Comparison of VIPER reanalysis of Voyager PLS ion data with previous analyses Voyager data sets

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Purpose

The following document describes the various graphs of ion and electron properties presented on the LASP Voyager web page. In this document, each graph number corresponds to the figure number next to the image on the website.

Original Sources of Data

The three sources of data presented on this page are

- Voyager Plasma Science (PLS) ions – re-analysis at LASP presented in the "Voyager trilogy": Bagenal et al. [2017], Dougherty et al. [2017], and Bodisch et al. [2017]. Below we compare the output of this analysis with previous publications.
- Voyager PLS electrons – data for Day 64 (March 5th), 1979 were published by Sittler & Strobel [1987].
- The Voyager Planetary Radio Astronomy (PRA) instrument measured the plasma emissions which were analyzed by Warwick et al. [1979] and by Birmingham et al. [1981] to derive electron density.

The Graphs – Generally

A. The abbreviations (Ne, Te, Tc etc.) come from the graphs of Sittler & Strobel 1987]. Ne = electron density, Te = electron temperature, Nc = density of cold electron population, Nh = density of hot electron population, Tc = temperature of cold electron population, Th = temperature of hot electron population.

B. Horizontal Axis. The time graphs are either in hours (0-24) of Day 64 or in decimal dates (64-65). The conversion from hours to decimal date is $\left(\frac{hour}{24}\right) + 64$ and the conversion from decimal date to hours is $(Decimal\ Date - 64) * 24$. The distance graphs are always measured as the distance from Jupiter's spin pole denoted ρ_{spin}. R_J and R_Θ are taken from the Viper ion analysis, where R_Θ is in degrees (hence the conversion to radians) and $R_J=(x^2+y^2+z^2)$ is in Jupiter Radii (1 R_J = 71,492 km). $\rho_{spin} = R_J * \cos\left(R_\Theta * \left(\frac{\pi}{180}\right)\right)$

C. Vertical Axis:

The temperature graphs are always measured in electron volts (eV)

The density graphs are always measured in cm^{-3}

D. The cold electron density is not given directly in the Sittler & Strobel paper, so it must be derived either from the sum of ion charge or from the equation below. The abbreviations of Nc and Nh come from the Sittler & Strobel paper itself, with Nc representing the cold electron density and Nh representing the hot electron density. The given values are the hot electron density and the ratio between cold and hot densities.

$$\left(\frac{Nc}{Nh}\right) * Nh$$

E. The hot electron temperature is also not directly given, so with the given ratio of cold electron temperatures to hot electron temperatures, $\frac{Tc}{Th}$, and the cold electron temperatures, Tc, we can derive the hot electron temperatures with the equation below.

$$\left(\frac{1}{\frac{Tc}{Th}}\right) * Tc$$

Each Graph (By Figure Number)

Electron Analysis

1. The electron densities, in cm^{-3}, from the 4 different analyses are plotted vs. distance from Jupiter in ρ_{spin}. The Sittler & Strobel data used from their paper was the total moment electron density (Ne). They did not derive separate electron parameters between hour 5 and hour 19 because much of the electron fluxes would have been below the 10 eV threshold. The Viper data used was the "Charge Density" column of the "CSV Data Set of Viper Ion Analysis" (Column 12).
2. The electron densities, in cm^{-3}, of the 4 different analyses are plotted vs. time on Day 64. The Sittler & Strobel data used from their paper was the total moment electron density (Ne). The Viper data used was the "Charge Density" column of the "CSV Data Set of Viper Ion Analysis" (Column 12).
3. The net electron density (Ne), measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}.
4. The net electron temperature (Te), measured in electron volts, as a function of distance to Jupiter in ρ_{spin}.
5. The net electron density (Ne), measured in cm^{-3}, as a function of time on Day 64.
6. The net electron temperature (Te), measured in electron volts, as a function of time on Day 64.
7. The cold electron density (Nc) as a function of distance from Jupiter in ρ_{spin}.
8. The cold electron temperatures (Tc) as a function of distance from Jupiter ρ_{spin}. The further you are from Jupiter, the warmer the cold electrons are.
9. The cold electron density (Nc), measured in cm^{-3}, as a function of time on Day 64.
10. The cold electron temperatures (Tc) as a function of time on Day 64.
11. The hot electron density (Nh) as a function of distance to Jupiter in ρ_{spin}.
12. The hot electron temperature (Th) as a function of distance to Jupiter in ρ_{spin}
13. The hot electron density (Nh) as a function of time on Day 64.
14. The hot electron temperature (Th) as a function of time on Day 64.
15. A comparison of the cold electron densities (Nc), hot electron densities (Nh), and the ratio of cold to hot electron densities $\left(\frac{Nc}{Nh}\right)$ as a function of distance to Jupiter in ρ_{spin}. The general shape of the graph is caused by the hot electron densities hovering around 1 for a majority of the time, making the cold electron densities and the comparison be very similar.

16. A comparison of cold electron temperatures (Tc), hot electron temperatures (Th), and the ratio between cold and hot electron temperatures $\left(\frac{Tc}{Th}\right)$ as a function of distance from Jupiter in ρ_{spin}.
17. A comparison of the cold electron densities (Nc), hot electron densities (Nh), and the ratio of hot electron density divided by the sum of the hot and cold electron density (See Equation Below) as a function of time on Day 64.

$$\frac{Nh}{Nh + Nc}$$

18. A comparison of cold electron temperatures (Tc), hot electron temperatures (Th), and the ratio between cold and hot electron temperatures $\left(\frac{Tc}{Th}\right)$ as a function of time on Day 64. The shape of the ratio is very similar to the hot electron temperatures because the cold electron temperatures (Tc) tend to be ~10 eV for a majority of the day, causing the drop in the magnitude and a similar shape.

Ion and Electron Comparisons – Ion data come from Papers 1,2,3 (Bagenal et al. 2017, Dougherty et al. 2017, Bodisch et al. 2017). The electron data are from Sittler & Strobel [1987].

19. The H^+ ion density, measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}. The peak occurring between 5 and 7 ρ_{spin} corresponds with the predicted location of plasma Torus.
20. The H^+ ion temperature, measured in electron volts, as a function of distance to Jupiter in ρ_{spin}. This measurement varies greatly because of how H^+, just a single proton, interacts with its surrounding plasma. While most ions are evenly distributed along the torus, the H^+ has a slightly different distribution (See Figures 51 & 53)
21. The H^+ ion density, measured in cm^{-3}, as a function of decimal time on Day 64. The two peaks, one at 64.333 (8 hours) and the other at 64.667 (16 hours), correspond to when the spacecraft is at about 6 ρ_{spin} (See Figure 19), and the dip in density in between these two peaks are the time when the space craft is at a location <6 ρ_{spin}.
22. The H^+ ion temperature, measured in electron volts, as a function of decimal time on Day 64. The dip down below 2 eV at about 64.417 (Hour 10) to 64.583 (Hour 14) corresponds with a drop in density (See Figure 21) and is located at a distance to Jupiter of <6 ρ_{spin} (See Figure 19).
23. The O^+ ion density, measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}. The same dip that occurred in the other ions when the spacecraft goes inside the radius of the plasma torus (<6 ρ_{spin}), with the largest density of ions in the torus itself.
24. The O^+ ion temperature, measured in electron volts, as a function of distance from Jupiter in ρ_{spin}.
25. The O^+ ion density, measured in cm^{-3}, as a function of time on Day 64.
26. The O^+ ion temperature, measured in electron volts, as a function of time on Day 64. The clear minimum at 64.5 (Hour 12) is caused by the spacecraft entering the area inside the radius of the plasma torus (<6 ρ_{spin}).
27. The O^{++} ion density, measured in cm^{-3}, as a function of distance from Jupiter in ρ_{spin}.
28. The O^{++} ion temperature, measured in electron volts, as a function of distance from Jupiter in ρ_{spin}.

29. The O^{++} ion density, measured in cm^{-3}, as a function of time on Day 64. You will see that there is a peak instead of a valley at 64.5, where we determined the spacecraft was inside the radius of the torus (<6 ρ_{spin}) (See Figure 27). This means that there is a higher density of this more positive ion inside the torus than of the O^{+} ion (See Figure 23), while the overall density is lower than O^{+}.
30. The O^{++} ion temperature, measured in electron volts, as a function of time on Day 64.
31. The S^{+} ion density, measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}.
32. The S^{+} ion temperature, measured in electron volts, as a function of distance from Jupiter in ρ_{spin}.
33. The S^{+} ion density, measured in cm^{-3}, as a function of time on Day 64.
34. The S^{+} ion temperature, measured in electron volts, as a function of time on Day 64.
35. The S^{++} ion density, measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}.
36. The S^{++} ion temperature, measured in electron volts, as a function of distance to Jupiter in ρ_{spin}.
37. The S^{++} ion density, measured in cm^{-3}, as a function of time on Day 64.
38. The S^{++} ion temperature, measured in electron volts, as a function of time on Day 64.
39. The S^{+++} ion density, measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}.
40. The S^{+++} ion temperature, measured in electron volts, as a function of distance to Jupiter in ρ_{spin}.
41. The S^{+++} ion density, measured in cm^{-3}, as a function of time on Day 64.
42. The S^{+++} ion temperature, measured in electron volts, as a function of time on Day 64.
43. The Na^{+} ion density, measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}.
a. The peak occurring between 5 and 7 $R\rho$ corresponds with the predicted location of plasma Torus.
44. The Na^{+} ion temperature, measured in electron volts, as a function of distance to Jupiter in ρ_{spin}. The dip where the temperature is < 1 eV corresponds to a dip in density inside the predicted radius plasma torus (See Figure 43), where the distance of the spacecraft to Jupiter is < 6 ρ_{spin}.
45. The Na^{+} ion density, measured in cm^{-3}, as a function of decimal time on Day 64. The two peaks, one at 64.333 (8 Hours) and the other between 64.417 (10 Hours) and 64.5 (12 Hours), correspond to when the spacecraft is at about 6 ρ_{spin} (See Figure 43), and the dip in density in between these two peaks are the time when the space craft is at a location <6 ρ_{spin}.
46. The Na^{+} ion temperature, measured in electron volts, as a function of decimal time on Day 64. The major drop at 64.5 (Hour 12) lines up with the location of the spacecraft when it is < 6 ρ_{spin}.
47. The SO_2^{+} ion density, measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}.
48. The SO_2^{+} ion temperature, measured in electron volts, as a function of distance to Jupiter in ρ_{spin}.
49. The SO_2^{+} ion density, measured in cm^{-3}, as a function of time on Day 64. t=0 represents 64.4 (Hour 9.6) and t=0.1 represents 64.5 (Hour 12).
50. The SO_2^{+} ion temperature, measured in electron volts, as a function of time on Day 64. t=0 is equivalent to 64.4 (Hour 9.6) and t=0.1 is equivalent to 64.5 (hour 12).
51. The total charge density, measured in cm^{-3}, as a function of distance to Jupiter in ρ_{spin}.
52. The total charge temperature, measured in electron volts, as a function of distance to Jupiter in ρ_{spin}. The total charge temperature measurement comes from the "CSV Data Set of Day 64

Density and Temperature". The column it comes from is the "Common Temperatures" (Column 3).

53. The total charge density, measured in cm^{-3}, as a function of time on Day 64.
54. The total charge temperature, measured in electron volts, as a function of time on Day 64. The total charge temperature measurement comes from the "CSV Data Set of Day 64 Density and Temperature". The column it comes from is the "Common Temperatures" (Column 3).
55. A comparison of the density of all of the ions in the graphs above and the total charge in the Io Plasma Torus as a function of distance to Jupiter in ρ_{spin}. The electrons are always highest because they result from being disassociated from their respective atoms, so the additive power of all the ions losing electrons make for the higher value. The two peaks are associated with the times when the space craft was inside the plasma torus, making the torus have the highest density of all the ions and electrons. This makes sense because all the of the ions are made by Io in the plasma torus.
56. A comparison of the temperature of all of the ions in the graphs above and the total charge in the Io Plasma Torus as a function of distance to Jupiter in ρ_{spin}. The total charge temperature measurement comes from the "CSV Data Set of Day 64 Density and Temperature". The column it comes from is the "Common Temperatures" (Column 3). The electrons are always highest because they result from being disassociated from their respective atoms, so the additive power of all the ions losing electrons make for the higher value. All the values of the ions and the total charge temperatures dip when the spacecraft is at a position of $< 5\ \rho_{\text{spin}}$, inside the radius of the Plasma Torus.
57. A comparison of the density of all of the ions in the graphs above and the total charge in the Io Plasma Torus as a function of time on Day 64.
58. A comparison of the temperatures of all the ions in the graphs above and the total charge in the Io Plasma Torus as a function of time on Day 64. The total charge temperature measurement comes from the "CSV Data Set of Day 64 Density and Temperature". The column it comes from is the "Common Temperatures" (Column 3).

Ion Comparisons with Previous Publications

To come – comparisons with McNutt and Bagenal papers with earlier analysis of Voyager PLS ion data.

References

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