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Overview and Motivation:

We decided that this topic would be interesting to undertake so we can learn about all the missions that have taken place over the course of time as we are all passionate about Space Exploration. Since there is an increase in the desire to explore space and the many things that it contains, the space race in the private space exploration industry has completely ramped up especially since it is in the early stages. This is because many companies out there have increased the frequency and depth of their research. Some notable companies that have done this are SpaceX, Blue Origin, Virgin Galactic, and Rocket Lab Electron.

Looking back at all the previous missions that have taken place we can now give better insight towards how all of these things have progressed over the years at NASA. There are often many different costs associated with missions in space and observing the data from previous missions can show how cost effective space exploration has been since the end of the Apollo missions.

Related Work:

The main inspiration for this visualization were both the visualizations discussed in class as well as the visualizations discussed throughout the meetings with Dr. Iuricich. The discussions surrounding streamgraphs, bar, and pie charts were particularly insightful and all led to the final iteration of the visualization.

Questions:

With this project we look to examine how operational costs, timelines, and mission specifications can shape a space faring mission. Naturally, the questions one must ask in order to examine previous missions include asking what combination of logistical constraints result in a more favourable outcome? How much does the overall budget influence other factors of the mission? Some of the benefits that we could foresee is if we are able to find a very cost effective means of launch, operations, and research to other planets then we could see many more explorations leading to new research and data being found.

Data:

The data from the above link is collected from The Planetary Society's website which collected the data from the following sources:

- Planetary Science "Actuals", 1998-2001. Callahan, Jason. "Budgeting for Exploration: History and Political Economy in Space Science 1959-2010" Presented at the AAS 45th Meeting of the Division for Planetary Sciences, Denver, Colorado. October 7, 2013.
  All other data compiled from original NASA budget estimates and reporting documents provided to Congress from 1961 to now.
- https://www.planetary.org/space-policy/every-nasa-budget-request , https://docs.google.com/spreadsheets/d/1QW8MaPWa2YXDik52h4M0LN4SVc_tINoFEwashbaOjgE

The dataset provided by The Planetary Society was stored in csv files and required minimal clean up. The data has been well organized in terms of mission types, years, and timeline of the

mission. There was light preprocessing applied in order to better fit the constraints of the dataset as there are some missions with missing data.

Exploratory Data Analysis:

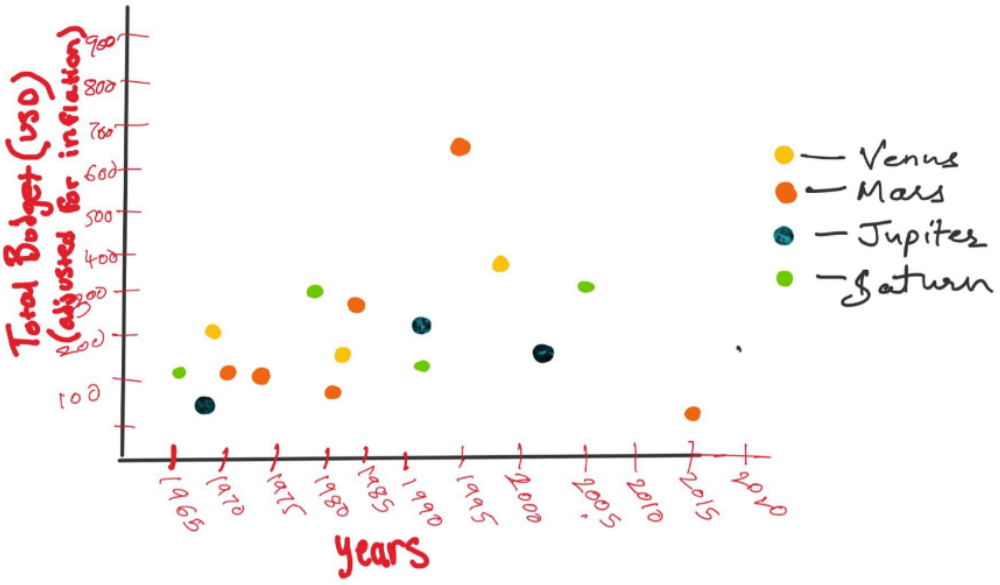
The initial visualizations we used to initially examine the data were included in the Google sheets document in which the dataset is contained. The graphs allowed us to view the change in cost over time, which showed us that there were interesting questions to be found in cost breakdowns.

Design Evolution:

The design has gone through a few iterations to improve the clarity of the data being presented and understood by the user.

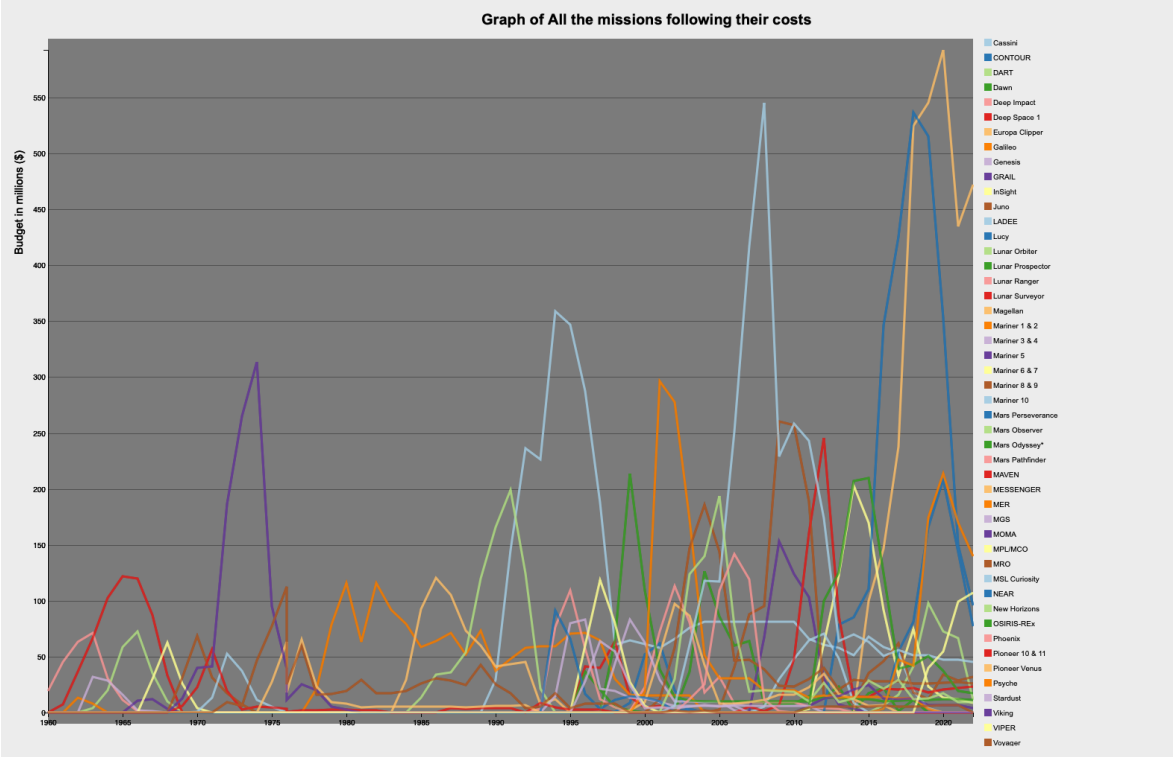
From the project proposal, we decided to pick the following graph for our main graph that contains the entire dataset.

The Main Graph



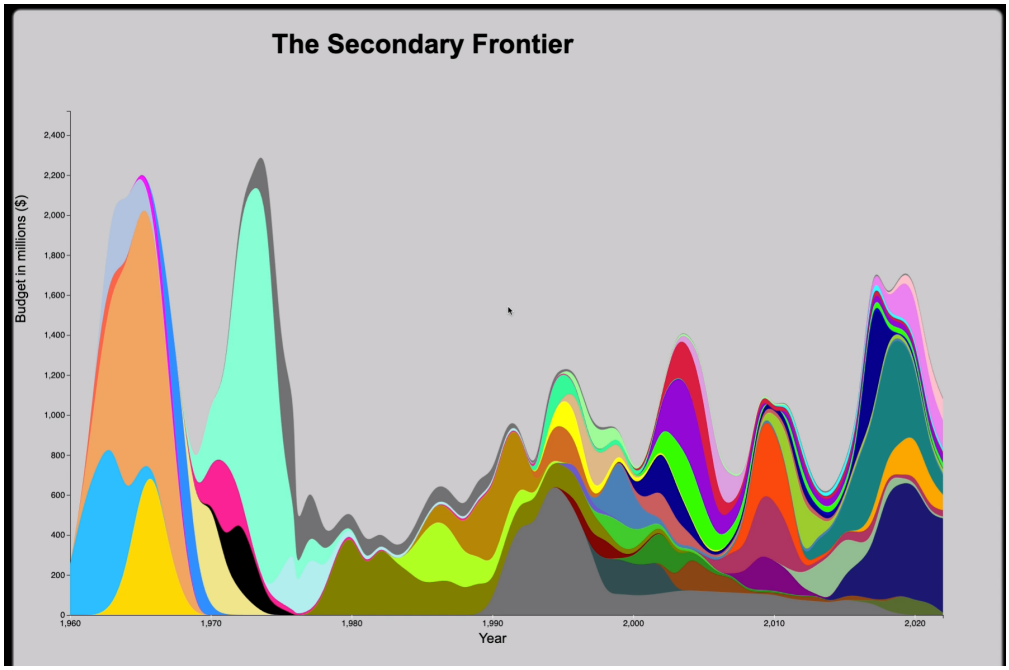
However, upon getting deeper into trying to provide much more information about the dataset, (such as length of the mission and cost associated with each year) we decided to deviate from the scatter plot to a multi-line graph to show the cost changes with each year.

Our second implementation of the main graph looked like the following image:

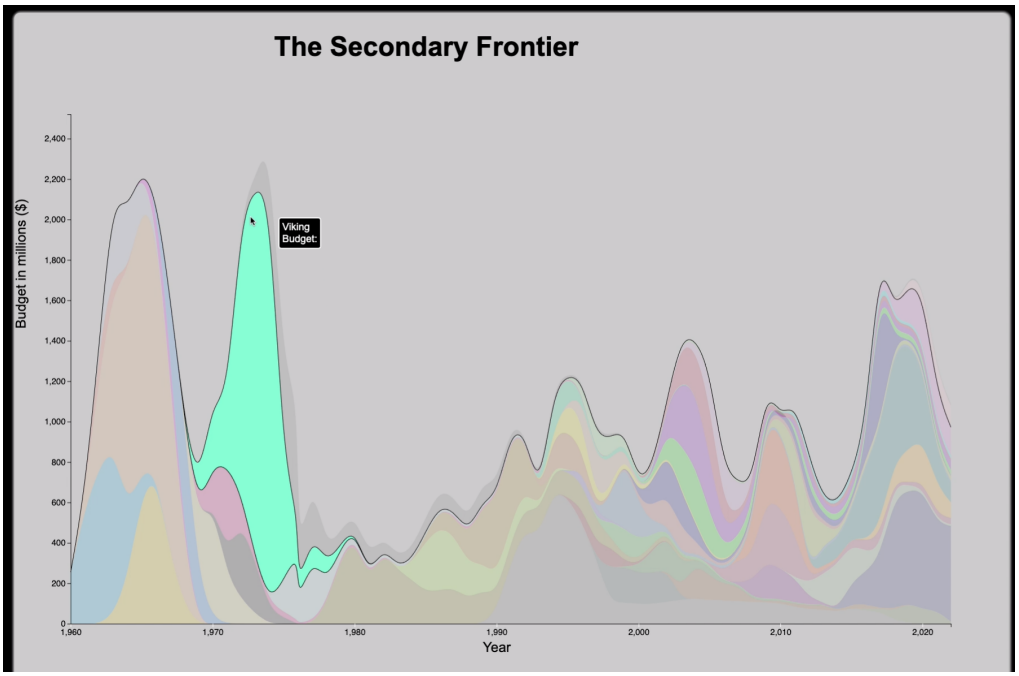


Upon Getting feedback from our course instructor, Dr Iuricich, and feedback from our peer evaluation with team g2, we realized that this visualization is much more confusing and ugly to look at. Lines following the missions are difficult to follow and colors assigned for the missions are overlapping. Hence, we decided to change our main visualization to a stacked area chart with distinct mission colors.

We manually picked 50 distinct colors to represent each mission and removed the legends from the right side to create an area to fit out secondary graphs. To address the issue of not being able to follow a single mission due to many different colors, we added a hover effect that highlights a mission. Our third iteration of our main graph looked like the following image.

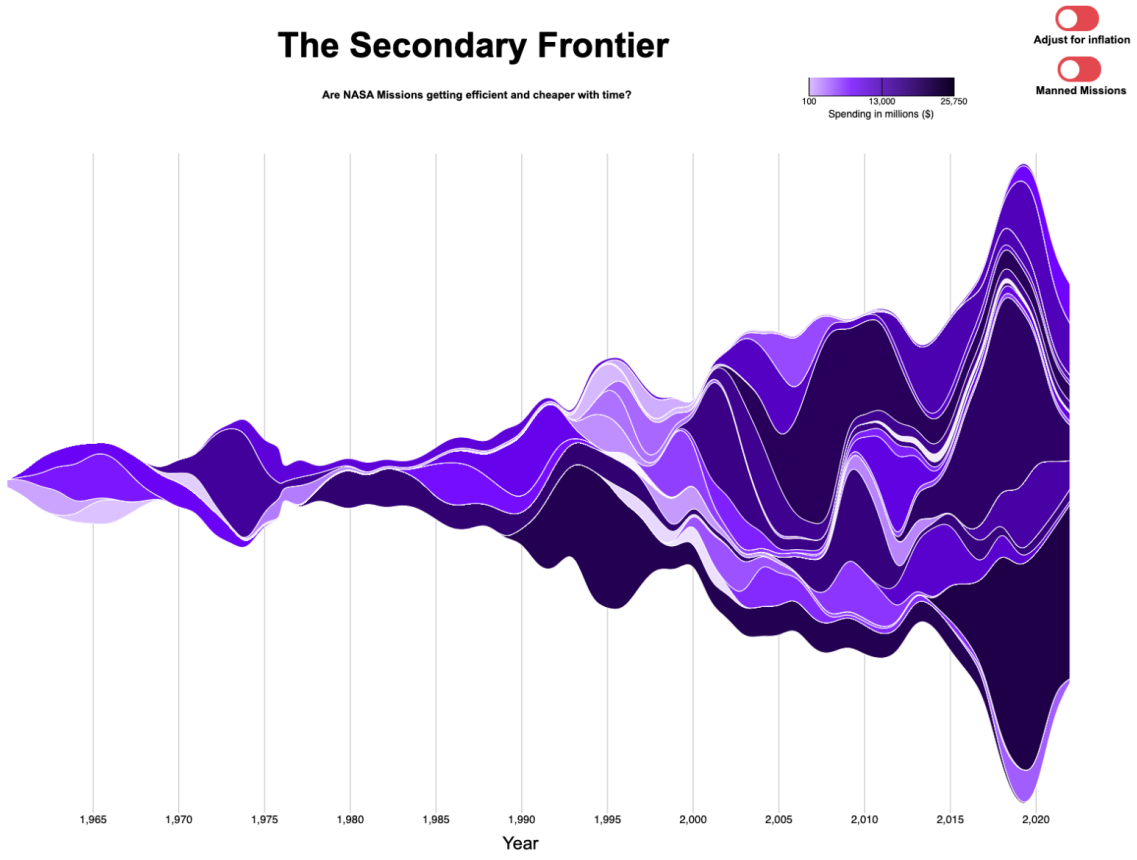


Without hover



With Hover

Upon a final meeting with Dr. Iuricich suggested the colors do not give out any additional information about the graph and can cause confusion with the color selection of our secondary graph. We changed our colors to a hue of blue based on the total cost of a given mission. Finally, we also changed the chart from being a stacked area chart to a stream area chart since the total cost was now associated with the color and hence there was not much need for the y-axis data. Our Final iteration of the main graph looked like the following.

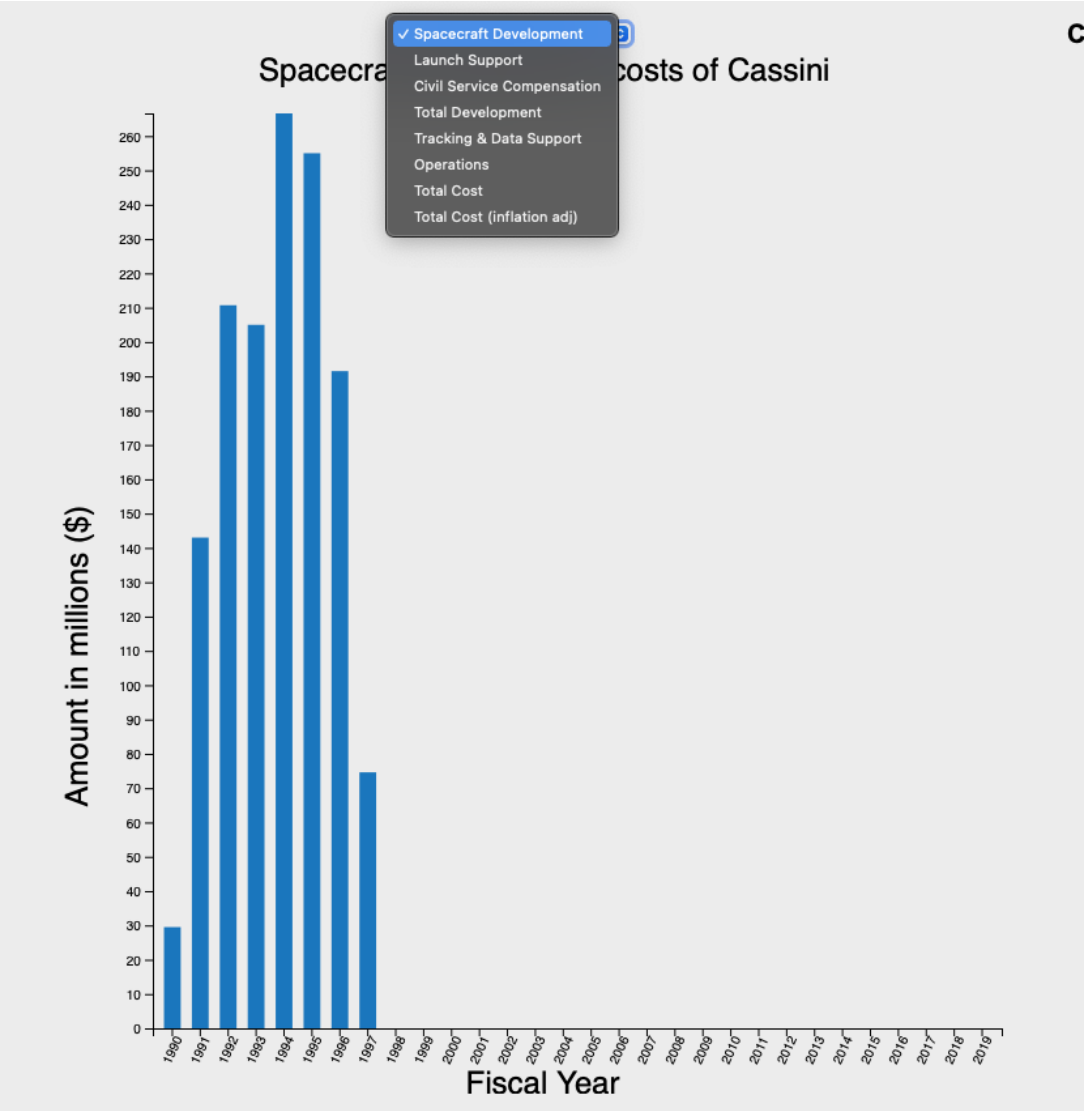


With the addition of the above filter elements such as ability to adjust the dataset for inflation, and including manned missions, our main graph showed much more useful information in the most efficient way possible.

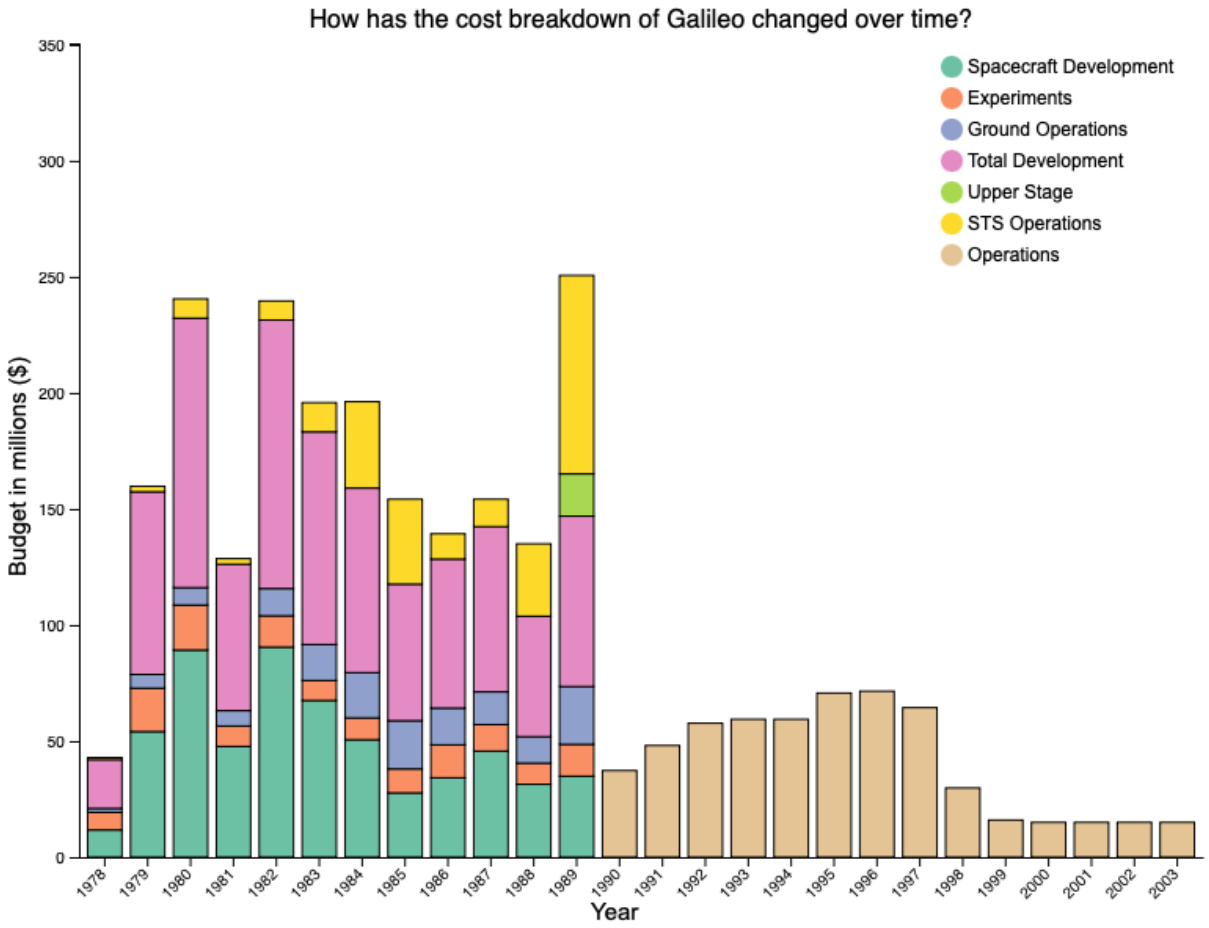
The Second Graph:

Our second graph was inspired from the following image of project proposal:

We immediately deviated from this graph mainly because the design of the above visualization seemed confusing, and did not give any information regarding spendings of selected missions throughout its course. We decided to go with a bar graph to show the cost of development throughout the course of a mission. Following image shows the first implementation of our second graph:



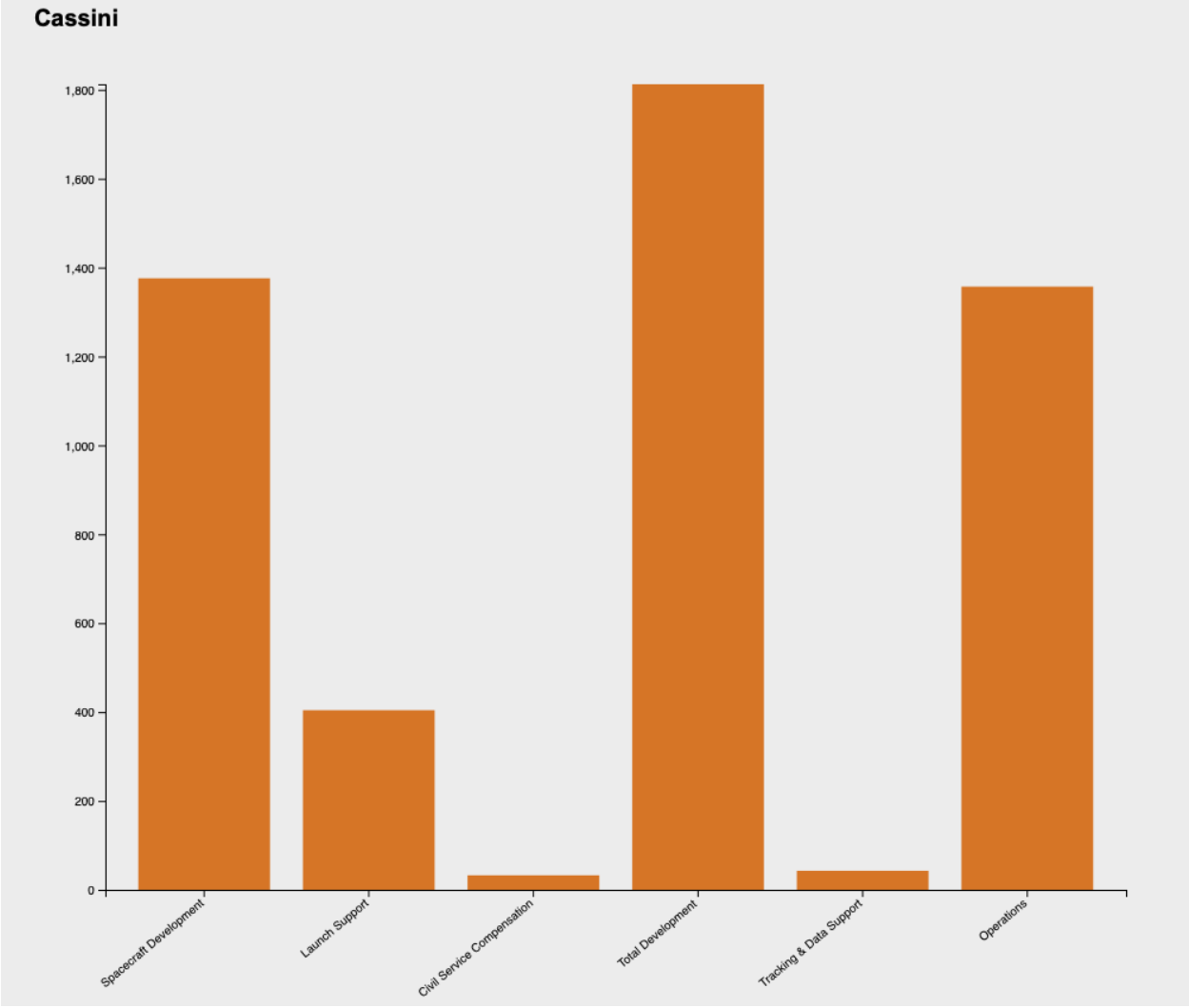
The user had options to see the timeline of a selected attribute of a mission. Upon getting feedback from Dr. Iuricich and peer evaluation, we realized that this graph can be made much more informative and interesting for the user to interact with. We changed the graph to be a stacked graph so remove the need to filter the type of cost and visualize the entire mission at the sametime. Our final implementation for this bar graph looked like the following:



This visualization incorporates all the information from the mission while maintaining simplicity and clarity.

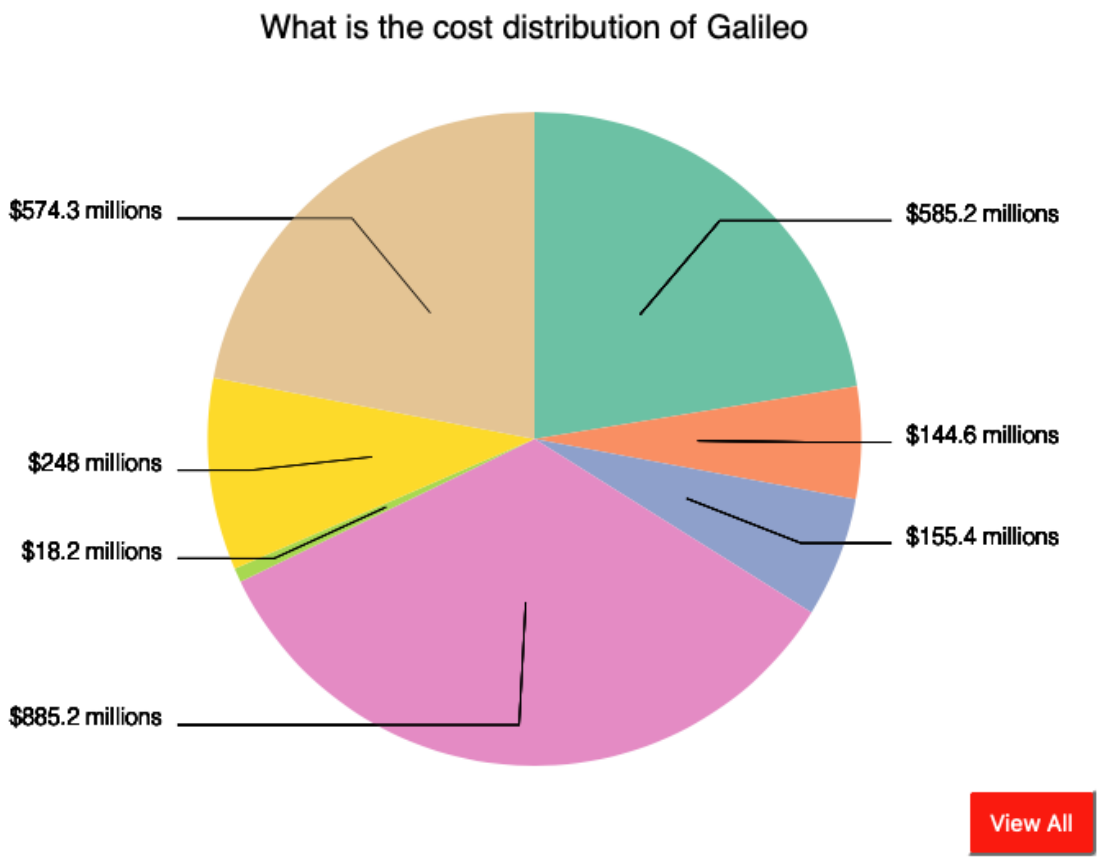
The Third Graph:

Our third and the last visualization was not initially inspired from any of our visualizations from our project proposal. Our group was confused as to what to show as a third visualization. Our first implementation was another bar graph that showed the different costs of a mission since that information was not visible in the second graph at that time of its implementation. Following is how our first implementation looked like.



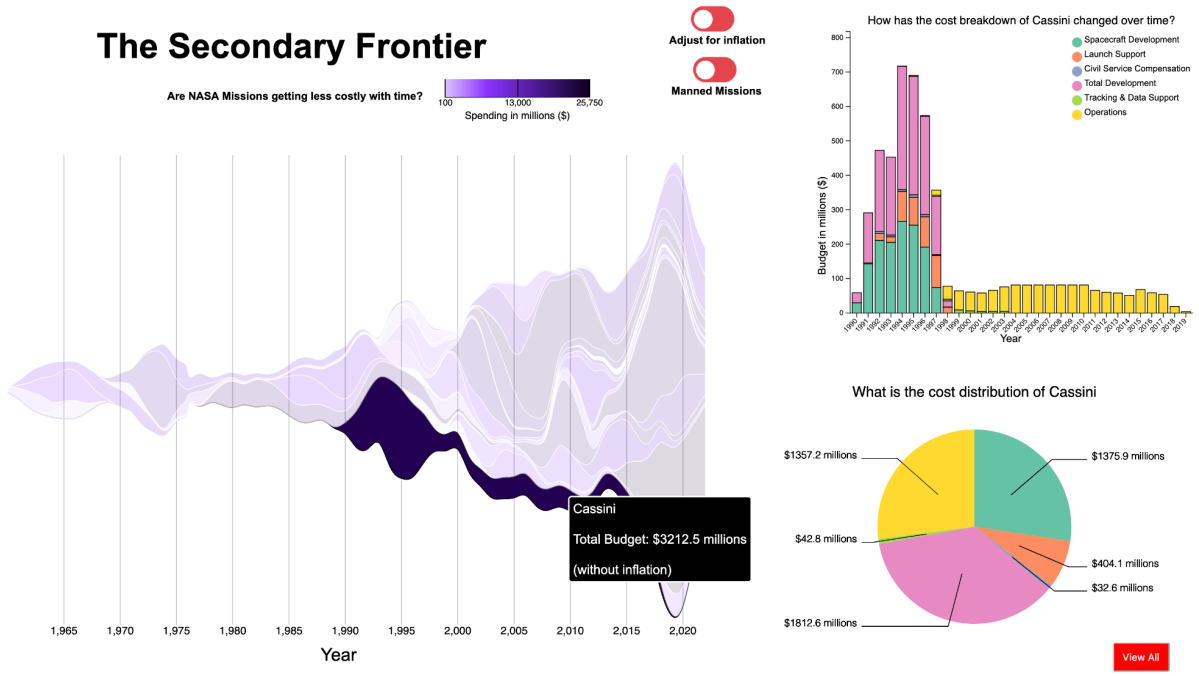
The graph felt too simple initially, and after the second graph was converted to a stacked graph, we decided to implement a pie chart to show the same cost types. The advantage with a pie chart was that a user can see what type of a cost took the most part of a total cost. Additionally, its interaction was attacked with the second graph where clicking on a certain type of cost filters the bar graph to show costs of only clicked attributes. Its interaction is discussed further in the Implementations section. Our pie chart went through several minor changes such as color selection, text placements, and interactivity implementations.

Following is the final implementation of our third graph/chart.



Implementation:

The intention of the interactive visualizations was to provide a clear and concise overview of how the cost effectiveness of space exploration missions has gotten better with time. The steam graph shown shows the total budget of each mission with inflation and without. Then the bar graph shows the cost breakdown of each category according to what mission is clicked on from the steam graph. Then the pie chart shows the cost distribution of each mission. These will all show different values according to what mission the user selected on the steam graph and it will show the data that follows.

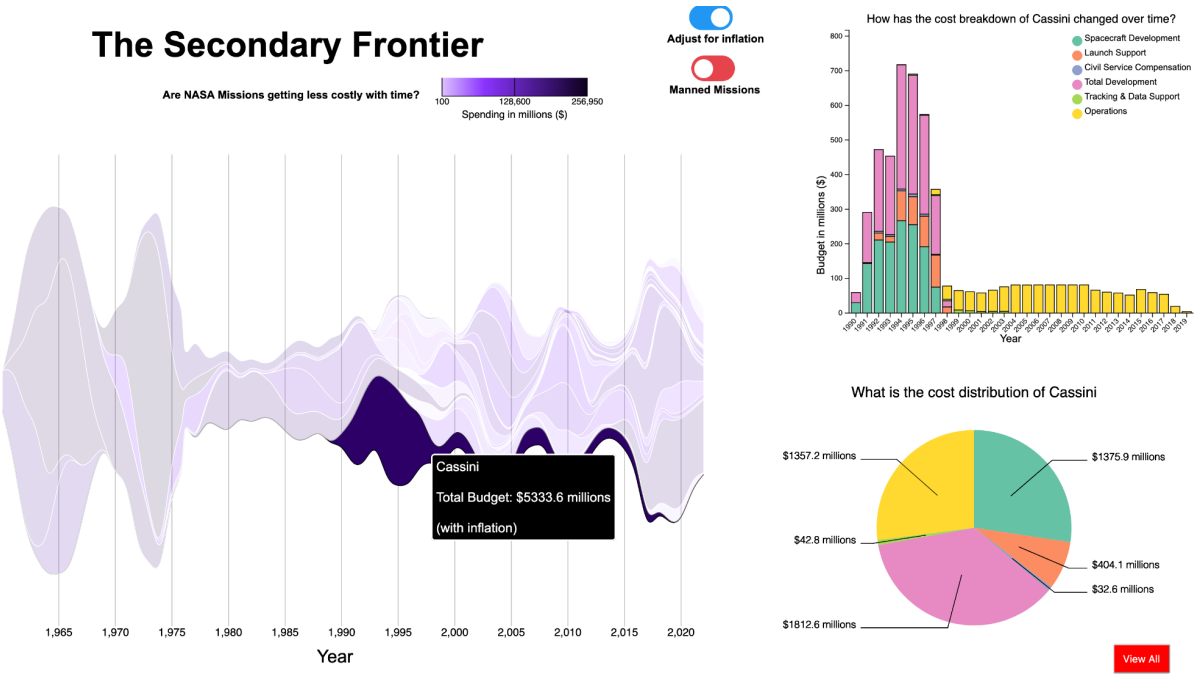


Intents and Interactions with the main graph:

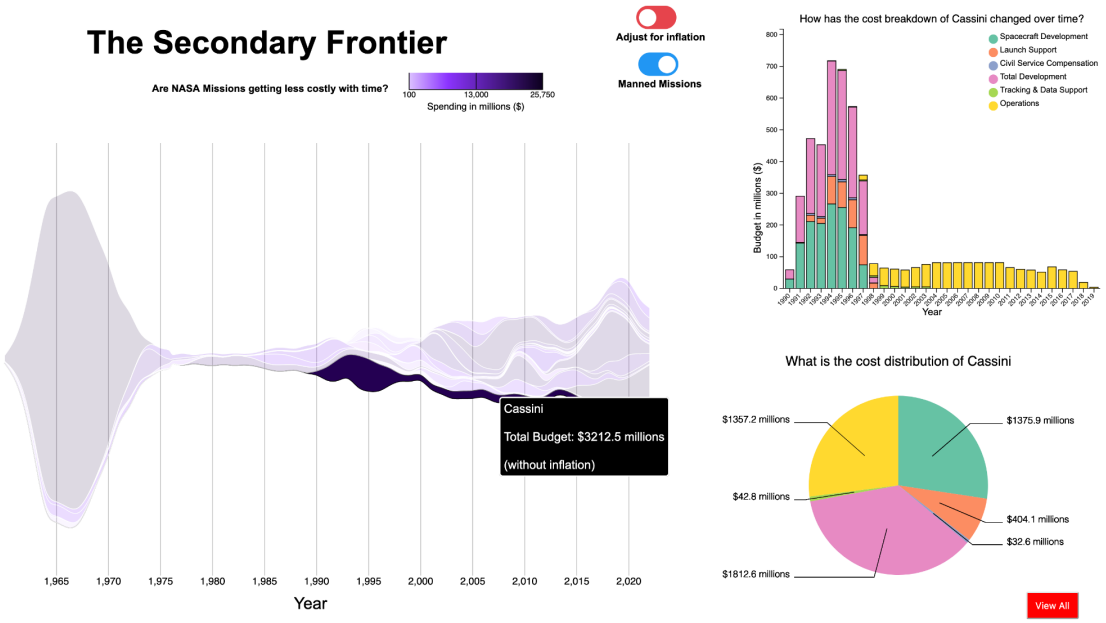
1. **Hover Effect**: Hover effect was implemented for the user to learn more about the mission by simply hovering over a stream of area they deem interesting. Once hovered over, a

text view shows the mission, its total cost, and whether or not it's adjusted for inflation. The opacity of all other missions is lowered so that the user can only see the stream area of the hovered over.

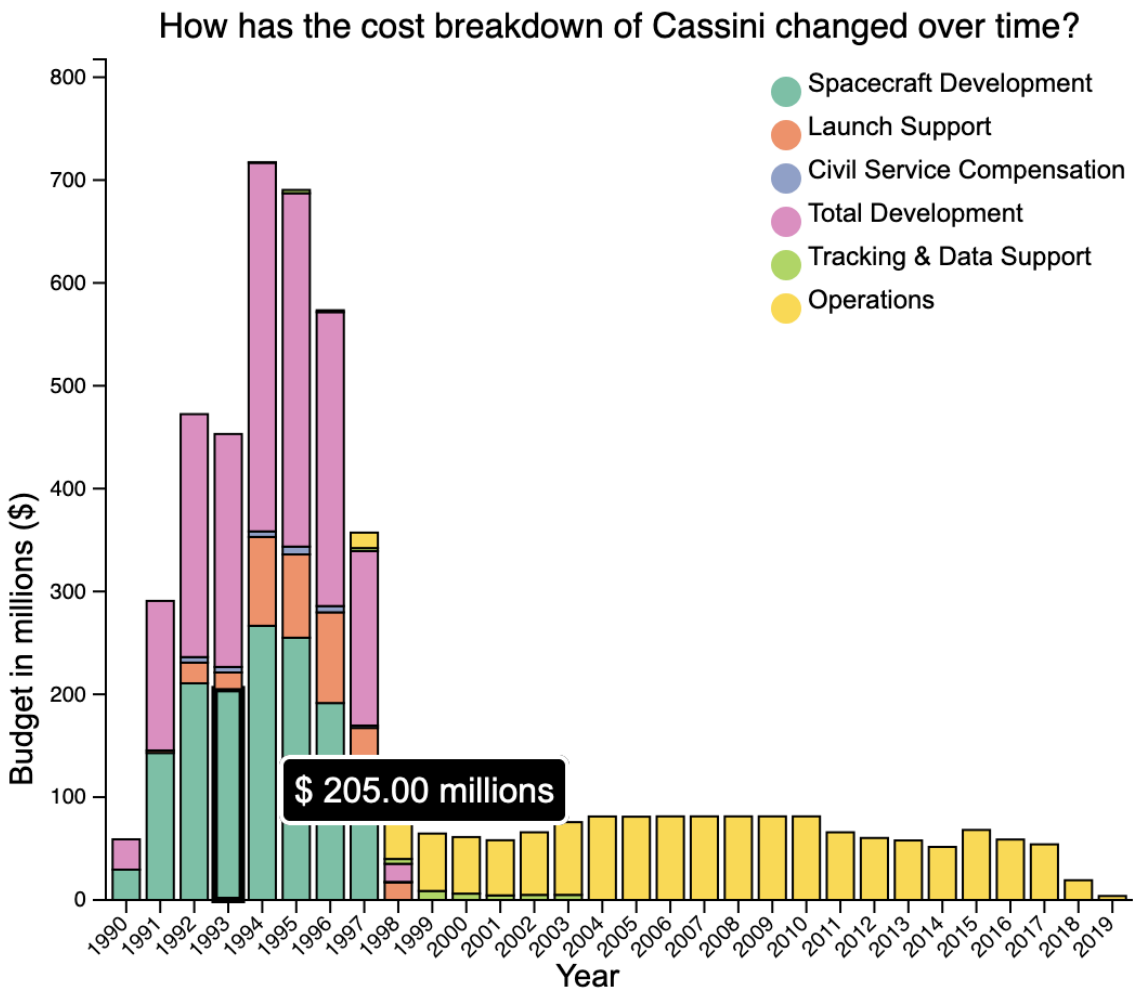
2. **Click to show bar graph and pie chart:** Additionally, Users can also click on this selected area to see the mission's cost breakdown as a whole and how its costs and cost types change over the years. Once the user clicks on a certain mission, the pie chart and the bar graph updates to show the information for that mission.

3. 

Toggle for inflation inclusion: This toggle was implemented for the user to compare fair costs of past missions. While the true costs of older missions are the real costs, one can argue that these costs are not fair compared to current time and interestingly once the inflation is adjusted for, it becomes apparent that in the 1960s and 1970s NASA did much fewer missions and they were much more expensive.



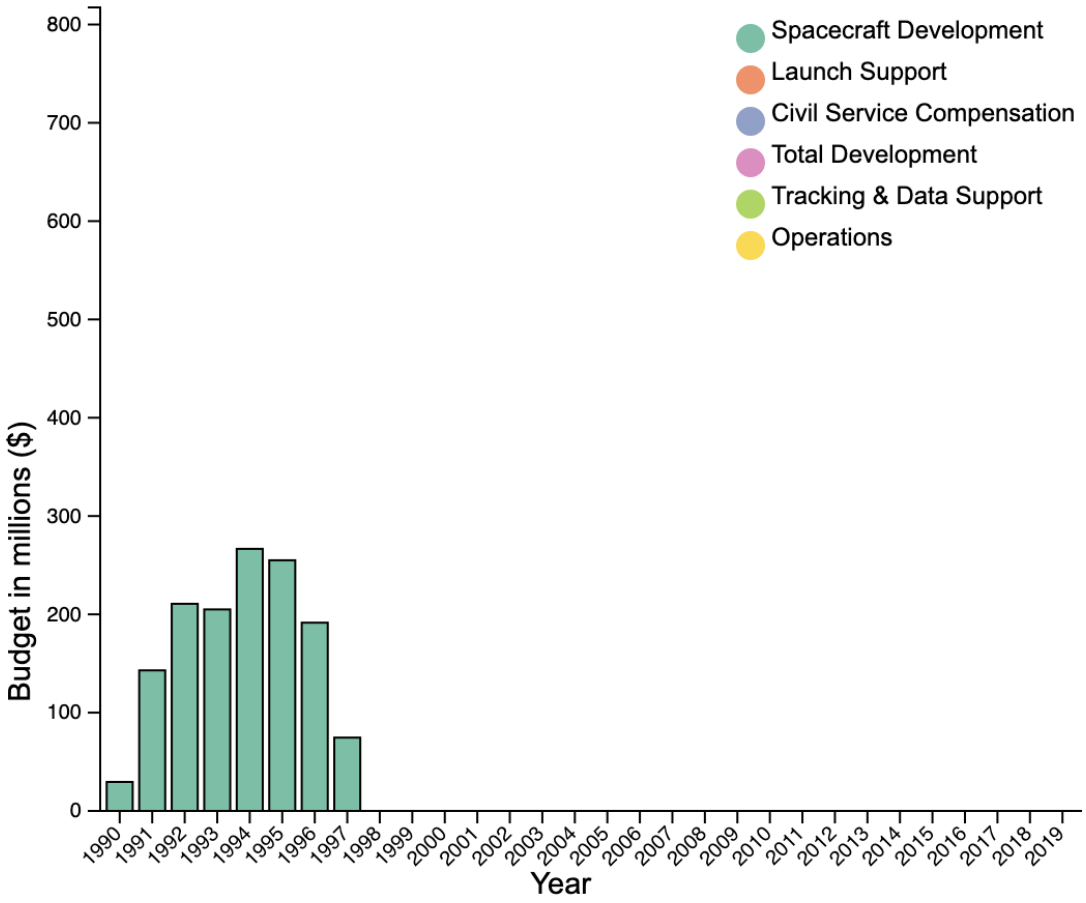
4. **Toggle for Manned Missions inclusion:** The Manned missions cost significantly more than unmanned missions and we considered it an extreme outlier. But we wanted the user to have an option to include the data for the manned missions (with and without inflation) and give the user the ability to visualize them. As seen above, even without adjusting for inflation, the area for the manned missions (Apollo) are significantly larger than any of the other missions.



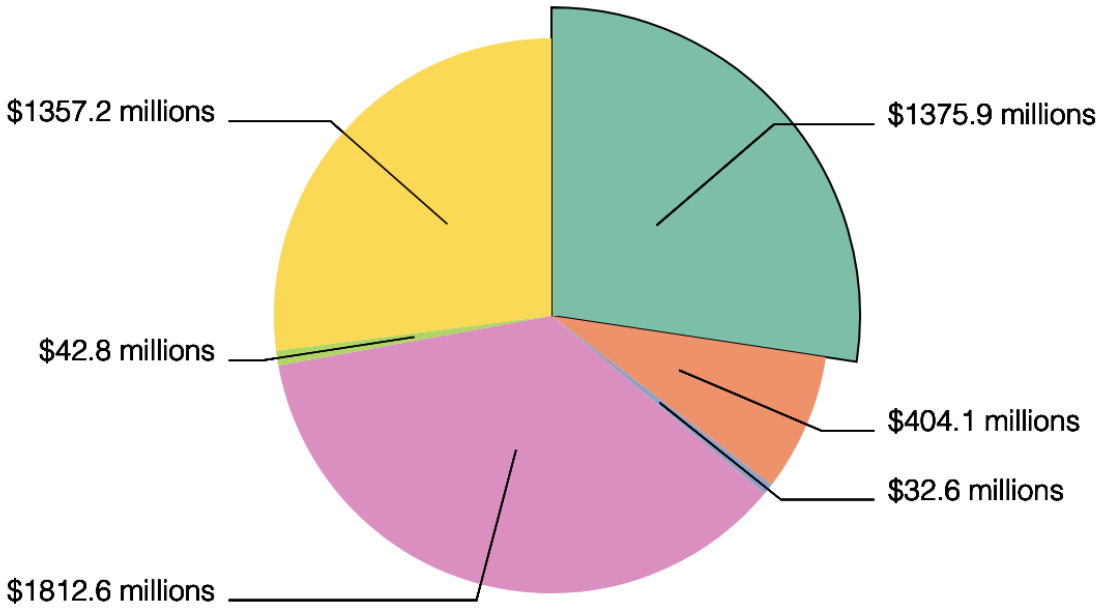
Intents and Interactions with the Second graph:

5. **Hover Effect**: The Hover effect was implemented for the user to be able to see what the cost was for that specific breakdown in that specific year. In the key it shows what all the different breakdowns are so then when the user hovers over a different breakdown per year itll show them that cost.

How has the cost breakdown of Cassini changed over time?



What is the cost distribution of Cassini



View All

Intents and Interactions with the third (and second) graph:

6. **Select Distribution:** When the user selects a cost distribution they want to see they can click a certain section of the pie chart and clicking on it will filter to only show that specific category on the bar graph. So for example in this image the user selected the spacecraft development category so then in the bar graph it'll only show when money was spent for that sector in that given year.

Evaluation:

The data showed us that, when accounting for inflation, the Apollo missions were by far the most expensive and ambitious space mission to occur as of now. Manned missions have also particularly seen a sharp, if not complete, decline since the early 1970s. Cost breakdown has also seen a shift due to the fact that the most current missions do not have a one-time goal, and instead are desired to operate past the initial use. This means that operational costs take the second to most if not the absolute most percentage of the total cost of modern day NASA missions, which is a stark difference to the Apollo missions.