and mapped onto the world map using D3.js. The meteorite locations are represented as circles on the map, with the size of the circles corresponding to the mass of the meteorites. The data is filtered based on the selected year range using the sliders, and the displayed meteorites are updated accordingly.

The creation and visualisation of geographic data through D3.js follows established methodologies [19]. GeoJSON data is retrieved via d3.json(), with cartographic rendering using d3.geoPath() and d3.geoMercator() [4, 3]. For meteorite data, d3.json() loads external data, with representations as ¡circle¿ elements using d3.scaleSqrt() and d3.scaleOrdinal() for size and colour [4]. Zoom and pan functionality are implemented with d3.zoom(), enhancing interactivity [5]. Year range sliders and tool-tips demonstrate D3.js versatility in UI design and interaction [4]. Download functionality uses standard web techniques for converting SVG to PNG, enabling offline use [31]. Overall, these practices reflect D3.js' capacity for engaging and informative visualisations [37].

3.1 WebApp Live

The live viewing of the visualisation can be accessed via the designated link: https://tiinuthomas.github.io/tiinuthomas-meteoritelandings.github.io

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A APPENDIX

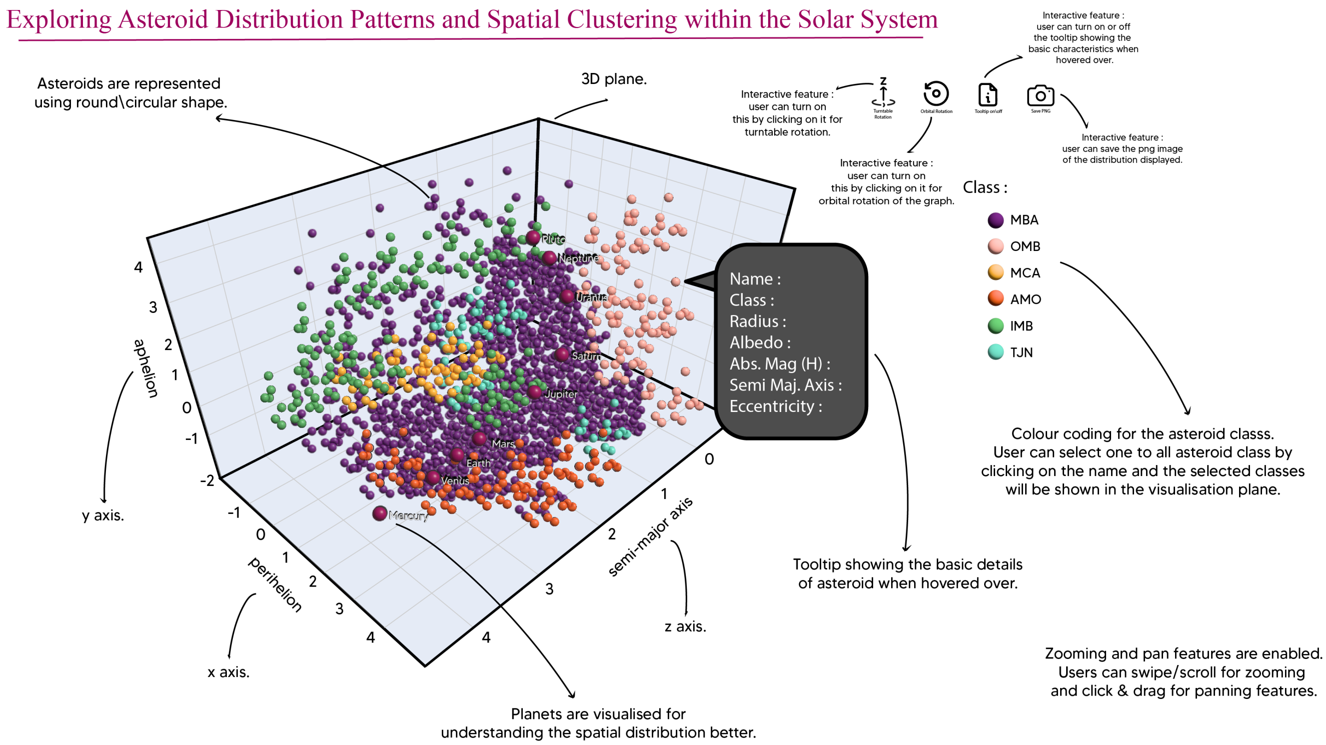

Figure 2:
Concept art: Exploring asteroid distribution patterns and spatial clustering within the solar system.
Inspiration: Asteroid Dataset - Exploration on Kaggle [22]
Link : https://www.kaggle.com/code/wumanandpat/asteroid-dataset-exploration

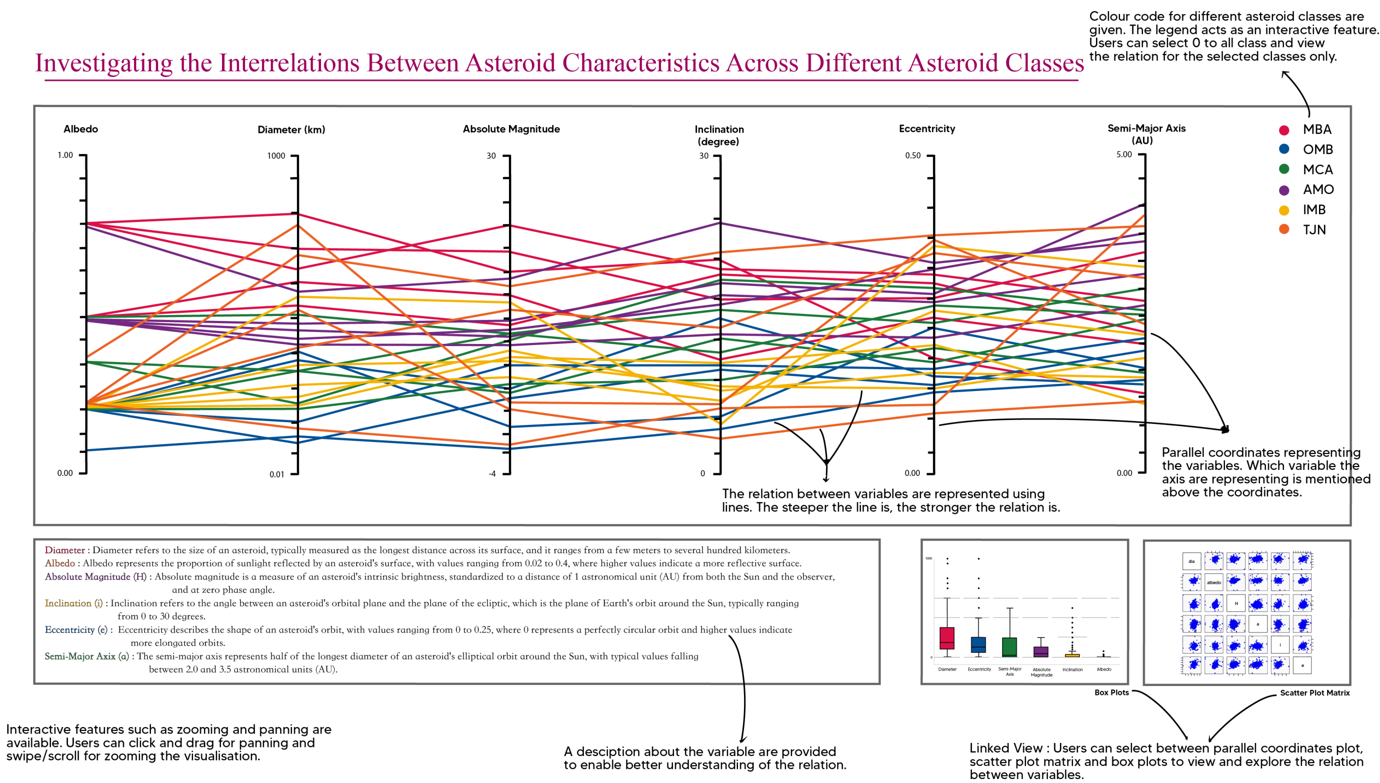

Figure 3:
Concept art: Investigating the Interrelations Between Asteroid Characteristics Across Different Asteroid Classes

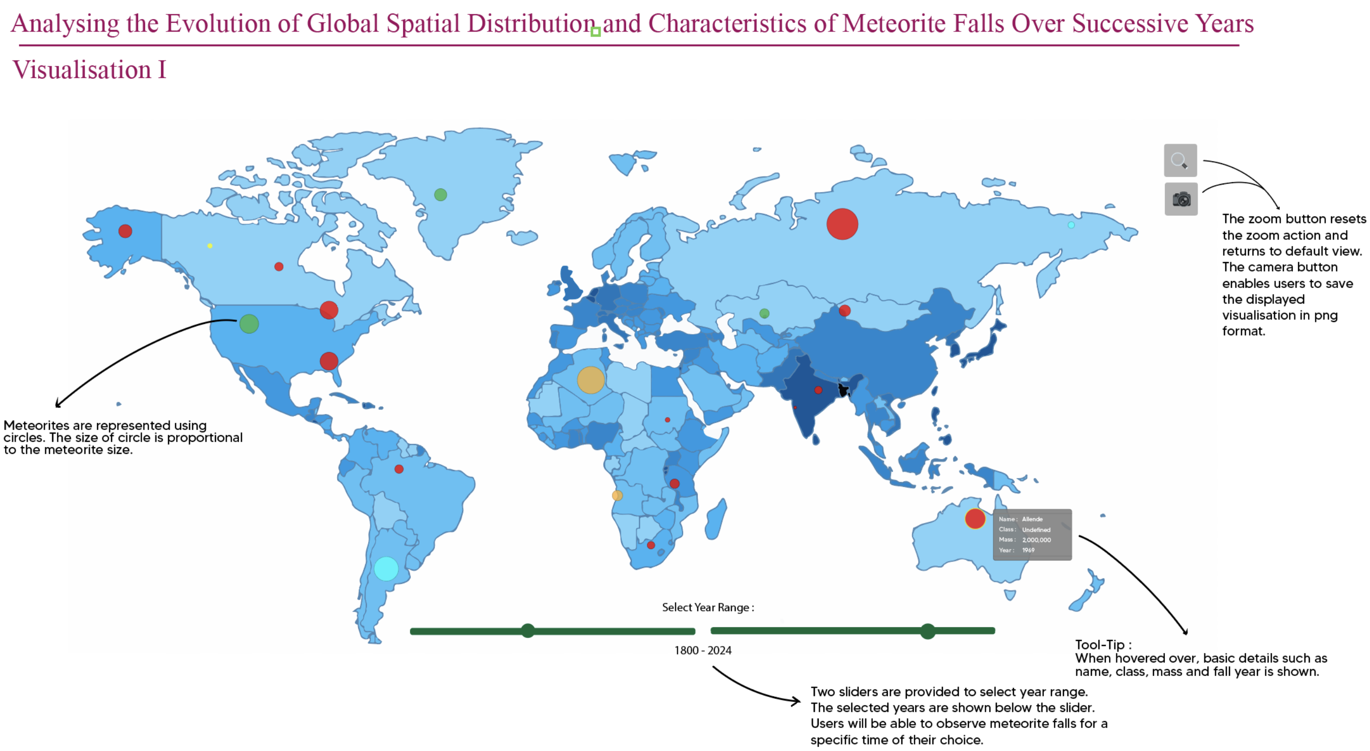

Figure 4:
Concept art: Analysing the Evolution of Global Spatial Distribution and Characteristics of Meteorite Falls Over Successive Years - Visualisation I
Inspiration : Map Visualisation Using D3 [23]
Link : https://github.com/abkunal/Map-Visualization-using-D3

Analysing the Evolution of Global Spatial Distribution and Characteristics of Meteorite Falls Over Successive Years

Visualisation II

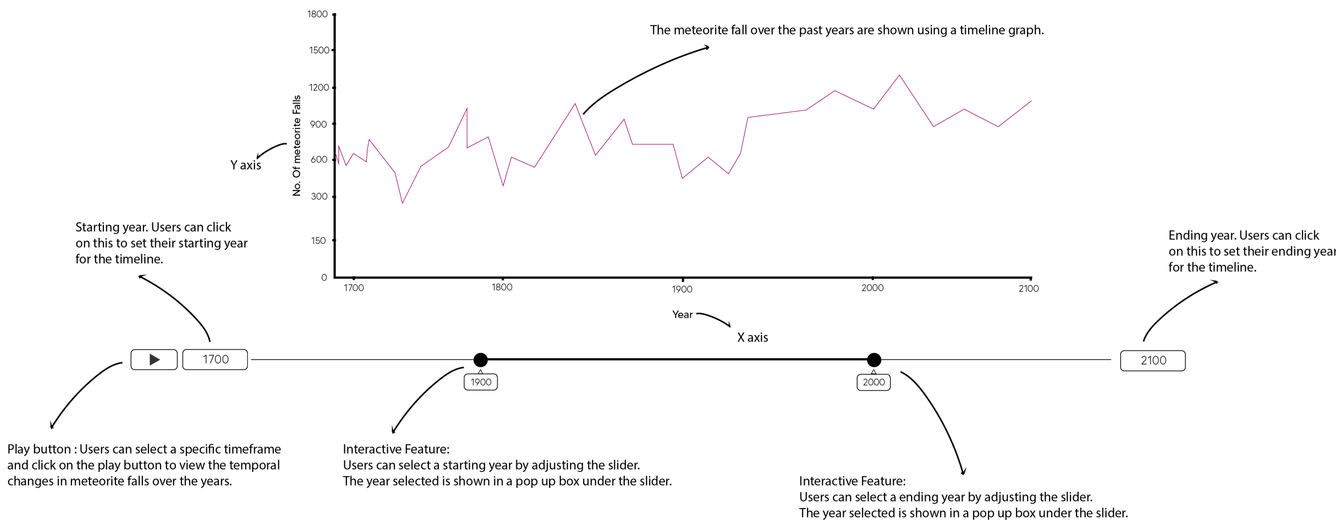

Figure 5:
Concept art: Analysing the Evolution of Global Spatial Distribution and Characteristics of Meteorite Falls Over Successive Years - Visualisation II
Inspiration : International Financial Support to Infrastructure [24]
Link : https://ourworldindata.org/grapher/total-oda-for-infrastructure-by-recipient?tab=chart