Isolated magnetic field structures in the Saturn magnetosphere

FREDRIK STETLER
Masters Thesis
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Abstract

This report’s primary focus is to use the data gathered by the Cassini satellite and analyze its magnetic field data around Saturn. By looking for isolated changes in magnetic field values locations of potential plasmoids can be determined and examined. These so called plasmoids are pockets of higher density plasma associated with an increase or decrease of the magnetic field strength, inside the magnetosheath, which may be important for the interaction between the solar wind plasma and the magnetosphere. The study has been made over 7 years, from the beginning of 2010 to the end of 2016. During this period a number of magnetic field structures have been found and documented in this report, along with analyzing some of their properties such as their width and magnetic field strength.

Denna rapports primära fokus är att använda data insamlad av Cassini satelliten och analysera dess magnetiska fältdata runt Saturnus. Genom att titta efter isolerade förändringar i magnetiska fältvärdena går det att lokalisera och examinera potentiella plasmoider. Dessa så kallade plasmoider är fickor med högre densitet av plasma, associerade med en ökning eller minskning av magnetisk fältdata, inne i magnetoskiktet, vilket kan vara viktigt för interaktionen mellan solvindens plasma och magnetosfären. Studien har gjorts över 7 års tid, från början av 2010 till slutet av 2016. Under denna period har ett antal magnetiska fältstrukturer hittats och dokumenterats i denna rapport, genom att analysera några av deras egenskaper så som deras bredd och magnetisk fältstyrka.
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Chapter 1

Acknowledgements

I would like to thank Tomas Karlsson for his help and guidance throughout this project. I would also like to thank The Royal Institute of Technology for making my education possible. A special thanks to all the people, friends, and family out there who have strongly supported me through these years. I will be forever grateful.
Chapter 2

Introduction

The exploration and study of different planets is a way of taking a step into becoming an interplanetary species. One area of study is the study of magnetic field data around different planets.

Our sun emits a constant flow of plasma in all directions, called the 'solar wind'. When the plasma, which carries with it a magnetic field, encounters different planets, the magnetic field of said planets will cause the plasma flow to change direction and flow around the them, much like the wind colliding with a round object.

When colliding with a planet, the collision will create a 'bow shock’. This 'bow shock’ is the outer most layer of the so called 'magnetosheath’, and it ends with the 'magnetopause’. These three things form a shield between the incoming Solar Wind and the planet.

Figure 2.1: Saturns magnetosheath
Inside the magnetosheath the density of the plasma is higher than in the regular solar wind, and it varies over different locations. In certain spots, there are so called 'plasmoids': pockets of high density plasma.

In October 15th, 1997, an unmanned spacecraft called 'Cassini-Huygens' was sent to the planet of Saturn. It went into orbit around Saturn on July 1st, 2004. There it orbited the planet and relaying data back to Earth. The spacecraft mission will end on September 17th, 2017, by diving into Saturn's atmosphere where it will be destroyed, and hopefully relaying as much of the unknown data of Saturn's never before explored surface as possible.

This report's main focus will be on analyzing the Magnetosheath and searching for the plasmoids aforementioned, and comparing it to the results of two reports made by Karlsson et al, which focus on the studying of the magnetosheath for Mercury and for Earth. It is done by downloading collected data from NASA's website [1] from the year 2010 to 2016, and both looking at, and analyzing, the magnetic data from said files.
Chapter 3

Background

Previous work has been done in this area for Earth and Mercury. 'Karlsson et al' has done similar analyzes on the topic of magnetosheaths around planets, and potential locations of plasmoids in said magnetosheath. Previous reports identified and studied different plasmoids around the planet of Mercury [2] and of Earth [3]. The study was done in a similar fashion as this report, where magnetic field data was collected by satellites and then studied. An example of a plasmoid from Karlsson et al [3] is shown in figure 3.1, there the top graph shows the density of the plasmoid, and the one below it shows the magnetic field strength. What can be seen is that a raise in density correlates to a decrease in magnetic field strength from figure 3.1, but sometimes instead of a decrease there is an increase in magnetic field strength.
There are three primary plots of interest made by the reports; one containing the plots for R over X, one for dB/B over dt (dt is width of the plasmoid, measured in time), and lastly one histogram for dt. These are shown and talked about in figure 3.2-3.4, where the plot for Earth can be shown to the left, and for Mercury to the right.

Figure 3.2: X R plot, Karlsson report, Earth and Mercury
As is shown in the figure above the plot consisting of X over R, where R is

\[ R = \sqrt{Y^2 + Z^2} \]  \hspace{1cm} (3.1)

one can see that the locations of the plasmoid around Earth (left) and around Mercury (right). A majority of positive structures here are located in the front part of the magnetosheath, while the negative structures exist further back.

Measurements for the dB/B vs dt, i.e. the difference in magnetic field strength dB divided magnetic field strength B vs the time width dt, was also plotted in the figure below.

The width in the left plot, dl, is measured in a distance instead of a time period, which results in having to convert the distance to time, through

\[ dt = \frac{v}{l} \]  \hspace{1cm} (3.2)

where the speed v is a typical magnetosheath velocity of approximately 400 m/s. \[4\] When looking at the plot relating to Earth it shows that the majority of the solar wind plasmoids are negative dB/B, while the majority of the plasmoids in the magnetosheath are positive. It shows also that the majority of the plasmoids, both negative and positive, starts around Re = 1, and goes up to the width of 40 Re, but the positive ones are generally lower, while the negatives are more spacious and have a larger spread in size. For Mercury, the same can be said about the positive and the negative, but the positive start earlier than the negative, and only go up to about 10 s in width, while the negative go up to as far as more than 100 s.
Lastly the histogram for the width is plotted for both Earth and Mercury. For Earth (left) the majority of plasmoids are located between Earth radius = 1 and Earth radius = 10, creating a bell like curve, while for Mercury the majority of the positive structures, just like in the previous dB/B over dt plot, are located in the lower part of the histogram, with the positive structures occupy the higher end.

This report’s main focus will be on studying the inside and the nearby outside of the magnetosheath of Saturn in search for so called ‘plasmoids’, and compare the results to the Karlsson report, talked about above. Plasmoids are small pockets of higher density of solar wind, formed as some sort of bubbles within the surrounding area of the magnetosheath. These plasmoids can be distinguished by the increase or decrease in magnetic field strength in these positions, coming from the higher density plasma in said position.
Chapter 4

Cassini Mission Data

In order to evaluate and understand a phenomenon, one must first gather data. In 1980 development of a satellite called the 'Cassini-Huygens Satellite' begun. The Cassini-Huygens Satellite was launched from Earth on October 15th, 1997 aboard a Titan IVB/-Centaur rocket. From there it traveled for 6 years and 62 days from Earth to Saturn, where it begun its prime mission by orbiting Saturn. It launched with a launch mass of 5,712 kg, and traveled with a dry mass of 2,523 kg [5]. It arrived at Saturn on July 1st, 2004. From there, the Huygens satellite separated from the orbiter, starting its mission by landing on one of Saturns moons, 'Titan', on January 14th, 2005.

Cassinis continued and begun to orbit the planet for an extended period of time, where it would document and relay different information about the planet, for example about its magnetic field and its properties. In the figure 4.1 the trajectories around Saturn are shown, measurements of position taken in intervals of 1 minute time. The plot below shows the XY plane for the trajectory around Saturn for the year 2016.
A quick overall summary of the primary objectives of the mission which is relevant for this report is to, both at the surface of Saturn, its rings, and in the Magnetosphere, investigate the relationship between the ionosphere, the magnetic field, and the plasma environment, among other things [6].
Chapter 5

Method

All of Cassini's magnetosheath data has been located and downloaded from NASA website 'PDS', 'Planetary Data System' [1]. Among multiple data files relating the Cassini system, two was chosen to analyze; 'Calibrated 1 Second Average Data' [7] and 'Calibrated 1 Minute Average Data' [8] containing magnetic field vectors for the entire mission, along with relevant information such as positioning. These two files were measured every one second and every minute, respectively. Loading into MATLAB these files from the year 2010 to the year 2016, six arrays were created containing 'time', magnetic field value 'B' for X, Y, and Z, in 'KSM' coordinates, and total B value. The description of the KSM coordinates are defined as follows; 'X points from Saturn to the Sun, the X-Z plane contains Saturn's centered magnetic dipole axis, M, and Y completes right handed set'. The visual representation of this can be shown in figure 5.1 below.
Figure 5.1: KSM Coordinate System

For each of these years and set of vectors, correlating time vectors were created with a one second interval between each point. These were then plotted, as can be seen as an example in the figure below for the year of 2016, start time 20:47:54.5, 7th of January, stop time 23:59:58.5, the 30th of June. The plots for year 2010 to 2016 are included in the appendix below.
Magnetic data for 2016, 7th of January to 31st of March, measured in KSM coordinates

- Bx, X-component, X points to sun
- By, Y-component, Y is perpendicular to the magnetic dipole (Omega) and the Saturn-Sun direction (Omega x X)
- Bz, Z-component, Z is defined such that the X-Z plane contains Saturn centered magnetic dipole axis (M)
- B_total, average full value
The downloaded file gives the data in the setup shown in the table below, where the example is given from the last point of interest from 2016.

<table>
<thead>
<tr>
<th>Time</th>
<th>X (nT)</th>
<th>Y (nT)</th>
<th>Z (nT)</th>
<th>total B (nT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/28/16 09:14 PM</td>
<td>6.3170</td>
<td>-14.7120</td>
<td>-1.8220</td>
<td>3.0120</td>
</tr>
</tbody>
</table>

The purple line represents the total magnetic field strength. The lower points of the data (the straight lines) represents the position of far away for the satellite, meaning where the satellite is outside of the direct contact with Saturn’s magnetosphere and magnetosheath, i.e. in 'outer space’ which is primarily dominated with solar wind. The higher spikes of the graph represent the immediate contact with Saturn’s inner magnetosphere, meaning much higher values of Magnetic field. In between these two sides, the Cassini satellite is positioned inside the magneto/sheath.

![Magnetosphere data, KSM coordinates, 2016](image)

**Figure 5.3: Example of potential plasmoids**

In the figure above the top graph shows the unaltered magnetic field data, represented by the red line, from the year 2016, zoomed in on an area of interest where there seem to be a clear indication of a plasmoid. For a more literal representation of the zoomed in location, imagine the beginning of the slope between the lower line and the
peak. It is in these particular areas where the 'Plasmoids' are searched for. Due to 'Plasmoids' being pockets of higher or lower densities of plasma, the clear and distinct spikes in Magnetic field data in a particular way gives an indication of the location of the 'Plasmoid’. This line in the plot is accompanied by its smoothed out line, which is plotted for getting a reference point in the plot, represented as the blue line. The smooth command is made through Matlab.

In the lower plot in the figure above, a straightened out line of the magnetic field data has been plotted, using the formula that is calculated below

\[ P = \frac{(S - B)}{S} \]  \hspace{1cm} (5.1)

where P is the quota, S is the smoothed out value (blue line) of the line of the magnetic field B, and B is the magnetic field strength (red line).

In order to successfully navigate through a large number of potential plasmoids, a limit has been set to where the unaltered magnetic field strength needs to surpass 50% change from its smoother out line, illustrated in the equation below.

\[ \frac{(S - B)}{S} > 0.5 \]  \hspace{1cm} (5.2)

These positions and areas of interest are shown in the bottom plot in the figure above, indicated by the green line.

A fine set of plasmoids can be seen in the figure above, where the clear drops in B, measured in Tesla, shows several plasmoids. These positions are of interest, and are the primary findings of this report. By looking and searching for these points of interest, ranging from 2010 to 2016, they have been documented and stored in a table. A total number of 88 positions have been chosen to analyze, and relating information for the magnetic field has been included. To be able to correlate the time in which the plasmoid was measured, the second file '1 Minute Average', containing the positions of the satellite for every minute measured, was analyzed. Each coordinate from the 1 Minute file was matched with its closest representative from the 1 Second file, resulting in a table containing 'time', Tesla B in X, Y, and Z directions, total B measured in nano Tesla 'nT', and the difference dB, which is the smoothed out vector of the magnetic field minus the normal magnetic field vector, measured also in 'nT'.

To better being able to analyze the positions of the satellite, it is important to get a representative outlook on the positions in relation to the magnetosheath. The magnetosheath contains a outer layer and an inner layer, both which can be calculated and plotted for visual effect.

The inner layer of the magnetosheath can be calculated using the calculation below.

\[ R = \frac{K}{1 + \epsilon \cos(\theta)} \]  \hspace{1cm} (5.3)

where the constant K is 25, the constant \( \epsilon \) is 1.05, and \( \theta \) goes from -120° to 120°. [9]
The outer layer of the magnetosheath can be calculated using the calculation

$$R = r_0 \cdot \frac{2}{1 + \cos(d(\theta))}^K$$  \hspace{1cm} (5.4)

where

$$r_0 = a_1 \cdot Dp^{-a_2}$$  \hspace{1cm} (5.5)

$$K = a_3 + a_4 \cdot Dp$$  \hspace{1cm} (5.6)

with the values $a_1 = 9.7$, $a_2 = 0.24$, $a_3 = 0.77$, $a_4 = -1.5$ are found in the table 1, and Dp found in table 2, both made by Arridge et al [10].

These calculations bring three plots looking at the positioning of the satellite from three different directions, one in XY plane, one in XZ, and one in YZ. The positions of the satellite relative to the magnetosheaths front and back is shown in the figures below.

![Figure 5.4: X Y plane for 2016](image-url)
Figure 5.5: X Z plane for 2016
These plots show the actual positioning of the satellite over time, but another way of looking at it is through calculating the absolute value of Z plus Y, calling it 'R’, and plotting it over X.

\[ R = \sqrt{Y^2 + Z^2} \]  

(5.7)

This gives the plot that is shown below.
Another area of interest is to analyze how the histogram of the magnetic field data looks. This plot shows the distribution of the peaks sizes of the plasmoids. Since only the interesting points are ones that are over 50% from the smoothed out line, only those ones are shown. The Histogram from 2016 can be seen in the figure 5.8.
When looking at the plasmoids and their dimensions, it’s not only important to look at their height, i.e. their dB value. It is also important to look at their width, measured in seconds. While dB shows what is inside the plasmoid, its density and correlating magnetic field strength, analyzing the width of the plot, here called dt as in difference in time, the general size of the plasmoid can be represented. One way of measuring this is to find the plasmoid, localize the height difference between the peak of the magnetic field versus the vertical point on smoothed out line, and meet in the middle. At this point, measure the width of the plasmoid in seconds. One major problem with this angle of attack is that due to the outlook of the plots, way too many spikes and interfering measurements would interfere with doing this by code, so this was done by hand by zooming in through matlab and using the measurement tools to get a set value dt. Below a figure is shown to give a visual representation of dB and dt.
This value was used for three different plots, all which are plotted below for the year of 2016 as an example. Further plots can be found in the appendix below. The first plot shows the relation between the width $dt$ in seconds and the difference in dB.

Figure 5.10: dB versus $dt$ for 2016

For the second plot for the width of the plasmoid it is of interest to look at its histogram, which is plotted below.
Lastly one takes a look at the correlation between the quota in tesla dB and the actual tesla B, over the width $dt$. This gives the plot below.
Figure 5.12: dB/B over dt for 2016
Chapter 6

Results

When first analyzing the magnetic field measurements the areas one will find are three areas of interest. The first one represents the area far away from Saturn, outside of its magnetosphere where the magnetic field level is low. In the second area, the satellite has just begun to pass Saturns magnetosheath, where the magnetic field levels are raising, experiencing lots of intense changes in Tesla due to a higher presence of Solar Wind. The third area of interest is withing proximity to Saturn itself, where the magnetic field is highly present, and the magnetic field levels are high. When studying the magnetosheath it can be found that the so called plasmoids, which are the topic of interest, can be spotted in several places throughout the years. In the table below, the year of 2016 with areas of interest has been documented. The rest of the years can be found in Appendix.

<table>
<thead>
<tr>
<th>Date</th>
<th>X (Rs)</th>
<th>Y (Rs)</th>
<th>Z (Rs)</th>
<th>B (nT)</th>
<th>dB (nT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>01/12/16 07:53 AM</td>
<td>-0.478</td>
<td>-20.820</td>
<td>0.485</td>
<td>2.006</td>
<td>2.705</td>
</tr>
<tr>
<td>01/12/16 05:27 PM</td>
<td>0.938</td>
<td>-18.210</td>
<td>-0.174</td>
<td>2.268</td>
<td>2.869</td>
</tr>
<tr>
<td>01/12/16 06:27 PM</td>
<td>1.085</td>
<td>-17.904</td>
<td>-0.266</td>
<td>2.649</td>
<td>3.133</td>
</tr>
<tr>
<td>01/28/16 08:09 PM</td>
<td>6.245</td>
<td>-15.142</td>
<td>-1.772</td>
<td>1.259</td>
<td>5.291</td>
</tr>
<tr>
<td>01/28/16 09:14 PM</td>
<td>6.317</td>
<td>-14.712</td>
<td>-1.822</td>
<td>3.012</td>
<td>4.176</td>
</tr>
</tbody>
</table>
These points have been identified and pinpointed by manually going over the data and looking for points of interest matching the description of a typical plasmoid. A typical plasmoid can be identified as a clear and distinct drop in the magnetic field level, where the most clear and distinct case can be seen in figure 6.1 for 2016, reposted here blow.

Figure 6.1: Good example of plasmoid peaks

A minimum distance in time between potential plasmoids have been established, as to not get mix ups between just high levels of magnetic field changes, and actual plasmoids.

As to make sure to avoid a too large of a frequency in changing magnetic data, a frequency limit has been set. For a spike in magnetic data to count, there has to be a time period of 30 minutes between each spike, nothing less. The final result is to plot all of the interesting values in the same plot for each year respectively. This is done below.
Figure 6.2: X Y plane for all years
Figure 6.3: X Z plane for all years
Figure 6.4: Y Z plane for all years
Figure 6.5: X R plane for all years
Figure 6.6: Number of values over 50% for all years
Figure 6.7: Number of dt values for all years
Figure 6.8: dB over dt for all years
Figure 6.9: dB/B over dt for all years
Figure 6.10: dB/B, Histogram, for all years
Figure 6.11: dB, Histogram, for all years
Chapter 7

Discussion and conclusion

Comparing the results between Karlsson et al [2][3] to this report, one can first take a look at figure 3.2 and figure 6.5. Both in Earths and Mercury's magnetosheath, the majority of plasmoids are negative, with some positive ones which are located strictly within the magnetosheath. The positive structures are located closer to the subsolar point of the bow shock, while the negative occupy space further back. Comparing this to the results from this report, the majority of the magnetic structures are negative, with only a few positive. There are too few positive structures, and too few Solar Wind structures to make a fair assessment of the situation. What actually can be seen is that the structures are largely concentrated in the front of the magnetosheath, for both Earth, Mercury, and Saturn.

Comparing figure 3.3 with figure 6.9, one can see that the positive and the negative structures for Earth start at around the same width with approximately the same dB/B maximum and minimum values with no larger dB/B than 1.5 and no less than -1, but the positive values doesn't go above 10 Re (Earth radius), while the negative stretch up to around 40 Re. For Mercury the positive values start earlier than the negative, at about 1 s compared to 2 s, and they end at approximately 10 s, while the negative end at more than 100 s. The dB/B values span though are approximately the same as for Earth. Compared to the results in this report, the dB/B over dt for Saturn shows that the plasmoids width are generally much larger; the majority of them are in the lower end of the spectrum, between 10 s and 400 s in width, but some are as large as 1000 s in width. These quotas are lower than the ones from Earth and Mercury though, with no values larger than 1, and no less than -2.5.

Lastly we compare the histograms of the width. From Karlsson et al [2][3], the majority of values are located within the range of 1 s and 100 s. For this reports results, the values are, as mentioned before, much larger, with values as high as 1700 s, with a majority of the values concentrated around 1 - 600 s.

In short, the results from the analysis shows that plasmoids are present in Saturn's magnetosheath just as for Mercury and Earth, only they are much larger in size, but seemingly fewer in number, and not as many in the Solar Wind as there are around Mercury.
and Earth. There are also fewer positive structures around Saturn than there are around Mercury and Earth, but that might just be incorrect analysis of the data when searching for the plasmoids.

As mentioned before there are very few positive magnetic structures available for the study. This can be explained by looking at the Parker spiral.

![Figure 7.1: Parker spiral around Sun](image1)

This shows how the magnetic field B varies in incoming angle of attack relative to its distance from the Sun; the closer to the sun it is, the more parallel the magnetic flow is to the X axis. Further away from the Sun means more perpendicular. A more parallel magnetic flow results in a larger amount of positive structures, while a more perpendicular flow results in fewer positive structures.

![Figure 7.2: X R plot, Karlsson report, Earth and Mercury](image2)

Figure 7.1: Parker spiral around Sun

Figure 7.2: X R plot, Karlsson report, Earth and Mercury
This result relates well to the findings of this report, since Saturn is further away from the Sun than Earth and Mercury, it is very logical that it has far fewer positive structures overall.
Chapter 8

Bibliography

[1] https://pds-ppi.igpp.ucla.edu/


[8] https://pds-ppi.igpp.ucla.edu/search/view?f=yes&id=pds://PPI/CO-E_SW_J_S-MAG-4-SUMM-1MINAVG-V1.0


Chapter 9

Appendix

9.1 2010

Figure 9.1: X Y plane for 2010
Figure 9.2: X Z plane for 2010

Figure 9.3: Y Z plane for 2010
Figure 9.4: X R plane for 2010

Figure 9.5: Number of values over 50% for 2010
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Figure 9.7: dB over dt for 2010
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Figure 9.12: 5.10e6-2010

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Figure 9.23: 2e6-2011
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Figure 9.25: 74e6-2011
2012 Cassini position versus Saturn when crossing plasmoids

Figure 9.28: X Y plane for 2012

2012 Cassini position versus Saturn when crossing plasmoids

Figure 9.29: X Z plane for 2012
2012 Cassini position versus Saturn when crossing plasmoids

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2012 Cassini position R over X

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Figure 9.40: 55e6-2012

Figure 9.41: 7.5e6-2012
Figure 9.42: 7.9e6-2012

Figure 9.43: 8.3e6-2012
Figure 9.44: 9.75e6-2012

Figure 9.45: 1.14e7-2012
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Figure 9.53: dB over dt for 2013
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Figure 9.55: Full range of Magnetic Data for 2013
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Figure 9.57: 1.07e6-2013
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Magnetosphere data, KSM coordinates, 2016

Measurement every 1 seconds

Figure 9.59: 1.76e7-2013

Magnetosphere data, KSM coordinates, 2013

Measurement every 1 seconds
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Figure 9.61: 2.76e7-2013
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9.5 2014

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Figure 9.75: 2.95e-7-2014
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Figure 9.81: Number of dt values for 2015
Figure 9.82: dB over dt for 2015

2015 width of Plasmoid measured in seconds

Figure 9.83: dB/B over dt plane for 2015

2015 dB/B over width of the plasmoid
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Figure 9.86: 1.80e7-2015

Figure 9.87: 1.22e7-2015
Figure 9.88: 1.33e7-2015

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Figure 9.91: 6.7e6-2015
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Figure 9.93: X Z plane for 2016
2016 Cassini position versus Saturn when crossing plasmoids

Figure 9.94: Y Z plane for 2016

2016 Cassini position R over X

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Figure 9.99: dB/B over dt plane for 2016
Figure 9.100: Full range of Magnetic Data for 2016

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Figure 9.103: 1.64e6-2016
9.8 All years

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Figure 9.105: X Z plane for all years
Figure 9.106: Y Z plane for all years

Cassini position YZ plane for all years

Figure 9.107: X R plane for all years

Cassini position R over X for all years
Figure 9.108: Number of values over 50% for all years

Figure 9.109: Number of dt values for all years
Figure 9.110: dB over dt for all years

Figure 9.111: dB/B over dt plane for all years
9.9 Satellite Positioning

Figure 9.112: X Y position for 2010

Figure 9.113: X Z position for 2010
Figure 9.114: Y Z position for 2010

Figure 9.115: X Y position for 2011
Figure 9.116: X Z position for 2011

Figure 9.117: Y Z position for 2011
Figure 9.118: X Y position for 2012

Figure 9.119: X Z position for 2012
Figure 9.120: Y Z position for 2012

Figure 9.121: X Y position for 2013
Figure 9.122: X Z position for 2013

Figure 9.123: Y Z position for 2013
Figure 9.124: X Y position for 2014

Figure 9.125: X Z position for 2014
Figure 9.126: Y Z position for 2014

Figure 9.127: X Y position for 2015
Figure 9.128: X Z position for 2015

Figure 9.129: Y Z position for 2015
Figure 9.130: X Y position for 2016

Figure 9.131: X Z position for 2016
9.10 Cassini Mission Objectives

At Saturn:

- Determine the vertical structure of the atmosphere, in particular, how its composition, cloud properties, density, and temperature vary with height;

- Understand the horizontal motions of the atmosphere: its waves, eddies, and storms – where they are located and how they form, grow, evolve, and dissipate;

- Determine the deep structure of the atmosphere, how it rotates, and how it relates to the upper atmosphere;

- Study how the atmosphere varies with time, both on short (daily) and long (seasonal) time scales;

- Investigate the relationship between the ionosphere, the magnetic field, and the plasma environment;

- Investigate the sources of lightning.

Ring science objectives:

- Map the composition and size distribution of ring material;

- Study the configuration of the rings and the dynamic processes responsible for their structure;

- Investigate the relationships between the rings and the embedded moons;

- Search for new ring-embedded moons;
• Study the interaction between the rings and Saturn’s magnetosphere, ionosphere, and atmosphere.

Icy satellite science objectives:

• Map their surface geology and composition and determine their geologic histories;
• Determine the physical processes responsible for the surface and subsurface structure;
• Determine their bulk compositions and internal structure;
• Investigate their interactions with Saturn’s magnetosphere and ring system.

Magnetosphere:

• Determine the global configuration and dynamics of hot plasma in the magnetosphere of Saturn through energetic neutral particle imaging of ring current, radiation belts, and neutral clouds;
• Study the sources of plasmas and energetic ions through in situ measurements of energetic ion composition, spectra, charge state, and angular distributions;
• Search for, monitor, and analyze magnetospheric substorm-like activity at Saturn;
• Use imaging and composition studies to determine the magnetosphere-satellite interactions at Saturn, and understand the formation of clouds of neutral hydrogen, nitrogen, and water products (such as protons, oxygen atoms or hydroxyl radicals);
• Study how satellite surfaces and atmospheres are modified due to plasma and radiation bombardment;
• Study Titan’s cometary interaction with Saturn’s magnetosphere (and the solar wind) via high-resolution imaging and in situ ion and electron measurements;
• Measure the high energy (Ee > 1 MeV, Ep 15 MeV) particle component in the inner (L < 5 RS) magnetosphere to assess cosmic ray albedo neutron decay (CRAND) source characteristics;
• Investigate the absorption of energetic ions and electrons by the satellites and rings in order to determine particle losses and diffusion processes within the magnetosphere;
• Study magnetosphere-ionosphere coupling through remote sensing studies of the aurora and in situ measurements of precipitating energetic ions and electrons
## Dates and Measured values

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