Voyager Plasma Science Instrument

John Belcher
617-253-4285
37-695 MIT
77 Massachusetts Avenue
Cambridge MA 02139

Comments and questions to jbelcher@mit.edu

A pdf copy of this word document not too far out of date can be found at
http://web.mit.edu/jbelcher/www/VoyagerDoc_2015.pdf

Table of Contents

Table of Contents
(*LIVE LINKS*)

Figure Captions

1 Overview

1.1 Important Dates

The launch dates of the Voyager I and II spacecraft were September 5 (DOY 248, first M mode spectrum at 1977 248 14) and August 20 (DOY 232, first M mode spectrum is at 1977 232 16 0 5 403), 1977, respectively. We discuss the PLS experiment's location on the spacecraft and its measurement capabilities.

Voyager 1:

Event	Date	PLS Mode Time
Launch	9/5/1977	1977 248 14
Final PLS failure	11/23/1980	1980 328 1024:14
Heliopause	8/25/2012	----

Voyager 2:

Event	Date	PLS Mode Time
Launch		
Shock	August 30 2007	
Heliopause		----

The table below gives the location of various data files discussed below, for easy reference. Note: While the files can still be accessed on the faraday d9 disk, Kenton thinks that all the faraday disks are very geriatric and could die at any time. Last year we copied the files to our new plas7 computer.

File	Location
V1 Short SEDR	/nfs/plas7/d2/vgr/v1/shortsedr
V2 Short SEDR	/nfs/plas7/d3/vgr/v2/shortsedr


```
You may want to use the following setenv statements:

                     setenv vgrDATA    /nfs/plas7/d3/vgr
                     setenv vgrWWW     /nfs/plas7/d8/vgr
                     setenv vgrDATAv1  /nfs/plas7/d2/vgr
```

1.2 Tasks

1.2.1 Document new data format

http://space.mit.edu/home/gsg/doc/Voyager/vgranl.html

/nfs/carrington/h1/jwb/src/test

From /nfs/carrington/h1/jwb/src/storage/ansTEST.f

```
c  this is the time
        WRITE(29,5) JTB,JTLMOD,jne,JCLK,kstat,ipls,ityp,lstat
 5    format(12I5,Z10)
c   write out answer array
        write(29,8) ANS,temp
 8    format(5E15.5)

     INTEGER*2 JDAT(512) ,JTB(6),JNE,JTLMOD,JCLK
      REAL  ANS(200)

      KSTAT = L1X(LSTAT)
      IPLS = MOD(KSTAT/2,2)
      ITYP = MOD(KSTAT/4,4)
```

1.2.2 Make galactic coordinate plot of voyager trajectories

2 Spacecraft and PLS Instrument

2.1 Configuration

The Plasma Science Experiment (PLS) is shown below. The various cups in the main sensor (A, B, C) have normals which make an angle of 20 degrees to the symmetry axis of the main sensor.

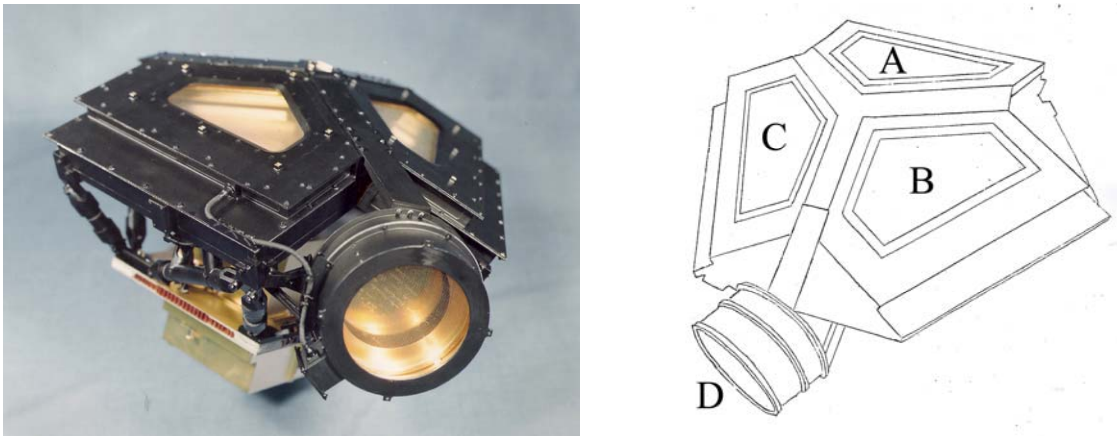


Figure 2.1-1: The Four Sensors of the Plasma Science Experiment

The experiment is mounted on the science boom as shown in the figures below.

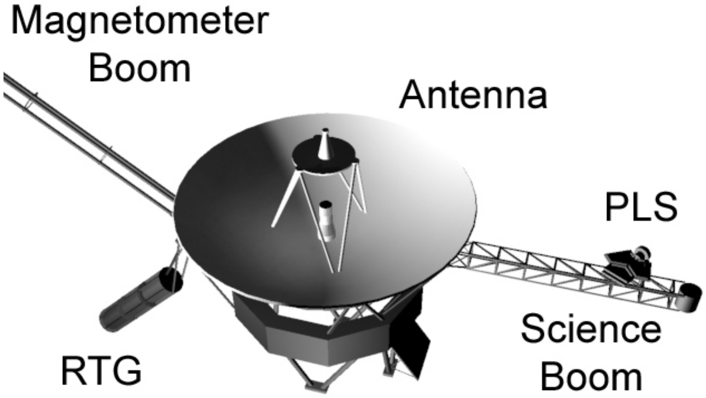


Figure 2.1-2: The Voyager Spacecraft

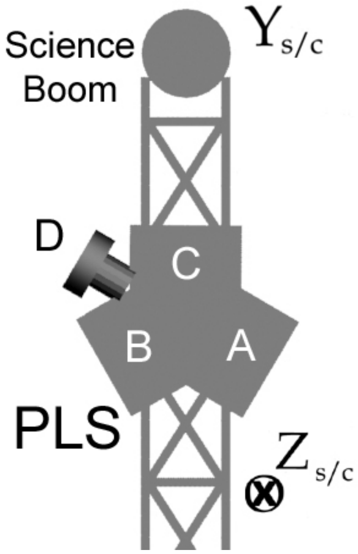


Figure 2.1-3: Close up of Science Boom and PLS Instrument

2.2 Spacecraft Coordinates and Cup Normals

The symmetry axis of the main PLS cluster is along the negative spacecraft Z axis (see Figure 2.2.1), which is aligned with spacecraft antenna. Thus when the spacecraft antenna is pointed at the earth (the usual configuration), the negative spacecraft Z axis points toward the earth, as does the symmetry axis of the main cluster. The definition of the spacecraft axes are shown in Figure 2.2.1.

The various cup normals to the four plasma sensors in spacecraft coordinates are given by

$$\hat{\mathbf{n}}_A = -\hat{\mathbf{X}}_{s/c} \sin 20^\circ \cos 30^\circ - \hat{\mathbf{Y}}_{s/c} \sin 20^\circ \cos 60^\circ - \hat{\mathbf{Z}}_{s/c} \cos 20^\circ \tag{2.2.1}$$

$$\hat{\mathbf{n}}_B = \hat{\mathbf{X}}_{s/c} \sin 20^\circ \cos 30^\circ - \hat{\mathbf{Y}}_{s/c} \sin 20^\circ \cos 60^\circ - \hat{\mathbf{Z}}_{s/c} \cos 20^\circ \tag{2.2.2}$$

$$\hat{\mathbf{n}}_C = \hat{\mathbf{Y}}_{s/c} \sin 20^\circ - \hat{\mathbf{Z}}_{s/c} \cos 20^\circ \tag{2.2.3}$$

$$\hat{\mathbf{n}}_D = \hat{\mathbf{X}}_{s/c} \cos 43^\circ + \hat{\mathbf{Y}}_{s/c} \sin 43^\circ \tag{2.2.4}$$

We can invert this non-orthogonal transformation to obtain

$$\hat{\mathbf{X}}_{s/c} = \frac{\hat{\mathbf{n}}_B - \hat{\mathbf{n}}_A}{2 \sin 20 \cos 30} \tag{2.2.5}$$

$$\hat{\mathbf{Y}}_{s/c} = \frac{1}{\sin 20^\circ \left(1 + \cos 60^\circ\right)} \left[\hat{\mathbf{n}}_C - \frac{\hat{\mathbf{n}}_A + \hat{\mathbf{n}}_B}{2} \right] \tag{2.2.6}$$

$$\hat{\mathbf{Z}}_{s/c} = -\left[\frac{\hat{\mathbf{n}}_A + \hat{\mathbf{n}}_B}{2 \cos 60^\circ} + \hat{\mathbf{n}}_C \right] \left[\frac{\cos 60^\circ}{\cos 20^\circ \left(1 + \cos 60^\circ\right)} \right] \tag{2.2.7}$$

When in the supersonic solar wind, the various cups in the main sensor measure the components of proton velocity *along the direction anti-parallel to the sensor normal*, so if V_A, V_B, and V_C are the measured components of the solar wind speed along the cup normals, they are related to the solar wind components in spacecraft coordinates by

$$V_A = V_{X\,s/c} \sin 20^{\circ} \cos 30^{\circ} + V_{Y\,s/c} \sin 20^{\circ} \cos 60^{\circ} + V_{Z\,s/c} \cos 20^{\circ} \tag{2.2.8}$$

$$V_B = -V_{X\,s/c} \sin 20^{\circ} \cos 30^{\circ} + V_{Y\,s/c} \sin 20^{\circ} \cos 60^{\circ} + V_{Z\,s/c} \cos 20^{\circ} \tag{2.2.9}$$

$$V_C = -V_{Y\,s/c} \sin 20^{\circ} + V_{Z\,s/c} \cos 20^{\circ} \tag{2.2.10}$$

and conversely

$$V_X = \frac{V_A - V_B}{2 \sin 20 \cos 30} \tag{2.2.11}$$

$$V_Y = \frac{1}{\sin 20^{\circ} \left(1 + \cos 60^{\circ}\right)} \left[-V_C + \frac{V_A + V_B}{2} \right] \tag{2.2.12}$$

$$V_Z = \left[\frac{\cos 60^{\circ}}{\cos 20^{\circ} \left(1 + \cos 60^{\circ}\right)} \right] \left[\frac{V_A + V_B}{2 \cos 60^{\circ}} + V_C \right] \tag{2.2.13}$$

Numerically, we have for the cup normals the following values

	Xs/c	Ys/c	Zs/c
A cup	-0.296198	-0.171010	-0.939693
B cup	0.296198	-0.171010	-0.939693
C cup	0.000000	0.342020	-0.939693
D cup	0.731354	0.681998	0.000000

(2.2.14)

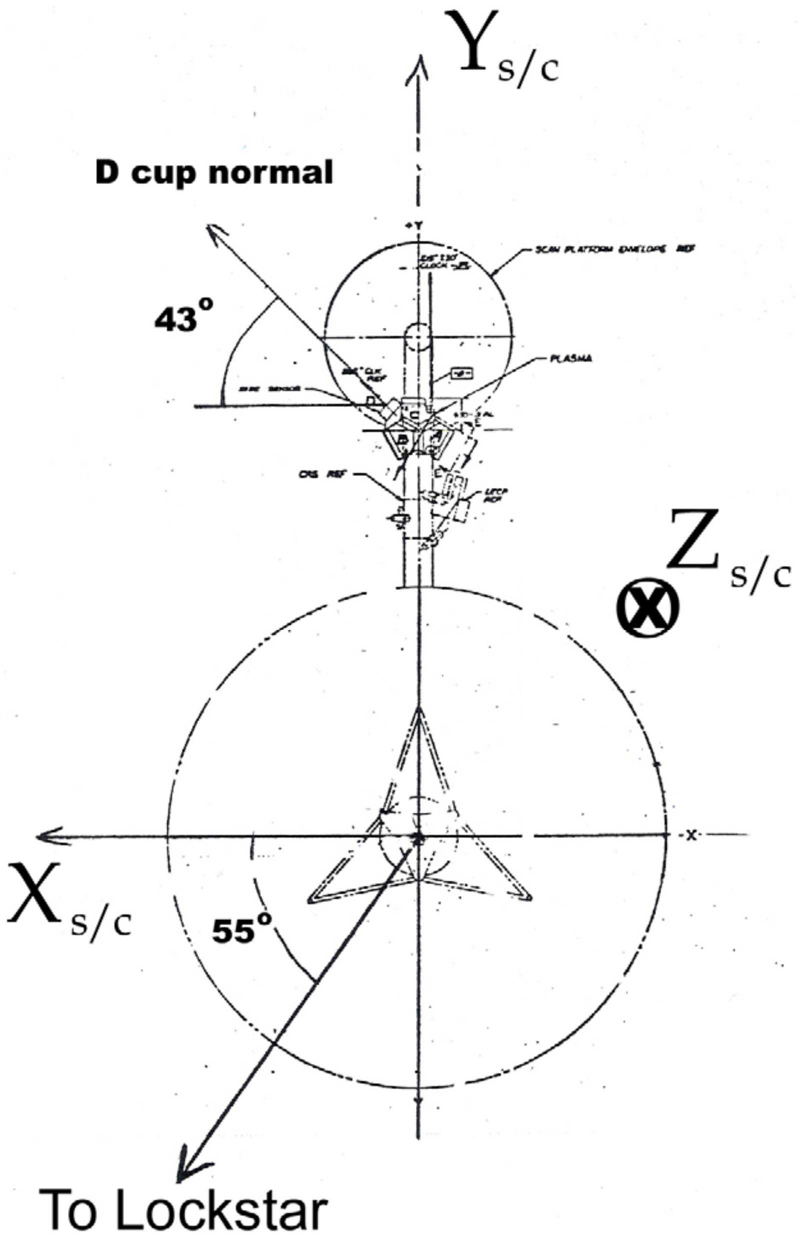


Figure 2.2-1: Spacecraft Coordinates

2.3 The Canopus Sensor

Consider a spherical polar coordinate system based on spacecraft coordinates. The Canopus sensor is an slit which is narrow in azimuth in this system. The narrow azimuth extent of the slit is centered at -55 degrees in azimuth (see Figure above). The slit is elongated in the polar angle, with the center of the elongated slit at a polar angle of 90 degrees (that is, in the $X_{s/c}$-$Y_{s/c}$ plane). When the Canopus sensor is on a given lock star, the direction to that star will lie somewhere in a plane perpendicular to the $X_{s/c}$-$Y_{s/c}$ plane with an azimuth angle of -55 degrees.

3 Instrument

3.1 Introduction

The Voyager I instrument failed just past Saturn encounter. The Voyager II instrument continues to operate up to the present time. A full description of the instrument is given in Bridge et al. (1977).

3.2 The Experimental Concept

The Voyager measurement concept for a supersonic plasma such as the solar wind provides: (1) complete coverage of phase space with high time resolution; (2) determination of the density, velocity, pressure tensor, and heat flux, with no model : The assumptions; (3) ease of data interpretation—that is the above properties can be obtained by the formation of sums based directly on the measured currents; (4) ease of a non-linear least squares fit analysis if desired.

These features are achieved the use of a cluster of three modulated grid Faraday cup plasma detectors (Figure 2.2-1). The axis of symmetry of the cluster (the spacecraft $-\hat{\mathbf{z}}$ direction) is approximately along the spacecraft-earth line, which is close to the spacecraft-sun line. The normal to each of the three cups (referred to as the A, B, and C detectors) are each 20 degrees from the symmetry axis and 120 degrees apart in azimuth. Each detector has an extremely wide field of view for full acceptance of the incident plasma ions, and the cluster as a whole has a common field of view which is a cone of approximately 45 degrees half-angle about the symmetry axis. All detectors have full acceptance in this common field of view.

3.2.1 Voltage Levels

Let Φ_k be the lower modulator voltage for the k-th energy window (*k* runs from 1 to 16 for the *L* (low resolution) ion mode and from 1 to 128 for the *M* (high resolution) ion mode. Then for the *L* mode, these lower (upper) voltage in channel k (k-1) are given by

$$\Phi_k = \left[60(1.33352)^{k-1} - 50\right] \text{ Volts} \quad k = 1 \text{ to } 17 \qquad (3.2.1.1)$$

and in the *M* mode by

$$\Phi_k = \left[60(1.03663)^{k-1} - 50\right] \text{ Volts} \quad k = 1 \text{ to } 129 \qquad (3.2.1.2)$$

Table 3-1 shows the various voltages and speeds in the *L* mode.

channel	Lower voltage	Lower speed	Average Speed	Delta Speed

1	10.0	43.8	59.8	32.1
2	30.0	75.8	90.0	28.4
3	56.7	104.2	118.6	28.7
4	92.3	133.0	148.3	30.7
5	139.7	163.6	180.4	33.6
6	203.0	197.2	215.9	37.4
7	287.4	234.7	255.7	42.2
8	399.9	276.8	300.7	47.8
9	550.0	324.6	351.9	54.5
10	750.1	379.1	410.3	62.3
11	1017.0	441.4	477.1	71.4
12	1372.8	512.9	553.9	82.1
13	1847.3	594.9	642.1	94.4
14	2480.1	689.3	743.7	108.7
15	3324.0	798.0	860.7	125.3
16	4449.3	923.3	995.5	144.4
17	5949.9	1067.7		

Table 3-1: Voltages and speeds for the L mode

In Table 1, a given voltage Φ_k corresponds to a proton speed given by

$$\tfrac{1}{2} m_{proton} \mathrm{v}_k^2 = q_{proton}\Phi_k \qquad \text{or} \qquad \mathrm{v}_k = \sqrt{\frac{2q_{proton}\Phi_k}{m_{proton}}} = 13841.8\sqrt{\Phi_k} \tag{3.2.1.3}$$

where in the last equation, if Φ_k is given in volts, then the speed is in km/s.

3.2.2 Reduced Distribution Function and Measured Currents

To understand the Voyager moments calculation, let $\hat{\mathbf{n}}$ be the unit normal to a given collector, and $\hat{\mathbf{t}}_1$ and $\hat{\mathbf{t}}_2$ be mutually perpendicular unit vectors which are transverse to $\hat{\mathbf{n}}$. Let A be the area of the sensor, and q_{proton} the charge on a proton. If v_k is the lower speed for the k-th energy channel, then the modulated current I_k measured by the Faraday cup for the k-th channel is related to the particle distribution function $f(\mathbf{v})$ by:

$$I_k = q_{proton} A \int_{\mathrm{v}_k}^{\mathrm{v}_{k+1}} d\mathrm{v}_n \mathrm{v}_n \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} d\mathrm{v}_{t1} d\mathrm{v}_{t2} f\left(\mathbf{v}\right) G(\mathbf{v},\hat{\mathbf{n}}) \tag{3.2.2.1}$$

In this expression $f(\mathbf{v})$ is the distribution function, $G(\mathbf{v},\hat{\mathbf{n}})$ is the fraction of the aperture that intercepts the collector when projected in a given direction $\mathbf{v}$, and $(\mathrm{v}_n, \mathrm{v}_{t1}, \mathrm{v}_{t2})$ are the components of the velocity along $(\hat{\mathbf{n}}, \hat{\mathbf{t}}_1, \hat{\mathbf{t}}_2)$. The three cups in the main cluster have been carefully designed to have wide fields of view, so that in the solar wind, the function

$G(\mathbf{v},\hat{\mathbf{n}})$ in equation (3.2.2.1) can be taken to be simply the transparency of the grids for all reasonable angles of incidence of the solar wind.

In addition in the inner solar system the thermal speed of the protons is much greater than the width of the channels in speed, as the velocity windows are narrow ($\Delta \mathrm{v} / \mathrm{v} \approx 1.8\%$), so that in equation (3.2.2.1) it is reasonable to assume that the distribution function is only slowly varying over a channel. With this assumption, and defining the average and difference speeds for a given channel as

$$\overline{\mathrm{v}}_k = (\mathrm{v}_{k+1} + \mathrm{v}_k)/2 \qquad \Delta \mathrm{v}_k = (\mathrm{v}_{k+1} - \mathrm{v}_k) \tag{3.2.2.2}$$

we can write equation (3.2.2.1) as

$$I_k = q_{proton} A_{eff} \Delta \mathrm{v}_k \overline{\mathrm{v}}_k \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} d\mathrm{v}_{t1} d\mathrm{v}_{t2}\, f\left(\overline{\mathrm{v}}_k, \mathrm{v}_{t1}, \mathrm{v}_{t2}\right) \tag{3.2.2.3}$$

where A_{eff} is the product of the area of the cups and the transparency of the grids. Let us define the reduced distribution function *F* as

$$F(\mathrm{v}_n) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} d\mathrm{v}_{t1} d\mathrm{v}_{t2}\, f\left(\mathrm{v}_n, \mathrm{v}_{t1}, \mathrm{v}_{t2}\right) \tag{3.2.2.4}$$

From the above equations, it is clear that a good estimate of *F* evaluated at $\overline{\mathrm{v}}_k$ is

$$F(\mathrm{v}_n)\Big|_{\mathrm{v}_n = \overline{\mathrm{v}}_k} = I_k / \left[q_{proton} A_{eff} \Delta \mathrm{v}_k \overline{\mathrm{v}}_k \right] \tag{3.2.2.5}$$

3.2.3 Moments Calculation

The direct connection between the measured currents and the reduced distribution function shown in equation (3.2.2.5) is the key to the simplicity of the Voyager data analysis in the warm, supersonic solar wind. Each detector samples the full distribution function in a manner which is differential for the velocity component parallel to the detector normal and integral for the velocity components perpendicular to the detector normal. The cluster as a whole provides measurements of the reduced distribution function in each of three well separated directions. This information can be used to obtain the moments of the full distribution function *f*, given the magnetic field direction, in a straight forward manner, as follows.

The definition of the moments of *f* through the third moment are given by

$$N = \iiint f\, d^3\mathrm{v} \tag{3.2.3.1}$$

$$\mathbf{V} = \iiint \mathbf{v}\, f\, d^3\mathrm{v} / N \tag{3.2.3.2}$$

$$\overleftrightarrow{\mathbf{P}} = m \iiint (\mathbf{v}-\mathbf{V})(\mathbf{v}-\mathbf{V})\, f\, d^3\mathrm{v} \tag{3.2.3.3}$$

$$\overleftrightarrow{\mathbf{Q}} = \tfrac{1}{2} m \iiint (\mathbf{v}-\mathbf{V})(\mathbf{v}-\mathbf{V})(\mathbf{v}-\mathbf{V})\, f\, d^3\mathrm{v} \tag{3.2.3.4}$$

where $\overleftrightarrow{\mathbf{P}}$ is a the second rank pressure tensor and $\overleftrightarrow{\mathbf{Q}}$ is the third rank heat flux tensor. If we assume that f is gyrotropic, then we can write

$$\overleftrightarrow{\mathbf{P}} = (P_{\parallel} - P_{\perp})\hat{\mathbf{b}}\hat{\mathbf{b}} + P_{\perp}\overleftrightarrow{\mathbf{I}} \tag{3.2.3.5}$$

$$\overleftrightarrow{\mathbf{Q}} = Q_{\parallel}\hat{\mathbf{b}}\hat{\mathbf{b}}\hat{\mathbf{b}} + Q_{\perp}\overleftrightarrow{\mathbf{I}}\hat{\mathbf{b}} \tag{3.2.3.6}$$

where $\hat{\mathbf{b}}$ is the unit vector along the magnetic field direction.

Consider a given detector with normal $\hat{\mathbf{n}}$. Let θ_n be the angle between the magnetic field direction and the cup normal. We can calculate the moments of *F* by approximating integrals by sums. From the equations above, it is clear that for each cup we can find the following moments of *F*.

$$N = \int F(\mathrm{v}_n)\, d\mathrm{v}_n = \sum_k \left[\frac{I_k}{q_{proton} A_{eff} \Delta\mathrm{v}_k \bar{\mathrm{v}}_k} \right] \Delta\mathrm{v}_k = \frac{1}{q_{proton} A_{eff}} \sum_k \left[\frac{I_k}{\bar{\mathrm{v}}_k} \right] \tag{3.2.3.7}$$

$$V_n = \int \mathrm{v}_n F(\mathrm{v}_n)\, d\mathrm{v}_n / N = \sum_k \bar{\mathrm{v}}_k \left[\frac{I_k}{q_{proton} A_{eff} \Delta\mathrm{v}_k \bar{\mathrm{v}}_k} \right] \Delta\mathrm{v}_k / N = \frac{1}{q_{proton} A_{eff}} \sum_k [I_k] / N \tag{3.2.3.8}$$

$$\begin{aligned} P_{nn} &= \hat{\mathbf{n}} \cdot \overleftrightarrow{\mathbf{P}} \cdot \hat{\mathbf{n}} = P_{\parallel} \cos^2\theta_n + P_{\perp} \sin^2\theta \\ &= m \int (\mathrm{v}_n - \mathrm{V}_n)^2 F(\mathrm{v}_n)\, d\mathrm{v}_n = \frac{m}{q_{proton} A_{eff}} \sum_k (\bar{\mathrm{v}}_k - \mathrm{V}_n)^2 \left[\frac{I_k}{\bar{\mathrm{v}}_k} \right] \end{aligned} \tag{3.2.3.9}$$

$$\begin{aligned} Q_{nnn} &= Q_{\parallel} \cos^3\theta_n + 3Q_{\perp} \cos\theta_n \\ &= \frac{m}{2} \int (\mathrm{v}_n - \mathrm{V}_n)^3 F(\mathrm{v}_n)\, d\mathrm{v}_n = \frac{m}{2 q_{proton} A_{eff}} \sum_k (\bar{\mathrm{v}}_k - \mathrm{V}_n)^3 \left[\frac{I_k}{\bar{\mathrm{v}}_k} \right] \end{aligned} \tag{3.2.3.10}$$

Each of these equations is repeated for each of the three cups. Thus, knowledge of the field direction and the moments of the three reduced distribution functions is sufficient to determine *N* (three independent estimates), **V**, $P_{\parallel}$ and $P_{\perp}$ (over-determined), and $Q_{\parallel}$ and $Q_{\perp}$ (over-determined). The sums indicated in the equations above are carried out by the Fortran routine *moments.f* (see Section 5.4 below).

3.2.4 Relationship between Pressure, Temperature, and Thermal Speed

To calculate a thermal speed W_{nn}, we have the following relationships:

$$P_{nn} = NkT_{nn} = N\left[\tfrac{1}{2} mW_{nn}^2\right] \qquad W_{nn} = \sqrt{\frac{2P_{nn}}{mN}} \qquad T_{nn} = \frac{\frac{1}{2} mW_{nn}^2}{k} \qquad W_{nn} = \sqrt{\frac{2kT_{nn}}{m}} \tag{3.2.4.1}$$

Comparing (3.2.4.1) with (3.2.3.9), we see that

$$W_{nn} = \sqrt{2\int \left(\mathrm{v}_n - \mathrm{V}_n\right)^2 F(\mathrm{v}_n)\, d\mathrm{v}_n / N} = \sqrt{\frac{2}{q_{proton} A_{eff}} \sum_k \left(\bar{\mathrm{v}}_k - \mathrm{V}_n\right)^2 \left[\frac{I_k}{\bar{\mathrm{v}}_k}\right] / N} \tag{3.2.4.2}$$

3.2.5 Theoretical Examples of the Voyager Measurement Scheme

To illustrate this scheme with two concrete examples, we show in Figure 2.2.2 and Figure 2.2.3 two different samples of the same distribution function. The distribution function consists of two bi-Maxwellians, with one hotter than the other. In each case, the bottom panel of the figure shows iso-density contours of the distribution function. For ease of presentation, we have assumed that the bulk velocity **V**, the magnetic field **B**, and a given cup normal $\hat{\mathbf{n}}$ all lie in the plane of the paper.

Also indicated in the lower panel is the manner in which a given detector slices the distribution function for a given $\hat{\mathbf{n}}$. .In the upper panel we show the measured currents which would result from this sampling for a given $\hat{\mathbf{n}}$. Note in particular the difference between the measured currents in the case when $\hat{\mathbf{n}}$ has a large projection along **B** (Figure 2.2.2) as contrasted to the case when $\hat{\mathbf{n}}$ has a small projection along **B** (Figure 2.2.3). Although over-idealized, these figures clearly illustrates in principle the three-dimensional capabilities of the Voyager measurements.

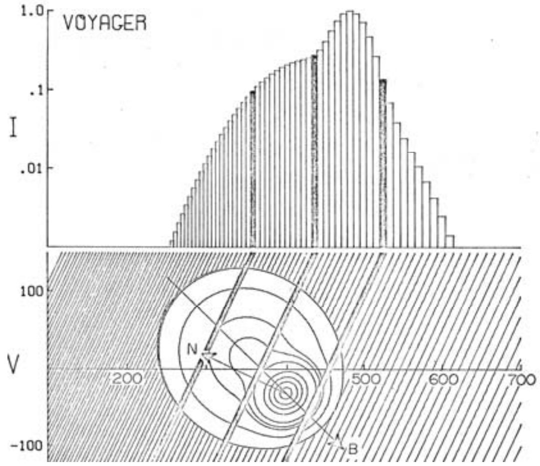


Figure 3.2-1: Theoretical currents, B and n close to parallel.

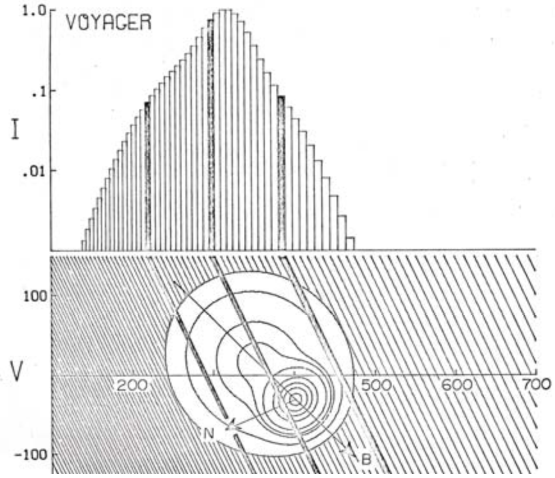


Figure 3.2-2: Theoretical currents, B and n close to perpendicular.

3.3 Measured Voyager Ion Spectra

3.3.1 Solar Wind M Modes

Figure 2.3-1 shows four sample spectra from the M mode sequence from early in the mission. Measured currents (fluxes) in each of the three detectors are indicated by the step-like lines. On each figure, we also give some of the results of the moment calculations for the proton peak (see the discussion in II above and IV A below). In two of the figures, least squares fit points using Maxwellians are indicated by crosses and diamonds. The instrument quantizes the currents logarithmically using eight bits to cover a range of four decades for each gain state of the instrument. The quantization error is thus + 1.8%.The noise level is = 6 x 10^{-14} amps for the integration time used in the measurements presented here. At the highest bit rate, an M mode spectrum is obtained every twelve seconds. For the alpha particles particle distribution, the peak is located at twice the energy of the proton peak in all detectors, because we are measuring energy per charge and an alpha particle moving at the same speed as a proton has twice the energy per charge (four times the mass and twice the charge).

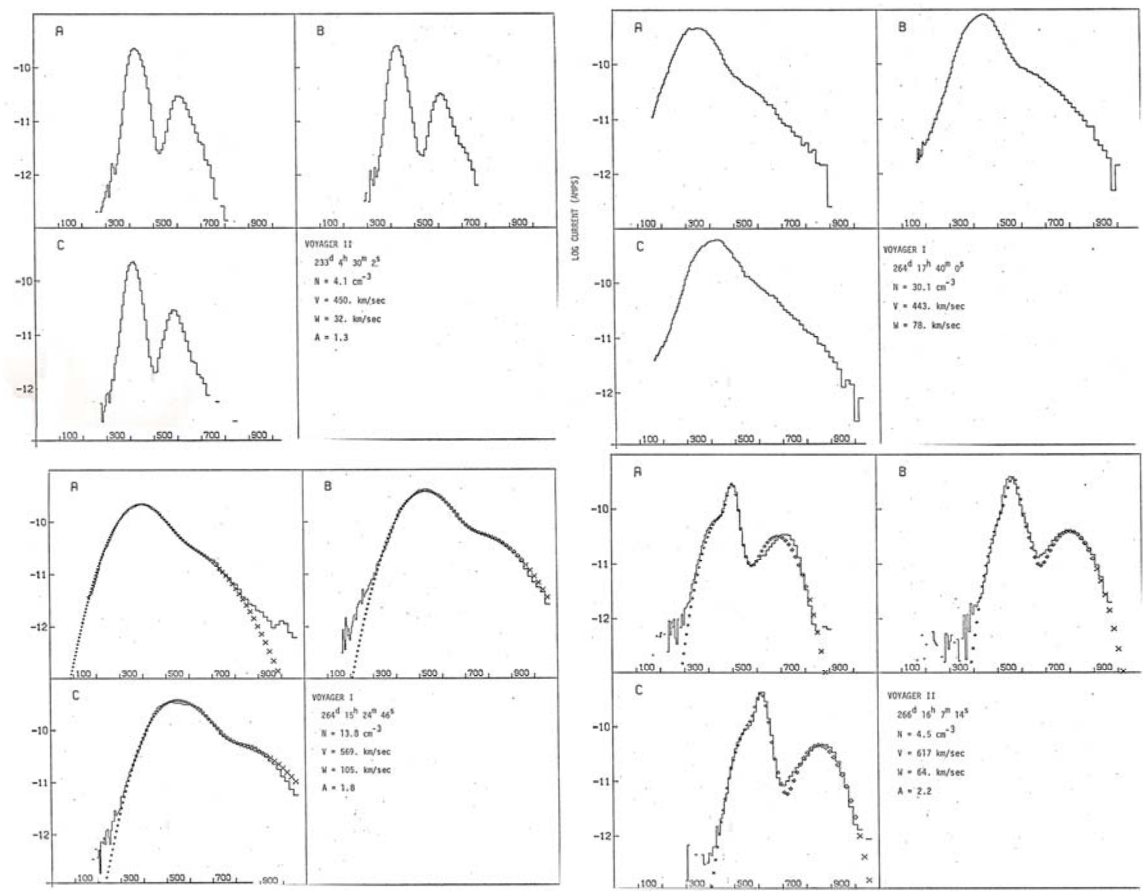
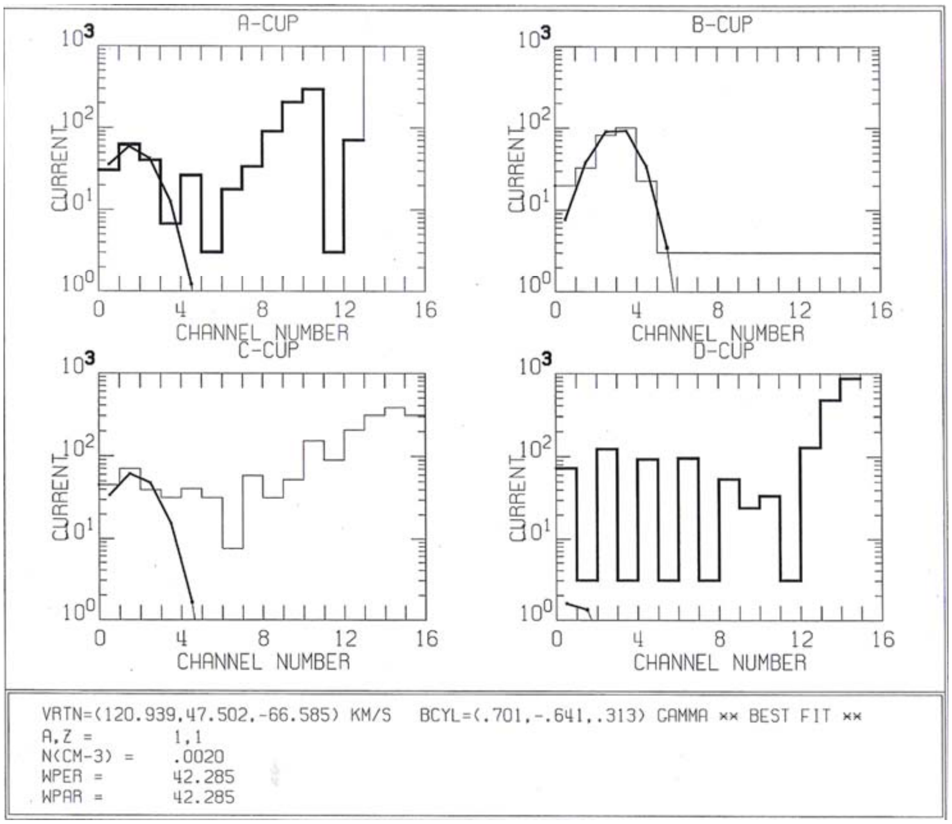


Figure 3.3-1: Examples of Measured Ion Currents in the M Mode

3.3.2 Heliosheath L Modes

Voyager 2 crossed the termination shock in August of 2007. Figure 2.3-2 shows a heliosheath spectra and least squares fit at the time indicated. Fit parameters are given at the bottom of the Figure.



```
VRTN=(120.939,47.502,-66.585) KM/S   BCYL=(.701,-.641,.313) GAMMA ** BEST FIT **
A,Z =          1,1
N(CM-3) =      .0020
WPER =         42.285
WPAR =         42.285
```

Vi outFigure 3.3-2: Heliosheath L Mode Spectra on 2007 day 267 1916 26.135

3.3.3 Fitting a Bi-Maxwellian to Voyager Spectra

In addition to the model independent moments calculation described above, we also frequently want to find a best fit of a bi-maxwellian to Voyager spectra. First we consider fitting a single maxwellian to one sensor. We assume the form of our reduced distribution function *F* is (see 3.2.2.4)

$$F(\mathrm{v}_n) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} d\mathrm{v}_{t1} d\mathrm{v}_{t2}\, f\left(\mathrm{v}_n, \mathrm{v}_{t1}, \mathrm{v}_{t2}\right) = \frac{n}{\sqrt{\pi} w_n} e^{-(\mathrm{v}_n - V_n)^2/w_n^2} \qquad (3.3.3.1)$$

This gives a density *n* of

$$n = \int_{-\infty}^{\infty} F(\mathrm{v}_n)\, d\mathrm{v}_n = \int_{-\infty}^{\infty} \frac{n}{\sqrt{\pi} w_n} e^{-(\mathrm{v}_n - V_n)^2/w_n^2}\, d\mathrm{v}_n = \frac{n}{\sqrt{\pi}} \int_{-\infty}^{\infty} e^{-x^2}\, dx = n \qquad (3.3.3.2)$$

and a thermal speed w_n of (cf. 3.2.4.2)

$$w_n^2 = 2\int \left(\mathrm{v}_n - \mathrm{V}_n\right)^2 F(\mathrm{v}_n)\, d\mathrm{v}_n / n = 2\int \left(\mathrm{v}_n - \mathrm{V}_n\right)^2 \frac{n}{\sqrt{\pi} w_n} e^{-(\mathrm{v}_n - V_n)^2/w_n^2}\, d\mathrm{v}_n \qquad (3.3.3.3)$$

$$w_n^2 = \frac{2}{w_n}\frac{n}{\sqrt{\pi}}w_n^3\int x^2 e^{-x^2}\,dx = w_n^2 \qquad (3.3.3.4)$$

If we now ask what the current in a given channel is when we integrate from the lower velocity window to the upper velocity window of the nth channel, it is given by (cf. 3.2.2.1)

$$I_k = q_{proton}A\int_{\mathrm{v}_k}^{\mathrm{v}_{k+1}} d\mathrm{v}_n\mathrm{v}_n\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} d\mathrm{v}_{t1}d\mathrm{v}_{t2}\,f\left(\mathbf{v}\right) = qA_{eff}\int_{\mathrm{v}_k}^{\mathrm{v}_{k+1}} d\mathrm{v}_n\mathrm{v}_n F(\mathrm{v}_n) \qquad (3.3.3.5)$$

$$I_k = qA_{eff}\int_{\mathrm{v}_k}^{\mathrm{v}_{k+1}} d\mathrm{v}_n\mathrm{v}_n\frac{n}{\sqrt{\pi}w_n}e^{-(\mathrm{v}_n-V_n)^2/w_n^2} = qA_{eff}\frac{n}{\sqrt{\pi}w_n}\int_{\mathrm{v}_k}^{\mathrm{v}_{k+1}} d\mathrm{v}_n\mathrm{v}_n e^{-(\mathrm{v}_n-V_n)^2/w_n^2} \qquad (3.3.3.6)$$

The above function can be integrated but it involves the *erf* function. For most purposes we combine (3.2.2.5) with (3.3.3.1) to obtain

$$F(\mathrm{v}_n)\Big|_{\mathrm{v}_n=\bar{\mathrm{v}}_k} = I_k/\left[q_{proton}A_{eff}\Delta\mathrm{v}_k\bar{\mathrm{v}}_k\right] = \frac{n}{\sqrt{\pi}w_n}e^{-(\mathrm{v}_k-V_n)^2/w_n^2} \qquad (3.3.3.7)$$

and we use this to fit our measured currents to a maxwellian.

3.4 The Status Word

The status word is an 8 bit word that indicates the measurement mode of the instrument (*L* mode, *M* mode, low energy electron mode *E1*, and high energy electron mode *E2*), the gain of the instrument, and the calibration mode of the instrument. For example, a status word of 2F means that we are in the L mode and IGAN = 1 and ICAP = 0 and the instrument is taking plasma data with the modulator on.

3.4.1 Bits 1 and 2 of status word code L, E1, E2, M

Table 3.2 shows how the upper two bits of the status word encodes the measurement mode of the instrument.

Mode	Bits 1 and 2
L	(0,0)
E1	(0,1)
E2	(1,0)
M	(1,1)

Table 3-2: Bits 1 and 2 Code L, E1, E2, and M

3.4.2 Bits 3 and 4 of status word code IGAIN and ICAP

(IGAN,ICAP)	Bits 3 and 4
(0,0)	(0,0)
(0,1)	(0,1)
(1,0)	(1,0)
(1,1)	(1,1)

Table 3-3: Bits 3 and 4 Code IGAIN and ICAP

If IGAN = 0 the gain *G* is 2.0, if IGAN = 1 the gain *G* is 20.0; if ICAP = 0 the capacitance *C* is 0.15, and if ICAP = 1 the capacitance *C* is 1.15.

3.4.3 Bits 5 through 8 of status word code calibration modes

Calibration Mode	Bits 5-8	Hex Value	Integer Value
DC Return Modulator Off	(0,0,0,0)	0	0
Modulator Calibration	(0,1,1,1)	7	7
Internal Current Calibration	(1,0,1,0)	A	10
DC Return Modulator On	(1,1,0,1)	D	13
Plasma Data Modulator Off	(1,1,1,0)	E	14
Plasma Data Modulator On	(1,1,1,1)	F	15

Table 3-4: Bits 5-8 and Calibration Modes

3.4.4 Examples of Status Word Decoding

For the M mode on Voyager 2 taken at 1991 160 12 4 48 372, the status word LSTAT printed out in hex (Z) format is FFFF0000. The clock parameter JCLK is 3, meaning this data is taken at the 930 ms integration time. We only want to look at the first eight bits of LSTAT, which are (1,1,1,1,1,1,1,1). Bits 5-8 tell us that this is Plasma Data Modulator On (cf. Table 3-4). Bits 3 and 4 tell us that (IGAN,ICAP) is (1,1). Bits 1 and 2 tell us that we are in the M mode (cf Table 3-2). From Table 3-5 below, we thus see that the threshold current in femtoamps for DN to current conversion is 23.0 femtoamps.

For the L mode on Voyager 2 taken at 1991 160 12 0 54 132, the status word LSTAT printed out in hex (Z) format is 2F2F0000. The clock parameter JCLK is 3, meaning this data is taken at the 930 ms integration time. We only want to look at the first eight bits of LSTAT, which is (0,0,1,0,1,1,1,1). Bits 5-8 tell us that this is Plasma Data Modulator On. Bits 3 and 4 tell us that (IGAN,ICAP) is (1,0). Bits 1 and 2 tell us that we are in the L mode (0,0). From Table 3-5 below, we thus see that the threshold current in femtoamps for DN to current conversion is 3 femtoamps.

For the E1 mode on Voyager 2 taken at 1991 160 12 0 33 20, the status word LSTAT printed out in hex (Z) format is 6F6F0000. The clock parameter JCLK is 3, meaning this data is taken at the 930 ms integration time. We only want to look at the first eight bits of LSTAT, which is (0,1,1,0,1,1,1,1). Bits 5-8 tell us that this is Plasma Data Modulator on. Bits 3 and 4 tell us that (IGAN,ICAP) is (1,0). Bits 1 and 2 tell us that we are in the E1 mode (0,0).

For the E2 mode on Voyager 2 taken at 1991 160 12 1 15 260, the status word LSTAT printed out in hex (Z) format is AFAF0000. The clock parameter JCLK is 3, meaning this data is taken at the 930 ms integration time. We only want to look at the first eight bits of LSTAT, which is (1,0,1,0,1,1,1,1). Bits 5-8 tell us that this is Plasma Data Modulator On. Bits 3 and 4 tell us that (IGAN,ICAP) is (1,0). Bits 1 and 2 tell us that we are in the E2 mode (0,0).

The code in *ansprt.f* computes the following integers from the status word:

```
KSTAT = L1X(LSTAT)
IPLS = MOD(KSTAT/2,2)
ITYP = MOD(KSTAT/4,4)
```

The first of these commands takes the first eight bits of the status word LSTAT, so in the example above (LSTAT = 6F6F0000), it would (in hex format) be AF. In bit format this corresponds to (1,0,1,0,1,1,1,1). IPLS is this integer divided by 2 modulo two, which will isolate the second bit from the right in the above sequence, e.g. 1. ITYP is this integer divided by four, modulo 4, which will take the third and fourth bits from the right in the above above sequence. A comparison with Table 3-1 shows that normal plasma measurements should have IPLS = 1 and ITYP = 3. But this can either be mod on or mod off. To make sure we have the modulator on, compute the following.

```
IPLSON = MOD(KSTAT,16)
```

To make sure we are only looking at plasma data modulator on, take only values of IPLON of 15.

3.5 DN (digital numbers) and EU (engineering units)

3.5.1 Determining the Threshold

The threshold value T for a given gain G and capacitance C and integration time Δt is given by

$$T = 372.\,\frac{C}{G\Delta t} \qquad (3.5.1.1)$$

The values of C and G are determined from the status word and the integration time is specified independent of the status word on the EDR. Table 3-5 gives the range of threshold values possible.

Capacitance (ICAP)	Gain (IGAN)	Integration Time (JCLK)	Threshold
0.15 (0)	2 (0)	0.03 (1)	930
1.15 (1)	2 (0)	0.03 (1)	7130.00
0.15 (0)	20 (1)	0.03 (1)	93.00
1.15 (1)	20 (1)	0.03 (1)	713.00
0.15 (0)	2 (0)	0.21 (2)	132.86
1.15 (1)	2 (0)	0.21 (2)	1018.57
0.15 (0)	20 (1)	0.21 (2)	13.29
1.15 (1)	20 (1)	0.21 (2)	101.86
0.15 (0)	2 (0)	0.93 (3)	30.00
1.15 (1)	2 (0)	0.93 (3)	230.00
0.15 (0)	20 (1)	0.93 (3)	3.00
1.15 (1)	20 (1)	0.93 (3)	23.00

Table 3-5: Thresholds for Gains, Capacitances, and Integration Times

3.5.2 Formula for Conversion DN to EU

Given a DN value from 0 to 255, and the threshold current *T* calculated above, the EU is given by (in femtoamps)

$$EU = T * 10^{(DN/64)}$$

For 0 DN we recover the threshold of 3 femtoamps, and for a DN value of 255 we are at 10^4 times threshold. The dynamic range of the current measurements is thus four orders of magnitude.

3.6 Calibration Sequence in the Heliosheath

Currently I am working on this in the directory

/nfs/carrington/h1/jwb/2015_voyager

Table 3-6 shows the calibration sequence in the heliosheath.

# Frames	Status	Mode
2	3	
2	7	Mod Cal
2	A	Current Calibration
2	F	Plasma data Mod On
2	A	Current Calibration
2	D	DC Return Mod On
2	F	Plasma data Mod On

2	A	Current Calibration
2	F	Plasma data Mod On
2	A	Current Calibration
2	7	Mod Cal
2	F	Plasma data Mod On
2	A	Current Calibration
2	F	Plasma data Mod On
2	B	

Table 3-6: Calibration Sequence in the Heliosheath

4 Calibration Data

4.1 Location of data files

4.1.1 v2_1977_233_260

Using following data sources

```
cd /nfs/plas7/d9/vgr/v2/vgr_staging/v2all_dir/v2all_files
```

More space

```
  cd /nfs/faraday/data/jwb
  cd /nfs/plas7/da/jwb
```

```
setenv vgrDATA    /nfs/plas7/d3/vgr
cd $vgrDATA/v2/vgr
ls -lt |head
```

should give:

```
[vgr@carrington:vgr]> cd $vgrDATA/v2/vgr
[vgr@carrington:vgr]> ls -lt |head
total 2067479
-rw-r--r--   1 vgr      8199160 Jul 18 15:07 v2_vgr_2011.001.08_2011.198.04.gz
-rw-r--r--   1 vgr      8028243 Jul 15 10:02 v2_vgr_2011.001.08_2011.195.07.gz
-rw-r--r--   1 vgr      7970242 Jul 14 10:05 v2_vgr_2011.001.08_2011.194.04.gz
```

Hi John -

Here is the location of the Voyager 2 ascii files and spec plots:

```
setenv vgrV2ALL    cd  /nfs/plas7/d9/vgr/v2/vgr_staging/v2all_dir

ls -lt $vgrV2ALL/v2all_files | head
ls -lt $vgrV2ALL/v2all_plots | head
```

- Leslie

4.2 Times of calibrations in heliosheath

2011/012
2011/040
2011/067
2011/095
2011/123
2011/151
2011/179

5 Running MJSANAL and VGRANL

5.1 MJSANAL

MJSANAL is the planetary encounter or heliosheath routines used to do a fit with the full response function of the instrument. The instructions below are for setting up these routines so that you can plot and analyze spectrum by spectrum the PLS data using the full sensor response for the instrument.

5.1.1 Setup

Create a directory named *mjsanal*. Go to *~jwb/mjsanal* and look at the file list:

```
-rwxr-xr-x   1 jwb            490 May 28 17:10 source.mjs
-rw-r--r--   1 jwb             29 May 28 17:10 time.mjs
-rwxr-xr-x   1 jwb            544 May 28 17:10 mjs.cru
-rw-r--r--   1 jwb           4636 May 28 17:10 cru.fits
-rw-r--r--   1 jwb            368 May 28 17:10 cru.fits.short
```

Copy all of these files into your new directory *mjsanal*. For example, type

```
cp ~jwb/mjsanal/*.mjs  ~/mjsanal/
cp ~jwb/mjsanal/mjs.cru  ~/mjsanal/
```

Now alter your .login file to include the following lines (type *vi ~/.login*) and save

```
if ( -e ~pls/startup/X_login ) then
      source ~pls/startup/X_login
endif
```

Now alter your *.cshrc* file to include the following lines (type *vi ~/.cshrc*) and save

```
if ( -f ~vgr/bin/X_cshrc ) then
      source ~vgr/bin/X_cshrc
endif
```

Log off and log back on. Go to your *mjsanal* directory (*cd ~/mjsanal*) and type *./mjs.cru* to run.

5.1.2 Source files

As far as I can see, the source fortran code is in */nfs/carrington/h3/vgr/src/mjs/mjsanl.f* etc. The short sedr files are at */nfs/faraday/d9/vgr/data/v2/shortsedr*. The data files containing plasma data are at */nfs/plas7/d3/vgr/v2/vgr*.

5.2 VGRANL

VGRANL are the routines used for cruise data analysis, where we can assume the we can take the response function of the instrument to be unit. The instructions below in principle can be used to run the standard cruise analysis. In practice they are used to dump data in a flat file for further analysis, any mode, either from *summary* files or from *vgr* files.

5.2.1 Setup

These instructions are in a flat file in *~jwb/insVGR*, if you want to copy and paste the commands below, use this file.

Go to your main directory and issue the following two commands:

```
ln -s lsb LIB
setenv vgrDATA /nfs/plas7/d6/cbg/data
```

Now create a *src/test* directory, by issuing the following commands, starting from your main directory. In addition to creating your *src/test* directory, the commands below will create a *src/storage* directory and copy over into that directory files from *~jwb/src/storage* that you will need subsequently in running VGRANL.

```
mkdir src
cd src
mkdir storage
cd storage
cp ~jwb/src/storage/* .
cd ..
mkdir test
cd test
```

At the end of the sequence of commands above, you are now in your src/test/ directory, and ***that directory is empty***. You now want to copy over and compile the VGRANL routines, along with any standard fortran routines in that package that you want to change and recompile, so that you get a output different from the standard output at run time. For our purposes this is mainly getting a copy of the standard *ansprt.f* routine, which prints out a lot of information from the analysis in its standard form. But you can get any of the standard routines by simply putting a space after ansprt.f in the command below and adding the name of the fortran routine, e.g. pranal.f.

```
GETFOR vgr ansprt.f
```

If you do an *ls* after you issue the following command from your *src/test* directory you will find that this directoy is no longer empty, and in particular contains a copy of the standart *ansprt.f.* To dump data using a new version of ansprt.f issue the following commands if you want to dump M modes. These commands are issued from your *src/test* directory.

```
rm ansprt.f
cp ../storage/ansprtM.f ansprt.f
```

If you want to dump L modes, issue the two commands

```
rm ansprt.f
cp ../storage/ansprtL.f ansprt.f
```

You also need to get a time interval which you are going to process. To get that time interval issue the command (you are still in your *src/test* directory)

```
cp ../storage/time.ans .
```

If you look at that file using *vi* it will look like this

```
2007 200 00  0 2007 201 00  0         0  00000000
```

The first three fields are integers giving the year day hour of the start time of the interval you want to process, the second three fields are integers giving the end time of the interval you want to process. You want to edit the first six fields in this file for the time interval you want, being very careful to preserve the spacing!

Now you are ready to compile and run VGRANL with the new version of ansprt.f for the time interval you want. Issue the following command to compile the new ansprt.f

```
mm
```

If this runs correctly you will see a long string of characters flash by followed by "DONE". We now run the make file to create the executable module you will be running.

If you want to read SUMMARY files, issue the command

```
mm  vgr vgr TYPE=sum TERM=n
```

If you want to read *vgr* files issue the command

```
mm  vgr vgr TYPE=vgr TERM=n
```

Now we are ready to run the module you have created. We still have not specified whether we are looking at Voyager 1 data or Voyager 2 data, which we will do now.

If you want to process SUMMARY files from Voyager 2, issue the command

```
RUN ans  sum time.ans 2 >& out.ans.test &
```

If you want to read Voyager 1 summary files, change the 2 in the command above to 1.

If you want to process *vgr* files from Voyager 2, issue the command

```
RUN ans  vgr time.ans 2 >& out.ans.test &
```

If you want to read Voyager 1 *vgr* files, change the 2 in the command above to 1.

Your dumped data should appear in the file *output* after the job you submit terminates.

To process other time periods change your time.ans files and follow the above procedure staring with the '*RUN ans sum time.ans 2 >& out.ans.test &*' command or the one appropriate to the spacecraft and the type of data file you are reading.

To change to a new version of *ansprt.f* etc. you must repeat everything above. To get rid of your src/test directory go to src and issue the commands

```
rm –f test
mkdir test
cd test
```

This will create a new empty test directory and you can start fresh

5.2.2 Source files

As far as I can see, the source fortran code is in */nfs/carrington/h3/vgr/src/vgr/.*

6 Code Snippets Data Analysis

The code snippets below are from files located in *~vgr/src/vgr*.

6.1 Voyager constants: plsbeg.f

Among many other things this subroutine sets the values of the constants used in the DN (digital numbers) to EU (Engineering Units, femtoamps) and in the moments calculation (see Sections 3.2 and 3.4 below).

```
DATA CLOCK/0.03,0.21,0.93/,CAP/0.15,1.15/,GAIN/2.0,20.0/,V0/372.0/

DATA   NK  /3*9.4419e-4,1.1097e-3,3*9.4419e-4,1.1097e-3/
DATA   SK  /3*9.633E-4,9.179E-4,3*9.633E-4,9.179E-4/
DATA   WK  /3*9.633E-4,9.179E-4,3*9.633E-4,9.179E-4/
DATA   QK  /3*9.633E-4,9.179E-4,3*9.633E-4,9.179E-4/
```

6.2 Converting Digital Number (DN) Values to Currents: kntcur.f

This routine converts DN values to current in femtoamps.

```
C
C   SET UP TABLE FOR DN TO EU CONVERSION
     IADSF =1
     ITYP=MOD(KSTAT/4,4)
C DOESN'T HANDLE HV MONITOR
     IF  (ITYP .EQ. 1)  GO TO 100
     IF(ITYP.EQ.1.OR.
    *  (ITYP.EQ.2.AND.(JTLMOD.EQ.1.OR.ITLMOD.EQ.4))) IADSF=4
```

```
      ICPGN=MOD(KSTAT/16,4)
C   CHECK TO SEE IF TABLE HAS ALREADY BEEN SET UP
      IF(ICPGN.EQ.LCPGN.AND.IADSF.EQ.LADSF.AND.JCLK.EQ.LCLK) GO TO 10
      ICAP = MOD(ICPGN/1,2)
      IGAN= ICPGN/2
      FACT = CAP(ICAP+1)/GAIN(IGAN+1)/CLOCK(JCLK)*V0
      NMAX = 256*IADSF
      xxx = 1D0/NMAX
      xxzeta = 1D4**xxx
      xxx = FACT
      NMAX = NMAX+1
      DO 1 I=1,NMAX
      TABL(I) = xxx
      X0 = SNGL(xxx)
      xxx = xxx*xxzeta
      TABL(I) = 0.5*(X0 + SNGL(xxx))
 1    CONTINUE
```

6.3 Generating Voltages and Speeds for Energy Channels: step.f

This code generates the voltages and velocities for the energy channels

```
      SUBROUTINE STEP(NUMCHN)
      IMPLICIT INTEGER*2(I-N)
      COMMON/VSTEP/VLIM(129,2),VAVE(129,2),VDIF(129,2)
      DIMENSION NUMCHN(2),RK(2)
      DATA VLT,DCBIAS/60.,50./
      DATA RK/1.33352,1.03663/
      DATA RT2EM/1.38418E+4/
C
C   SET UP VELOCITY LIMITS FOR L(M=1) AND M(M=2) MODES
C   VELOCITIES ARE CALCULATED IN KM/SEC
C   RT2EM IS SQRT OF CHARGE TO MASS RATIO OF PROTON TIMES TWO
C
      DO 20 M=1,2
      NLIM=NUMCHN(M)+1
      FACTE = RK(M)
      DO 30 L=1,NLIM
      VLIM(L,M)=RT2EM*SQRT(VLT*FACTE**(L-1)-DCBIAS)/1000.
      IF(L.EQ.1) GO TO 30
      VDIF(L-1,M)=VLIM(L,M)-VLIM(L-1,M)
      VAVE(L-1,M)=(VLIM(L,M)+VLIM(L-1,M))/2.
   30 CONTINUE
   20 CONTINUE
      RETURN
```

```
      END
```

6.4 Calculating Plasma Moments: moment.f

This code is called from *pranal.f* (see below) to generate the plasma moments in a given cup. The constants FM1,F0,F1,F2 encode the cup areas and the electron charge in the appropriate units, and are given by the values of NK,SK,WK,QK as set in the subroutine *plsbeg.f* (see above). *R* is the current matrix in femtoamps (?) in the cup. XCRIT is the current value below which you do not do the sum, I can't figure out what it is, but for the moment set it to 0.

```
      SUBROUTINE
MOMENT(L1,L2,V,R,RMM1,RM0,RM1,RM2,FM1,F0,F1,F2,XCRIT,
     *  IQUALY)
      IMPLICIT INTEGER*2 (I-N)
C        DATE   JAN  9 1978
      DIMENSION V(128),R(512),RV(128)
C
C   RMM1 IS DENSITY (CM-3)
C   RM0 IS VEL (KM/SEC)
C   RM1 IS THERMAL SPEED ((KM/SEC)**2)
C   RM2 IS THIRD MOMENT DIVIDED BY DENSITY ((KM/SEC)**3)
C
      IQUALY=0
      RMM1=0.
      RM0=0.
      RM1=0.
      RM2=0.
      DO 10 L=L1,L2
      IF(R(L).LE.XCRIT) GO TO 10
      IQUALY = IQUALY+ 1
      RV(L)=R(L)/V(L)
      RMM1=RMM1+RV(L)
      RM0 = RM0 + R(L)
   10  CONTINUE
      IF(RMM1.NE.0.) GO TO 30
      IF (IQUALY.EQ.0) RETURN
      PRINT 2649,L1,L2,RMM1,RM0,RM1,RM2,FM1,F0,F1,F2,RV
       IQUALY = -IQUALY
      RETURN
30    RMM1=FM1*RMM1
      RM0= F0*RM0/RMM1
      DO 20 L=L1,L2
      IF(R(L).LE.XCRIT) GO TO 20
      DEL= V(L)-RM0
      PROD=RV(L)*(DEL**2)
```

```
    RM1=RM1+PROD
    RM2 = RM2 + PROD*DEL
 20   CONTINUE
    RM1= 2.*F1*RM1/RMM1
    RM2= F2*RM2/RMM1
    IF (RM1.GE.0) RETURN
    PRINT 2649,L1,L2,RMM1,RM0,RM1,RM2,FM1,F0,F1,F2,RV
    RM1 = -RM1
     IQUALY = -IQUALY
    RETURN
 2649 FORMAT (' MOMENT ERROR',2I4,8G12.3/(1X,10G12.4))
    END
```

6.5 Moment Analysis of Proton Data: pranal.f

```
  DO 10 K=1,NCUP
    JX = (K-1)*NE+1
    IP=IPK(K)
    IF(IP.EQ.0.AND.K.EQ.4) GO TO 10
C
    IF(K.EQ.4) GO TO 5001
    IF(IP.EQ.0) RETURN
C
C
 5001 J1=MAX0((IP-IPQ(K,MD))*1,1)
    J2=MIN0((IP+IPR(K,MD))*1,NE*1)
    ANS(K)=A(JX+IP-1)
    ANS(K+4)=IP
    JN = 12+K
    JV = 16+K
    JW = 26+K
    JQ = 35+K
c         let us not look outside gap of more that n1 "0" channels
          n1 = 2
          n1 = 1
          ipt = ip
          call przero( n1, ipt, a(jx), rmark, j1, j2)
          j1a(k,1) = j1
          j2a(k,1) = j2
    IF(MD.EQ.1)
   1 CALL MOMENT(J1,J2,VJNL,A(JX),ANS(JN),ANS(JV),ANS(JW),ANS(JQ),
   2 NK(K,1),SK(K,1),WK(K,1),QK(K,1),XCRIT,IQUALY)
    IF(MD.EQ.2)
   1 CALL MOMENT(J1,J2,VJNM,A(JX),ANS(JN),ANS(JV),ANS(JW),ANS(JQ),
   2 NK(K,2),SK(K,2),WK(K,2),QK(K,2),XCRIT,IQUALY)
    ANS(K+8)=IQUALY
```

```
c     IF(IQUALY.LT.3.AND.K.NE.4)LQUAL=.TRUE.
c
c Criterion changed due to COLD solar wind at large
c heliocentric distences; SW is many times confined to only
c 2 M-mode channels
c
c Change made by rlm 3/13/89
c Changed by gsg jr 4/26/89 to voyager memo # 176
      IF(IQUALY.LT.iqualm.AND.K.NE.4)LQUAL=.TRUE.
   10 CONTINUE
```

7 Location of Analyzed Data Files

Most Voyager data can be found in the subdirectories of */nfs/plas7/d8/vgr*/. *ha* denotes hourly averages, *sedr* denotes trajectory files, and *key* denotes key parameters (fits).

7.1 Individual Spectra

Individual spectra are typically also referred to as “high resolution data.” The best fit velocities, densities, and temperatures from individual isotropic maxwellian fits can be found in */nfs/plas7/d8/vgr/SC/key/* where *SC* is *v1* for Voyager 1 and *v2* for Voyager 2. These data are in ASCII tables. Refer to the README files in each data directory for detailed information.

Files names are formatted with the associated date range *SC_keys_YYYY.DDD.DD_YYYY.DDD.DD* where *YYYY* is year and *DDD.DD* is decimal ordinal day of year.

7.2 Hourly Averages

Hourly averages of the spectral fits can be found in */nfs/plas7/d8/vgr/SS/ha/key*/. The file and file name formats are the same as for the individual spectra.

7.3 Daily Averages

Daily averages for the Voyager 2 plasma data are in */nfs/plas7/d8/vgr/v2/daily/*.

7.4 Merged Data

IDL save files containing merged plasma, trajectory, and field data for Voyager 1, Voyager 2, and many near-earth spacecraft are available in the subdirectories of */nfs/plas7/da/mike/reduced/SS/plsmag/*. These files are in 20-day increments, with data rate sampled down the slowest contributing instrument. Filenames are formatted

SC_plsmag.YYYY.DDD.EEE.idl where *DDD* is the ordinal start day and *EEE* is the ordinal end day.

7.5 WIND Data

```
setenv windDATA /nfs/plas7/d1/wind
setenv windWWW  /nfs/plas7/d8/wind

---------------------------------------------------------------

WIND SWE fine resolution data (single day, ascii format)

$windWWW/kp_files/2009/rdP2009082.01
  year 2009, day 082 (March 23, 2009)
...
$windWWW/kp_files/1994/rdP1994365.03
  year 1994, day 365 version 3 (December 31, 1994))

see  $windWWW/kp_files/000_README_WIND_P_FILES.TXT for more info

--------------------------------------------------------------------

WIND SWE hourly averages data (cumulative, by year, ascii format)

$windWWW/kp_files_hr_aves/2009_WIND_hourly_averages
  hourly averages year 2009, day 001 thru day 082 (updated as new data
received) ...
$windWWW/kp_files_hr_aves/1994_WIND_hourly_averages
  hourly averages year 1994, partial year

see $windWWW/kp_files_hr_aves/000_README_before_WIND_ftp for more info
```

7.6 Magnetic Field Data

http://nssdcftp.gsfc.nasa.gov/spacecraft_data/voyager/voyager2/magnetic_fields/

`http://cohoweb.gsfc.nasa.gov/`

8 Loading Voyager Data in IDL

8.1 ASCII Data

The easiest way to load ASCII data in IDL is with the *READ_ASCII* function. An ASCII template may be used, but is not necessary. Data columns are read into tags in a single structure as in

Data = READ_ASCII(filename)

Where *Data.field01* contains the first column data, *Data.field02* the second, and so on. See the IDL documentation for more information.

8.2 IDL Save Files

Plsmag files may be loaded in their totality with the *RESTORE* procedure, however it is often more convenient to use the *LOAD_PLASMA* procedure. To incorporate this procedure in all IDL sessions, modify the *~/.idlrc* file to include the following line:

```
!PATH = Expand_Path('~jck/idl/science/loaddata') + ":" + !PATH
```

To load data quantities *X* and *Y* for year *YEAR* from *START_DAY* to *END_DAY* from spacecraft *SC*, one would type the following at the IDL prompt or in a routine:

```
LOAD_PLASMA, YEAR, START_DAY, END_DAY, /SC, X=X, Y=Y
```

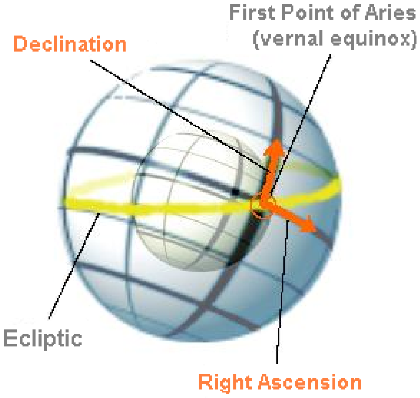
Data arrays are loaded by keyword. Available data keywords are *DOY, BX, BY, BZ, BMAG, VMAG, VX, VY, VZ, T, DEN, EW, NS, X, Y, Z, HEOVH.* Available spacecraft are *V1, V2, WIND, ACE*, and *IMP*.

New l modes file /nfs/plas7/d3/vgr/v2/lmodes/

9 Trajectory and Pointing

9.1 Coordinate Systems

9.1.1 Earth Equatorial to Ecliptic ECL50



The right ascension α and declination δ of a star in earth equatorial coordinates can be used to compute the ECL50 XYZ components of the direction to the star as follows. First calculate the XYZ coordinates in earth equatorial coordinates using the following equation

$$\mathbf{X}_{\text{equatorial}} = \begin{pmatrix} \cos\delta\cos\alpha \\ \cos\delta\sin\alpha \\ \sin\delta \end{pmatrix} \tag{8.1.1}$$

Then rotate this vector about the X-axis by φ = 23.445789 degrees, the tilt of the earth's spin axis from the normal to the plane of its orbit, to get the coordinates of the vector in ECL50.

$$\mathbf{X}_{\text{ECL50}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & \sin\varphi \\ 0 & -\sin\varphi & \cos\varphi \end{pmatrix} \mathbf{X}_{\text{equatorial}} \tag{8.1.2}$$

9.1.2 ECL50

The ECL50 coordinate system is based on the ecliptic plane, that is, the plane of the orbit of the earth about the sun. The x-axis of this system is defined by the intersection of the plane of the earth's orbit with the plane of the earth's rotational equator, with zero longitude being defined in terms of the ascending node (see Figure 8.1-1).

9.1.3 RTN Heliographic

RTN Heliographic coordinates are based on the rotational equator of the sun (which defines the solar equatorial plane, see Figure 8.1-1). The normal to that plane is tilted at an angle of θ_s=7.25 degrees from the normal to the ecliptic. The intersection of the plane of the solar equator and of the ecliptic occurs defines the x axis of the RTN system, with the longitude of the ascending note (the x axis of RTN) at an angle of ϕ_s=75.07 degrees as measured in ECL50 coordinates.

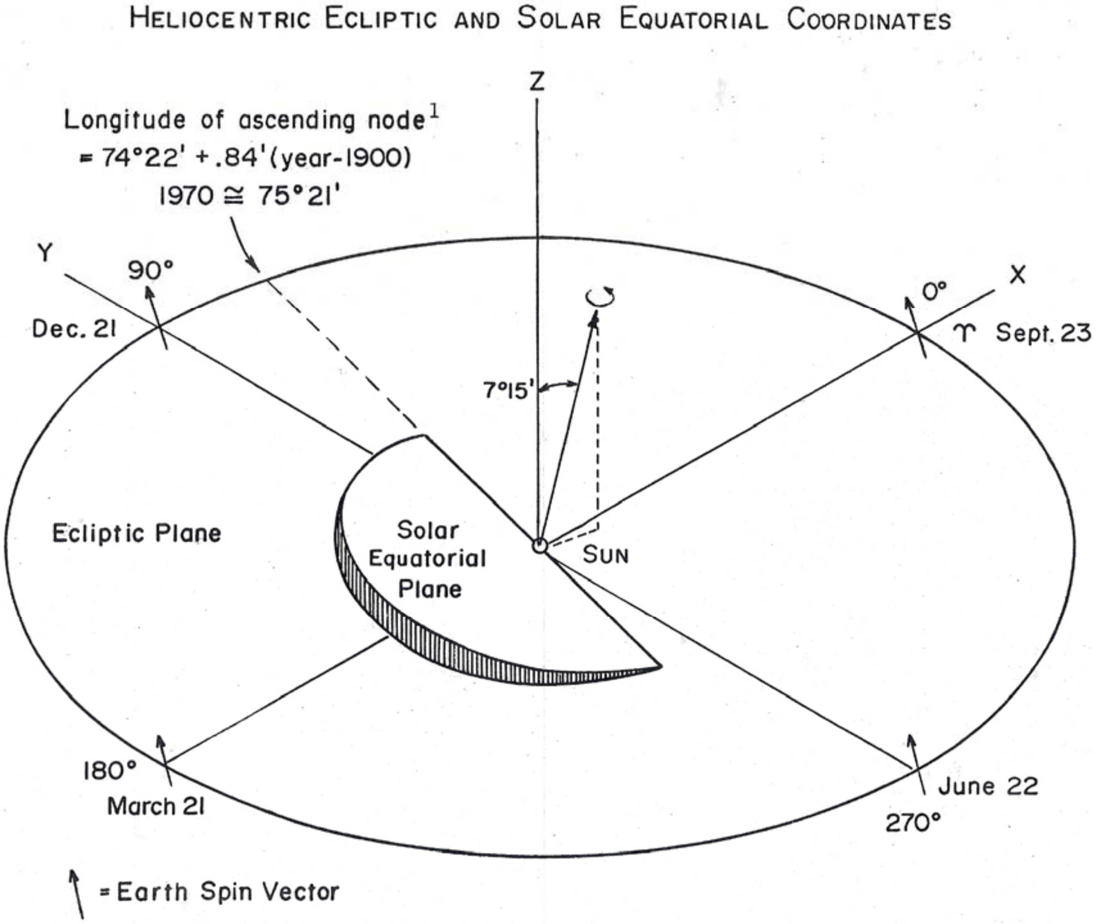


Figure 9.1-1: Ecliptic and Solar Equatorial Coordinates

To rotate from ECL50 to RTN coordinates, we first rotate in the *xy* ECL50 plane to get to the RTN x-axis and then rotate about the x-axis to tilt the z-axis over to the appropriate orientation. That is, if $\mathbf{X}_{ECL50}$ is a Cartesian coordinate vector in ECL50, then its Cartesian coordinate vector in RTN, $\mathbf{X}_{RTN}$, is given by

$$\mathbf{X}_{RTN} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_s & \sin\theta_s \\ 0 & -\sin\theta_s & \cos\theta_s \end{pmatrix} \begin{pmatrix} \cos\phi_s & \sin\phi_s & 0 \\ -\sin\phi_s & \cos\phi_s & 0 \\ 0 & 0 & 1 \end{pmatrix} \mathbf{X}_{ECL50} \qquad (8.1.3)$$

or

$$\mathbf{X}_{RTN} = \begin{pmatrix} \cos\phi_s & \sin\phi_s & 0 \\ -\cos\theta_s\sin\phi_s & \cos\theta_s\cos\phi_s & \sin\theta_s \\ \sin\theta_s\sin\phi_s & -\sin\theta_s\cos\phi_s & \cos\theta_s \end{pmatrix} \mathbf{X}_{ECL50} \qquad (8.1.4)$$

We can invert this easily to give

$$\mathbf{X}_{\mathbf{ECL50}} = \begin{pmatrix} \cos\phi_s & -\sin\phi_s & 0 \\ \sin\phi_s & \cos\phi_s & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_s & -\sin\theta_s \\ 0 & \sin\theta_s & \cos\theta_s \end{pmatrix} \mathbf{X}_{\mathbf{RTN}} \tag{8.1.5}$$

or

$$\mathbf{X}_{RTN} = \begin{pmatrix} \cos\phi_s & -\cos\theta_s \sin\phi_s & \sin\theta_s \sin\phi_s \\ \sin\phi_s & \cos\theta_s \cos\phi_s & -\sin\theta_s \cos\phi_s \\ 0 & \sin\theta_s & \cos\theta_s \end{pmatrix} \mathbf{X}_{ECL50} \tag{8.1.6}$$

9.1.4 IHC Interstellar Heliospheric Coordinates

We now define IHC coordinates as a coordinate system whose z-axis lies in the direction opposite to the interstellar wind direction. This is the direction to the inflow of neutrals into the solar systems, and we use the directions given by Lallement et al. (1990). These authors give the direction to the incoming neutrals of ecliptic longitude λ of 252 degrees and ecliptic latitude β of 7 degrees, a speed of 20 km/s, and a temperature T of 8000 K. The components of this vector in ECL50 are

$$\mathrm{Z}_{\mathrm{IHC}}^{\mathrm{ECL50}} = \begin{pmatrix} \cos\delta \cos\lambda \\ \cos\delta \sin\lambda \\ \sin\delta \end{pmatrix} = \begin{pmatrix} -0.306714 \\ -0.943967 \\ 0.121869 \end{pmatrix} \tag{8.1.7}$$

If we use the transformation from ECL50 to RTN given above this gives us

$$\mathrm{Z}_{\mathrm{IHC}}^{\mathrm{RTN}} = \begin{pmatrix} -0.991122 \\ 0.068112 \\ 0.1141867 \end{pmatrix} \tag{8.1.8}$$

Note that this vector lies almost in the solar equatorial plane.

Now we define the x-axis and y-axis of our IHC coordinates such that

$$\mathrm{X}_{\mathrm{IHC}} = \frac{\mathbf{Z}_{\mathrm{RTN}} \times \mathbf{Z}_{\mathrm{IHC}}}{\left|\mathbf{Z}_{\mathrm{RTN}} \times \mathbf{Z}_{\mathrm{IHC}}\right|} \qquad \mathrm{Y}_{\mathrm{IHC}} = \mathbf{Z}_{\mathrm{IHC}} \times \mathbf{X}_{\mathrm{IHC}} \tag{8.1.9}$$

which in RTN are given by

$$X_{\mathrm{IHC}}^{\mathrm{RTN}} = \begin{pmatrix} -0.068560 \\ -0.997647 \\ 0.0 \end{pmatrix} \qquad Y_{\mathrm{IHC}}^{\mathrm{RTN}} = \begin{pmatrix} 0.113918 \\ -0.007829 \\ 0.993459 \end{pmatrix} \tag{8.1.10}$$

Note that the z-axis in IHC is almost the negative x-axis in RTN, the x-axis in IHC is almost the negative y axis in RTN, and that the y-axis in IHC is almost the z-axis in RTN.

9.1.5 Ecliptic to Galactic Coordinates

ecliptic coordinates (λ,β) of galactic pole G and direction to galactic center B and
λG=180◦.01 βG= =+29◦.80 λB = 266◦.84 βB = −5◦.54.

<ref name=al36_3_220>{{citation | last1=Bobylev | first1=V. V. | title=Searching for stars closely encountering with the solar system | journal=Astronomy Letters | volume=36 | issue=3 | pages=220–226 |date=March 2010

9.1.6 Going from Measured Cup Speeds to Velocity in RTN or IHC

We summarize the procedure for going from a measurement of V_A, V_B, and V_C from the observed data to the velocity vector in RTN or IHC. First we use equations (2.2.11) through (2.2.13) to find the velocity components in s/c coordinates. Then we use the pointing information from the SEDR (see Section 8.5 below), which gives the s/c axes in ECL50, to find the velocity components in ECL50. Then we must correct for aberration by ***adding*** the s/c velocity in ECL50 coordinates to the velocity vector in ECL50 we just computed. The s/c velocity in ECL50 is also given in the SEDR. Then we have the velocity vector in ECL50, and we can transform that vector from ECL50 to RTN or IHC using the transformations given above.

9.1.7 Galactic Coordinates

John,

I used Google to search for "radial velocities of nearby stars". Some useful references came up. One of them is the paper at

http://arxiv.org/abs/1207.6212

and another is a somewhat older (2002) paper by Reid et al.

http://adsabs.harvard.edu/abs/2002AJ....124.2721R

I hope this helps.

-- Al

The International Astronomical Union (IAU) defined the galactic coordinate system in reference to the Equatorial coordinate system in 1958[2] The north galactic pole is defined to be at right ascension 12h 49m, declination +27.4° (B1950), and the zero of longitude is the great semicircle that originates from this point along the line in position angle 123° with respect to the equatorial pole. The galactic longitude increases in the same direction as right ascension. Galactic latitude is positive towards the north galactic pole, the poles themselves at ±90° and the galactic equator being zero.[3]

The equivalent system referred to as J2000 has the north galactic pole at 12h 51m 26.282s +27° 07′ 42.01″ (J2000), the zero of longitude at the position angle of 122.932°.[4] The point in the sky at which the galactic latitude and longitude are both zero is 17h 45m 37.224s −28° 56′ 10.23″ (J2000). This is offset slightly from the radio source Sagittarius A*, which is the best physical marker of the true galactic center. Sagittarius A* is located at 17h 45m 40.04s −29° 00′ 28.1″ (J2000), or galactic longitude 359° 56′ 39.5″, galactic latitude −0° 2′ 46.3″.[5]

http://www.atlasoftheuniverse.com/12lys.html

http://lambda.gsfc.nasa.gov/toolbox/tb_coordconv.cfm

http://physics.stackexchange.com/questions/88663/converting-between-galactic-and-ecliptic-coordinates

ecliptic coordinates (λ,β) of galactic pole G and direction to galactic center B and
λG=180∘.01 βG= =+29∘.80 λB = 266∘.84 βB = −5∘.54.

9.2 Lock stars

We show below a table that gives the common lock stars for Voyager, their right ascension and declination, and their ECL50 coordinates, computed using equations 8.1.1 and 8.1.2.

Table 9-1: Lock stars and their ECL50 Coordinates

Lock Star	Declination α	Right Ascension δ	X ECL50	Y ECL50	Z ECL50
CANOPUS	-52.6674	95.7107	-0.060344	0.237243	-0.969574
RIGILKENTAURUS	-60.6243	218.9856	-0.381294	-0.629850	-0.676686
HADAR	-60.133	210.0684	-0.430973	-0.573945	-0.696311
ACRUX	-62.8222	185.9498	-0.454293	-0.397389	-0.797308
SPICA	-10.9012	200.6384	-0.918936	-0.392778	-0.035792
ARCTURUS	19.4253	213.3351	-0.787912	-0.343138	0.511322

MIMOSA	-59.4158	191.1954	-0.499122	-0.433160	-0.750500
MIAPLACIDUS	-69.5101	138.1616	-0.260792	-0.158497	-0.952295
VEGA	38.74	278.81	0.119463	-0.458163	0.880804
FOMALHAUT	-29.89	343.73	0.832263	-0.421122	-0.360548
ALKAID	49.5621	206.3913	-0.581023	0.038322	0.812984
ACHERNAR	-57.4905	23.9654	0.491107	-0.135258	-0.860534
DENEB[1]	45.27	310.325	0.45542	-0.20958	0.86526

9.3 Generating Pointing Given the Lockstar and $\mathbf{Z}_{s/c}$

If we know the vector $\mathbf{Z}_{s/c}$ and the lockstar, we can compute the orientation of the spacecraft axes as follows. Let **S** be the vector in ECL50 of the lockstar, and assume we know the spacecraft z-axis in ECL50 as well (this is the earth spacecraft vector, and is usually given in the navigation block of the SEDR). We define the two directions

$$\hat{\mathbf{Y}}_S = \frac{\hat{\mathbf{Z}}_{s/c} \times \mathbf{S}}{\left|\hat{\mathbf{Z}}_{s/c} \times \mathbf{S}\right|} \qquad \hat{\mathbf{X}}_S = \hat{\mathbf{Y}}_S \times \hat{\mathbf{Z}}_{s/c} \tag{8.3.1}$$

Given this construction, we can compute the spacecraft **X** and **Y** axes using the equations (refer to Figure 2.2-1 and Section 2.3)

$$\hat{\mathbf{X}}_{s/c} = \hat{\mathbf{X}}_S \cos 55^\circ + \hat{\mathbf{Y}}_S \sin 55^\circ \tag{8.3.2}$$

$$\hat{\mathbf{Y}}_{s/c} = \hat{\mathbf{Y}}_S \cos 55^\circ - \hat{\mathbf{X}}_S \sin 55^\circ \tag{8.3.3}$$

For example, on the Short SEDR file for $2009^{y}\ 1^{d}\ 23^{h}\ 59^{m}\ 59s\ 1^{ms}$, the vector for the spacecraft z-axis in ECL50 is given as (0.2663, -0.8042, 0.5313). If we assume the lock star is Vega and use its ECL50 components as given in Table 8.1, then we find using the equations above that the predicted spacecraft X axes has ECL50 components of (-0.7024,-0.5394,0.4644) and the predicted spacecraft Y axis has components of (-0.6601,0.2495,-0.7086). These are the same as the values given in the pointing block to four significant figures.

$$\hat{\mathbf{n}}_A = -\hat{\mathbf{X}}_{s/c} \sin 20^\circ \cos 30^\circ - \hat{\mathbf{Y}}_{s/c} \sin 20^\circ \cos 60^\circ - \hat{\mathbf{Z}}_{s/c} \cos 20^\circ \tag{8.3.2}$$

-0.7024 -0.5394 0.4644
-0.6601 0.2495 -0.7086

-0.7035 -0.5366 0.4660 -0.6603 0.2509 -0.7079 0.2630 -0.8057 -0.5308

---

[1] From http://www.astro.utoronto.ca/~garrison/oh.html

```
    X=COS(RD*R(5,N))*COS(RD*R(6,N))
      Y=COS(RD*R(5,N))*SIN(RD*R(6,N))
      Z=SIN(RD*R(5,N))
EP0=23.445789
      STAR(1)=X
      STAR(2)=Y*COS(RD*EP0)+Z*SIN(RD*EP0)
      STAR(3)=-Y*SIN(RD*EP0)+Z*COS(RD*EP0)
```

9.4 Location of Trajectory Files

The short SEDR trajectory files (see Voyager Memo 180) are in the directory */nfs/faraday/d9/vgr/data/v1/shortsedr* for Voyager 1 and in */nfs/faraday/d9/vgr/data/v2/shortsedr* for Voyager 2. The names of all files contain the starting and ending time tags in YYYY.DDD.HH (Year, Day, Hour) format.

9.5 Short SEDR File Format

This section is based on Voyager Memo #180. A short SEDR is a shortened version of a full SEDR (Supplemental Experiment Data Record). Items 1-62 below are from the Navigation Block of the full SEDR (containing information about the location of the S/C, planets, and so on). Items 63-79 below are from the Pointing Block of the full SEDR (containing information about the orientation of the S/C). The Cartesian State of an object is six words long. The first three words contain the location of the object referred to in ECL50 coordinates; the second three words of the Cartesian State are the velocity components of the object referred to in ECL50.

Table 9-2: The format of the Short SEDR file

Word #	Type	Description
1-6	Int*4	SCE GMT year,day,hr,mn,s,ms
7-18	Real*4	Cart. St. of S/C; Earth and Sun centered ECL5O (km,km/s)[2]
19-30	Real*4	See Note[3]
31-36	Real*4	Cart. St. of Earth in Sun centered ECL5O
37-48	Real*4	Cart. St. of Jupiter and Saturn in Sun centered ECL5O
49	Real*4	Range of S/C from Sun (km)
50	Real*4	Earth-Sun-S/C angle
51-62	Real*4	Cart. St. of Uranus and Neptune in Sun centered ECL5O
63-70	Int*4	SCE GMT and FDSC MOD16 and MOD60
71-79	Real*4	Cart. unit vector for S/C X,Y,Z axis in S/C centered ECL5O

---

[2] The earth centered is first, then sun centered.

[3] For data originating from Launch or Cruise tapes, items 19 - 24 and 25 - 30 are the Cartesian state of the S/C in Jupiter and Saturn centered ECLSO coordinates (km, km/s), respectively. For data originating from Extended Cruise tapes, items 19 - 24 and 25 - 30 are the Cartesian state of the S/C in Uranus and Neptune centered ECLSO coordinates, respectively. When Extended Cruise data are used, items 51 - 62 are set to 0.0.

		(Rotation matrix from S/C to ECL5O coordinates)

The time resolution of the files is 5 days unless a change of at least 1 degree takes place in which case the change is bracketed. All data was written with FORTRAN unformatted write. An example of how to read these files is given in the next section.

Note that on the Voyager 2 short SEDR files there is a long gap of about 18 days between the following times: 1979 186 18 2 23 220 and 1979 205 0 2 21 984. There are also frequent gaps of length around 5.1 days, and one longer gap around 6 days. If the user is really worried about time coverage he or she should check the SEDR for gaps in coverage around the time of interest.

10 Code Snippets Trajectory/Pointing Data

10.1 Lock Stars: refer.f

See Voyager Memo #53. The code below is a subroutine *refer.f*, a fortran file in */nfs/carrington/h3/vgr/src/sedr.*

```
c ***** used August 1989 at O.I.T. to create SEDR with pointing for
GSFC
C
C 8/15/89
C MODIFIED TO PRODUCE IBM FORMAT TAPE FOR GSFC
C PRODUCTION DURING NEPTUNE ENCOUNTER OB AND FE PHASES.
C USES PREDICT SEDR WITH NAV ONLY AS INPUT.
C
C IF NO POINTING INFO IS PRESENT, SXRED CALLS THIS ROUTINE
C WITH N=1 AND ONLY TWO ARGUMENTS: ISR AND STAR; THE LATTER
C IS TO BE RETURNED TO CALCULATE THE POINTING VIA THE SUBROUTINE
C NOMDIR.
C
C RLM
C
      SUBROUTINE REFER (/N/,STAR,STRNM)
C     N SPECIFIES THE REFERENCE STAR
C
C         1           CANOPUS
C         2    RIGILKENTAURUS
C         3             HADAR
C         4             ACRUX
C         5             SPICA
C         6          ARCTURUS
C         7            MIMOSA
C         8       MIAPLACIDUS
C         9              VEGA
C        10         FOMALHAUT
C        11            ALKAID
C        12          ARCHENAR
C
C     'STAR' CONTAINS THE CARTESIAN COORDINATES OF THE UNIT VECTOR
C     POINTING TO THE REFERENCE STAR IN THE ECL50 SYSTEM
```

```
C
C ACCESS TIME OF NAVIGATION BLOCK
C
      COMMON/NAVBUF/NAV(252)
      DIMENSION STAR(1)
      DIMENSION STRNM(1)
      REAL*4 R(6,12)
      LOGICAL LFIRST
      DATA LFIRST /.TRUE./
      DATA R   /'    ','    ',' CAN','OPUS',-52.6674, 95.7107,
     2          ' RIG','IL K','ENTA','URUS',-60.6243,218.9856,
     3          '    ','    ','   H','ADAR',-60.1330,210.0684,
     4          '    ','    ','   A','CRUX',-62.8222,185.9498,
     5          '    ','    ','   S','PICA',-10.9012,200.6384,
     6          '    ','    ','ARCT','URUS', 19.4253,213.3351,
     7          '    ','    ','  MI','MOSA',-59.4158,191.1954,
     8          '    ',' MIA','PLAC','IDUS',-69.5101,138.1616,
     9          '    ','    ','    ','VEGA', 38.74  ,278.81  ,
     A          '    ','   F','OMAL','HAUT' -29.89  ,343.73  ,
     B          '    ','    ','  AL','KAID', 49.5621,206.3913,
     C          '    ','    ','ACHE','RNAR',-57.4905, 23.9654/
      DATA IT1/77461/
      DATA IT2/1072981/
      DATA IT3/9649103/
C
C ALKAID AND ACHENAR ADDED 8/15/89 FOR NEPTUNE ENCOUNTER;
C COORDINATES ARE DEC AND R.A. FOR JAN. 1, 1980 IN EME50
C (FROM P.III-247 OF JPL 618-116).
      CALL NUMP(NARG)
      EP0=23.445789
      RD=3.141593/180.
C
C LOOP AROUND IF NOT NEPTUNE ENCOUNTER
C
      IF (NAV(1) .NE. 1989) GO TO 10
      N=1
C
C STAY ON CANOPUS IF
C       BEFORE 1989-116/0000:00 OR AFTER 1989-227/2359:59
C
      IF (NAV(2) .LT. 116) GO TO 10
      IF (NAV(2) .GT. 227) GO TO 10
C
C CHANGE TO ALKAID   (N=11) AT 1989-116/2131:01 IT1=  77461.0
C CHANGE TO ACHERNAR (N=12) AT 1989-128/1003:01 IT2=1072981.0
C CHANGE TO CANOPUS  (N=1)  AT 1989-227/1618:23 IT3=9649103.0
C
      IT= (NAV(2)-116)*24 + NAV(3)
      IT=IT*3600+NAV(4)*60+NAV(5)
C
C VARIABLE "IT" IS THE NUMBER OF SECONDS FROM THE
C BEGINNING OF DAY 116 (OF 1989).
C
      IF (IT .LT. IT1) GO TO 10
      IF (IT .GT. IT3) GO TO 10
      IF (LFIRST) PRINT 2673
      LFIRST = .FALSE.
```

```
 2673 FORMAT (/,' FIRST USE OF A NON-CANOPUS STAR BY REFER ROUTINE.')
      IF ((IT .GE. IT1) .AND. (IT .LT. IT2)) N=11
      IF ((IT .GE. IT2) .AND. (IT .LT. IT3)) N=12
C
C CONTINUE EXECUTION AND GENERATE VECTOR STAR
C
   10 CONTINUE
      X=COS(RD*R(5,N))*COS(RD*R(6,N))
      Y=COS(RD*R(5,N))*SIN(RD*R(6,N))
      Z=SIN(RD*R(5,N))
      STAR(1)=X
      STAR(2)=Y*COS(RD*EP0)+Z*SIN(RD*EP0)
      STAR(3)=-Y*SIN(RD*EP0)+Z*COS(RD*EP0)
      IF (NARG .EQ. 2) RETURN
C **  DO 1 I=1,4
C * 1    STRNM(I)=RCHAR(I,N)
      RETURN
      END
```

10.2 Transforming from ECL50 to RTN (solar heliographic): helio.f

See Voyager Memo #33. The code below is a subroutine in *helio.f,* a fortran file in */nfs/carrington/h1/jwb/voyager/voy.traj/* .

```
      subroutine HEEC(xh,xe)
      dimension xh(3),xe(3),r(3,3)
c  routine to rotate vector in ecl50 to heliograhic
c  see voyager memo #33
c  note:  the x axis of heliographic is along the
c  longitude of the ascending node
      data phis/75.07/, ts/7.25/
      data rd/57.29578/
      data istart/0/
c  set up rotation matrix first time through
      if(istart.ne.0) go to 10
      istart = 1
      p=phis/rd
      t=ts/rd
      r(1,1)=cos(p)
      r(1,2)=sin(p)
      r(1,3)=0.
      r(2,1)=-sin(p)*cos(t)
      r(2,2)=cos(p)*cos(t)
      r(2,3)=sin(t)
      r(3,1)=sin(p)*sin(t)
      r(3,2)=-cos(p)*sin(t)
      r(3,3)=cos(t)
   10  continue
      do 20 i=1,3
```

```
   xh(i)=0.
   do 30 j=1,3
   xh(i)=xh(i)+r(i,j)*xe(j)
30  continue
20  continue
   return
   end
```

11 Appendices

11.1 Voyager Memo #187: Optimal Lock Star Heliosheath and Interstellar Flow

To: Voyager Internal, E. J. Franzgrote, O. Divers
From: John Belcher
Subject: Optimal Lock Star for Detecting Heliosheath and Interstellar Flow
Date**:** March 1, 1994

The purpose of this memo is to determine the optimal lock star for PLS for observations while the spacecraft is in the heliosheath or in the interstellar medium (e.g., post termination shock or post heliopause). We conclude that of the available lock stars for Voyager 2 with Canopus ratio (CR) greater than 0.25, Vega is the optimal lock star for PLS. This conclusion is based on the list of available lock stars given in the table on page JCH-3 of the minutes for the SSG meeting of 4/21/92. Deneb is the preferred lock star for PLS of the lock stars in this table, but its CR is only 0.18. If that precludes its use as a lock star, then PLS prefers Vega for the lock star.

To justify this conclusion, we make the plausible assumption that the plane containing heliosheath and interstellar flow is the plane defined by the sun-spacecraft vector and the interstellar neutral wind vector, as defined by Lyman alpha measurements. To optimize the ability to measure heliosheath and interstellar plasma, we need to orient the PLS side sensor (the D cup) so that its normal lies as close as possible to being in the plane expected for such flow, with this flow having a positive component into the D cup.

For reference, the figure below shows the trajectory of the Voyager 2 spacecraft in a cylindrical sun-centered coordinate system where the horizontal axis is along the direction from which the interstellar wind flow comes and the vertical axis is cylindrical distance from this axis. We also show on this Figure model heliopause and termination shock shapes.

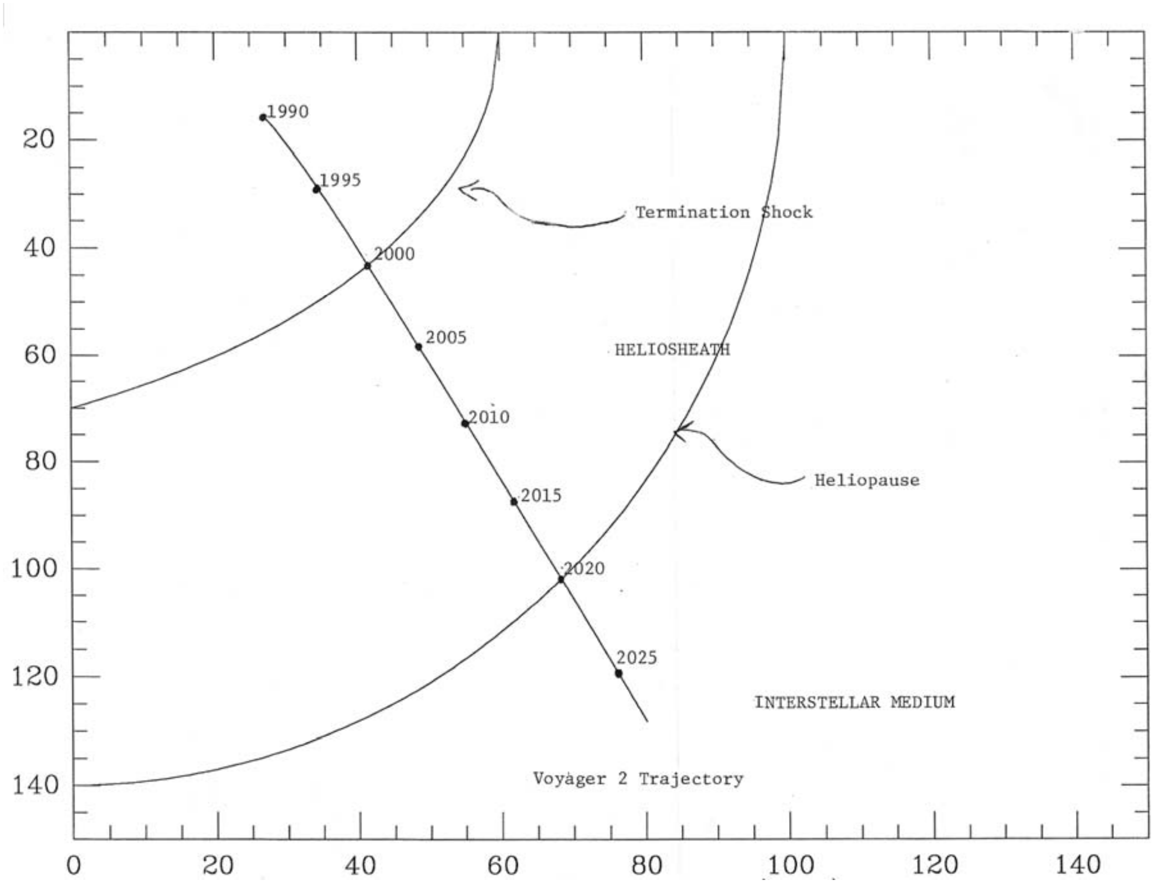


Figure 11.1-1: Trajectory of Voyager 2

The figure below shows the optimal roll angle of the spacecraft with respect to Canopus for detecting heliosheath and interstellar flows, as a function of time from 1995 through 2030. This is the roll angle that puts the D cup normal in the plane containing such flow, as defined above. The last section of this memo gives ECL50 components of various vectors of interest, for reference purposes. The roll angle of Vega (the current planned lock star in this epoch) with respect to Canopus is about 180 degrees. The roll angle of Spica (the lock star requested by LECP) with respect to Canopus is about -90 degrees. The roll angle of Arcturus with respect to Canopus is about -120 degrees. The roll angle of Deneb with respect to Canopus is about 158 degrees. Vega, Spica, and Arcturus are the three lock stars with CR's greater than 0.25. Of these three, Vega is clearly preferred. Deneb is better than Vega, but has a CR less than 0.25.

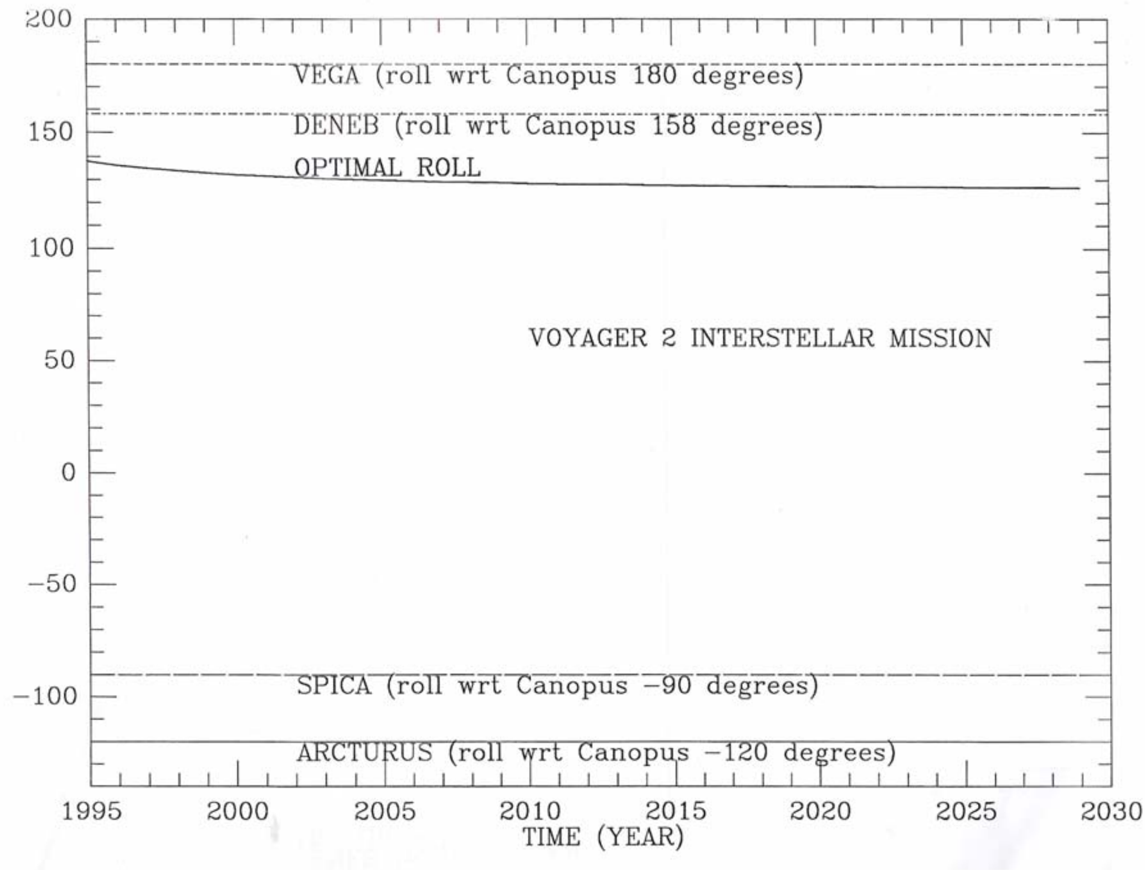


Figure 11.1-2: Optimal role with respect to Canopus versus time

Model Heliosheath and Interstellar Flows

To understand more clearly why Vega and Deneb are preferred over Spica and Arcturus, the next two figures below show characteristics of the flow of heliosheath and interstellar ions into the PLS sensors as a function of time, for the four different lock stars. These figures have been produced using the following scenario for crossing of the termination shock and heliopause:

1. From 1995 until 2000, Voyager 2 is in the unshocked solar wind, and the plasma flow is solar wind flow at 400 km/s radially away from the sun.
2. In 2000, Voyager crosses the termination shock. For the next 20 years, until 2020, Voyager 2 is in the heliosheath. In this period, we assume that the shocked solar wind has a speed of 200 km/s. We assume that the flow direction in 2000, and that just after the shock crossing, is still radially away from the sun. Over the course of the next 20 years, the flow direction turns from radially away from the sun toward the direction of the interstellar wind. That is, the flow direction varies linearly with time over this interval, until it is within 30 degrees of being along the direction of the interstellar wind, in 2020.

3. In 2020, Voyager 2 crosses the heliopause. It is then in the shocked interstellar medium. We assume that the flow speed there is 20 km/s, the speed derived for interstellar neutrals from Lyman alpha measurements. For the flow direction, we assume that the flow is 30 degrees from the interstellar wind direction, deflected toward the radial direction. This would be appropriate for flow deflected by the solar cavity along the flanks of the heliosphere. For all these cases, the plasma flow is properly aberrated for spacecraft velocity.

The figure below shows as a function of time the angle that this model flow makes with the normal to the A cup, for the four different lock stars we have mentioned. The A cup is the cup in the main sensor cluster whose normal is furtherest away from the D cup normal.

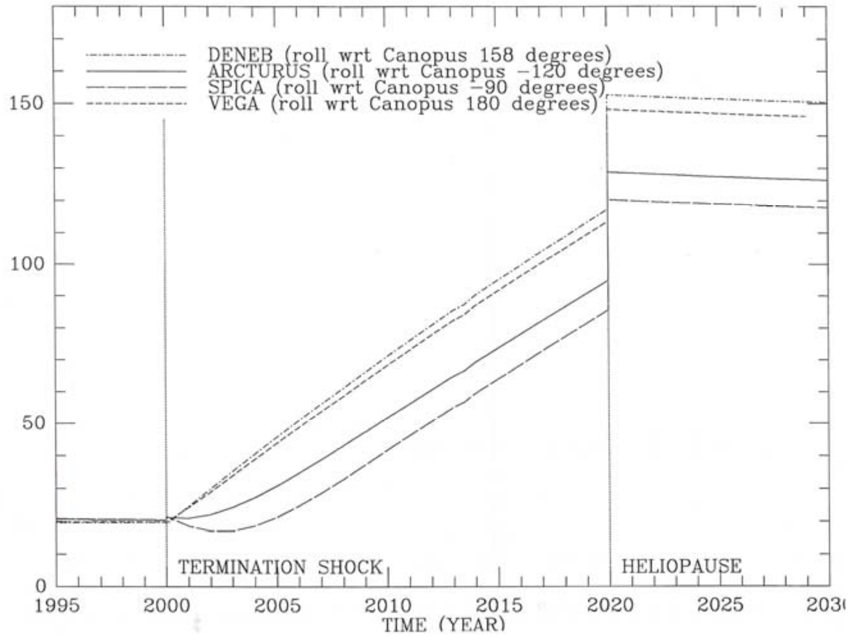


Figure 11.1-3: Angle between A sensor normal and heliosheath flow direction

The figure below is similar to the figure above, except we consider the D cup in this Figure. Before the terminal shock, the flow is 20 degrees from being directly into the A cup (0 degrees is into the cup). After the terminal shock is crossed, the flow makes a greater and greater angle to the A cup normal, as it turns from radial towards the direction of the interstellar wind. Eventually, the flow begins to come from the back of the A cup (the angle is greater than 90 degrees). For the D cup, in contrast, the flow starts out essentially perpendicular to the D cup normal before the terminal shock is crossed, for all four lock stars. After the shock, the flow turns so that it is closer to being into the D cup (the angle decreases) for Vega and Deneb. In contrast, the flow turns so that it is further away being into the D cup for Arcturus and Spica. Having the D cup in the Vega or Deneb orientation is crucial to being able to determine flow directions as the heliosheath flow turns toward the interstellar wind direction. At some point, having the D cup in this orientation may be crucial to detecting the flow at all, since in the later years, before the heliopause crossing, the flow may be coming from the back of the main sensor cluster.

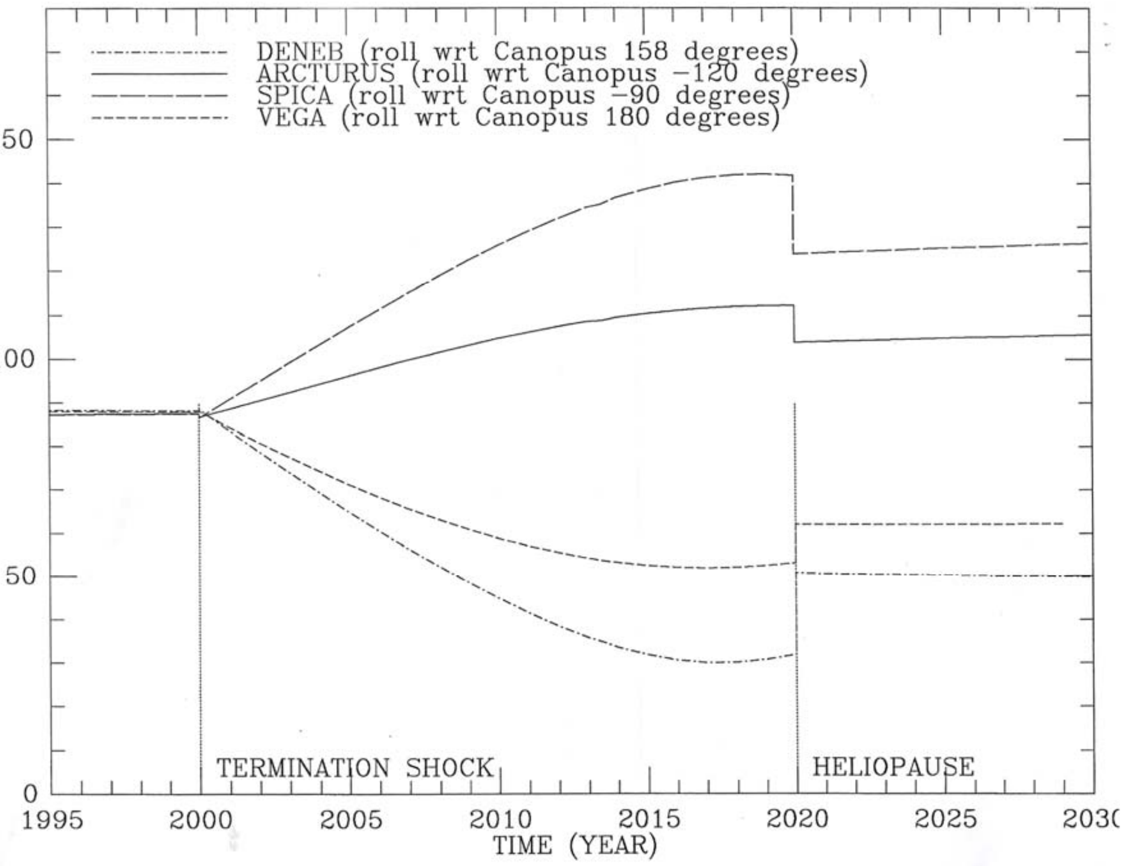


Figure 11.1-4: Angle between D sensor normal and heliosheath flow direction

When the heliopause is crossed, there is an abrupt change in apparent flow angle into both the A and the D cups, even though there is no change in the direction of the direction of the flow in an inertial sun-centered system. This change occurs because of the larger effects of aberration due to spacecraft velocity, as the model speed drops from the 200 km/s we have assumed to be characteristic of heliosheath flow, to the 20 km/s we have assumed for the shocked interstellar flow.

The reasons for the behavior of the angles shown in the figures above can be easily understood by considering the geometry, as illustrated in the figure below. The plane of this figure contains the sun-spacecraft line and the interstellar wind direction in 2010. Assuming the spacecraft is at a roll angle of 180 degrees (Vega),we show the projection of the D cup and the A cup normals onto this plane, and the projection of the spacecraft velocity onto this plane. The A cup normal makes an angle of 17 degrees with respect to this plane, and the D cup normal makes an angle of 67 degrees with respect to this plane. The spacecraft velocity is within 10 degrees of being in the plane. The magnitude of the spacecraft speed is 15.5 km/s at this time. Although we show these vectors in 2010, there is little qualitative change in the geometry past 2000.

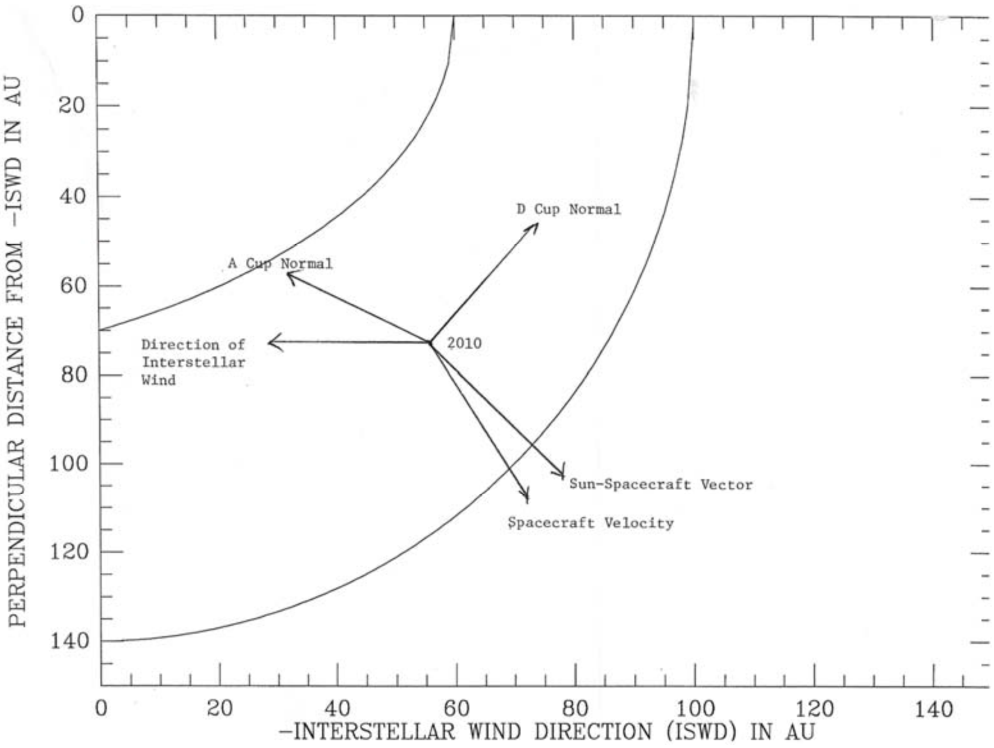


Figure 11.1-5: PLS A and D Cup Normal Orientation in 2010

In consideration of the figure above, it is clear that when the flow is radially away from the sun in our model, it is more or less into the A cup. After 2000, as the flow changes from radially away from the sun towards the interstellar wind direction, the flow moves out of the A cup and increasingly into the D cup, when the lock star is either Vega or Deneb. This explains the qualitative behaviors we discussed above.

As far as flows in the heliosheath are concerned, it is clear from these figures that Deneb is the preferred lock star, with Vega second. If Deneb cannot be used because of its CR, then Vega is the preferred lock star.

Simulation of Interstellar Proton Observations

It is also interesting to note that in the (relatively unlikely)event that Voyager 2 crosses the heliopause in its lifetime, there is some chance that the PLS instrument will be able to detect interstellar protons. We show in the next figure a model calculation of observations in the D cup of interstellar protons moving at the velocity of our model in the post heliopause region (a speed of 20 km/s at a deflection angle of 30 degrees from the direction of the interstellar neutral flow, with appropriate aberration).We assume a thermal speed of 20 km/s and a density of 1 proton per cubic centimeter. The Figure shows the expected currents in the M-mode, for the lock star Vega. On this lock star, the current in the first channel in the M-mode D cup is about 180 femtoamps. This current will scale as the density for other densities than our assumed one.

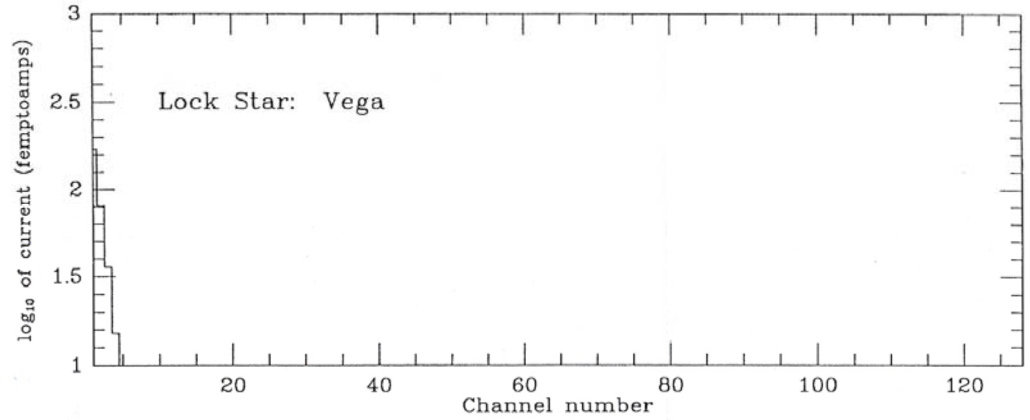


Figure 11.1-6: Model calculation of observations in the D cup of interstellar protons

The next figure shows the lower channels of the M-mode from a recent Voyager 2 observation of the solar wind. Our threshold in this mode is around 3 femtoamps, with a noise level of the order of 30 femtoamps. Thus we in principle may be able to detect interstellar ions with densities of the order of 30 femtoamps/180 femtoamps times 1 per cubic centimeter, or around 0.2 protons per cubic centimeter, and perhaps considerably less than this using long term averaging of many M-modes. Assuming local thermodynamic equilibrium, interstellar protons are thought to have densities on the order of 0.01 per cubic centimeter and less, but there are no direct measurements (seeW. I. Axford, "The Heliosphere", in Physics of the Outer Heliosphere, edited by S. Grzedzielske and D. E. Page, Cospar Colloquia Series, Pergamon Press, 1990). There is some chance that PLS may be able to detect interstellar ions directly, although clearly this is on the edge of what is possible.

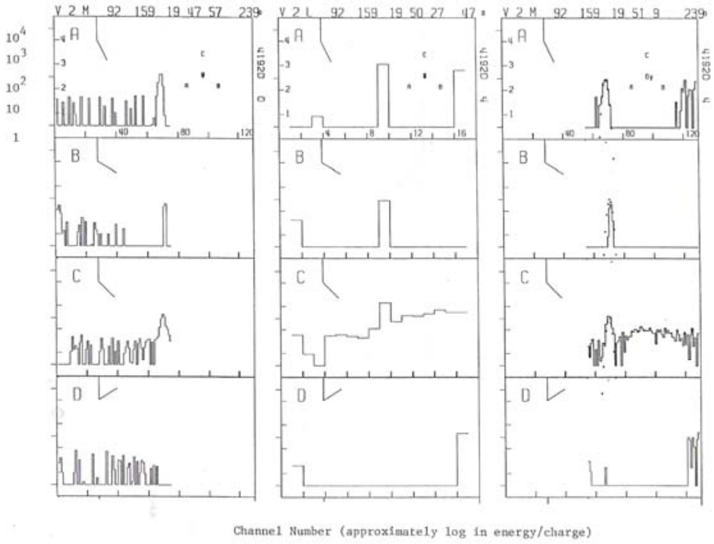


Figure 11.1-7: Voyager 2 observations in 1992

Interstellar Wind Direction

We use the direction of the interstellar wind as quoted by R. Lallement, J. L. Bertaux, E. Chassefiere, and B. R. Sandelin "Lyman-Alpha observations from Voyager (1-18 AU)", in the book cited above, page 74 (but also see below). They give the direction to the incoming neutrals of ecliptic longitude λ of 252 degrees and ecliptic latitude β of 7 degrees, a speed of 20 km/s, and a temperature T of 8000 K. This leads to a unit direction of the interstellar wind (which points opposite the incoming direction) in ECL50 Cartesian coordinates of (0.307,0.944,-0.122). In 2000, the unit vector from the sun to the spacecraft in ECL50 Cartesian coordinates is (0.254,-0.871,-0.421). The cross product of this vector with the interstellar wind vector, normalized so that it is a unit vector, is (0.699,-0.136,0.702). This is the normal to the plane containing the heliosheath flow in the year 2000.

Updated wind direction: The article by Lallement et al. Science **307** 1447 (2005) gives the angles as ecliptic longitude λ 252.2 degrees and ecliptic latitude β of 9 degrees.

11.2 Detailed Terminal Session for Running MJSANAL

This is what happens when you type *./mjs.cru* as per the instructions above. **Bold face roman letters** indicate terminal input by user, ***bold face italics*** indicates what is happening with the plots produced and where we are in the code from *mjsanl.f*.

./mjs.cru

```
Enter the spacecraft id (1 - Voyager 1; 2 - Voyager 2):
```

`2`

```
Enter the mission analysis starting time:
  (format: YYDDD)
```

`78001`

```
data_base /nfs/faraday/d9/vgr/data ,  data
/nfs/faraday/d9/vgr/data/v2/vgr
 dirs   data /nfs/faraday/d9/vgr/data/v2/vgr after else
 DEBUG_perl
 y1 1978 d1 001 h1 0   tn 2923 2
 y2 1978 d2 002 h2 24   tl 2925 2
 y1 1978 d1 001 h1 0   tn 2923 2
 y2 1978 d2 002 h2 24   tl 2925 2
test_dir /nfs/faraday/d9/vgr/data/v2/vgr data_base
/nfs/faraday/d9/vgr/data ,  data /nfs/faraday/d9/vgr/data/v2/shortsedr
 dirs   data /nfs/faraday/d9/vgr/data/v2/shortsedr after else
 DEBUG_perl
 y1 1978 d1 001 h1 0   tn 2923 2
 y2 1978 d2 002 h2 24   tl 2925 2
 y1 1978 d1 001 h1 0   tn 2923 2
 y2 1978 d2 002 h2 24   tl 2925 2
```

```
test_dir /nfs/faraday/d9/vgr/data/v2/shortsedr
2 /nfs/carrington/h3/vgr/bin/RUN mjs vgr
```

RUN is a file which has a 2004 date

```
time1 77200 time2 130366 timef time.mjs
Sourcing: /nfs/carrington/h1/ksg/default/source.search
Sourcing: source.mjs
using given ft02 /nfs/faraday/d9/vgr/data/const/cntrl.data instead of
control.mjs 0.0u 0.0s 0:00 0% 0+0k 0+0io 0pf+0w
```

this directory is the official const directory for all voyager data, and in particular maintains a copy of the files needed for alan barnett's voyager fit programs.

```
t1 1977 200 0 0 2030 366 24 60 , t2 1977 200 0 0 2030 366 24 60
time1 77200.00 time2 130367.01
using given ft32 GETDATA 78001 78002 2 vgr | using given ft33 GETDATA
78001 78002 2 shortsedr | 0.0u 0.0s 0:00 0% 0+0k 0+0io 0pf+0w 0.0u 0.0s
0:00 0% 0+0k 0+0io 0pf+0w TT TT dir /nfs/carrington/h1/ksg/LIB/O/9/ job
mjsvgrx PARMS prtft ft35=/nfs/carrington/h1/jwb/plots/plot
```

mjsvgrx in this director is a file dated 2001

```
ft36=mjsfit.out
ft32=GETDATA 78001 78002 2 vgr |
ft33=GETDATA 78001 78002 2 shortsedr |
ft29=cru.fits
ft28=cru.fits.short
ft02=/nfs/faraday/d9/vgr/data/const/cntrl.data
ft13=temp
ft15=tin
ft17=trec
ft30=/nfs/faraday/d9/vgr/data/const/conrd.data
ft31=/nfs/faraday/d9/vgr/data/const/redart.data
```

this directory is the official const directory for all voyager data, and in particular maintains a copy of the files needed for alan barnett's voyager fit programs.

```
ft01=time.mjs
ft03=/nfs/carrington/h1/ksg/default/bfield.data
```

bfield.data is a small file

```
setenv PARMSa " "
if ( $?DEBUG ) then

if ( $?DISPLAY ) then
if ( ! $?SCREEN && $T != n ) setenv SCREEN "`testx | tail -1`"
if ( $?SCREEN ) then
set ss= ( $SCREEN 500 500 500 500 )
@ w = $ss[2]
@ h = $ss[3]
if ( $w < 900 ) then
else
@ h *= 12
@ h /= 13
if ( ! $?GEO_X_0 ) setenv GEO_X_0 ${w}x${h}+0+0 if ( ! $?WIN_X_0 )
setenv WIN_X_0 $DISPLAY endif set dd=" "
set xx=" "
endif
if ( $?TIME ) then
if ( ! $?PARMS ) then
echo > /tmp/RUN_TT_$$ $dd $* ${PARMS}
if ( $?DISPLAY ) then
echo " "
```

```
echo GEO_X_0 $GEO_X_0 WIN_X_0 $WIN_X_0
GEO_X_0 600x500+0+0 WIN_X_0 :0.0
echo h $h
h 830
echo w $w
w 1152
echo " "

endif
source /tmp/RUN_TT_$$
/nfs/carrington/h1/ksg/LIB/O/9/mjsvgrx
```

mjsvgrx in this director is a file dated 2001

```
 DEBUG                                          DEBUG
 file  ft36,  number  36 opened on file mjsfit.out
form formatted   , iostat =  0
 file  ft13,  number  13 opened on file temp
form UNformated  , iostat =  0
 file  ft29,  number  29 opened on file cru.fits
form formatted   , iostat =  0
 file  ft28,  number  28 opened on file cru.fits.short
form formatted   , iostat =  0
data_base /nfs/faraday/d9/vgr/data ,  data
/nfs/faraday/d9/vgr/data/v2/vgr
 dirs   data /nfs/faraday/d9/vgr/data/v2/vgr after else
 DEBUG_perl
 y1 1978 d1 001 h1 0   tn 2923 2
 y2 1978 d2 002 h2 24   tl 2925 2
 y1 1978 d1 001 h1 0   tn 2923 2
 y2 1978 d2 002 h2 24   tl 2925 2
test_dir /nfs/faraday/d9/vgr/data/v2/vgr
GGG_COPY /nfs/carrington/h1/ksg/LIB/O/9/batnto1
```

LIB is a link that takes you to /nfs/faraday/d5/ksg/LIB/
Batnto1 is a file dated 2001

`YEAR=  1978` ***this the first output from mjsanl.f***

```
 ========================================
     Cruise Mode (Mission tape)
 ========================================

 Trajectory file selection:
 0 ==> Do not mount trajectory file
 1 ==> Use short cruise file (via PHASE3)

1

 SEDR S/C ID: Voyager 2
data_base /nfs/faraday/d9/vgr/data ,  data
/nfs/faraday/d9/vgr/data/v2/shortsedr
 dirs   data /nfs/faraday/d9/vgr/data/v2/shortsedr after else
 DEBUG_perl
 y1 1978 d1 001 h1 0   tn 2923 2
 y2 1978 d2 002 h2 24   tl 2925 2
 y1 1978 d1 001 h1 0   tn 2923 2
 y2 1978 d2 002 h2 24   tl 2925 2
```

```
test_dir /nfs/faraday/d9/vgr/data/v2/shortsedr
GGG_COPY /nfs/carrington/h1/ksg/LIB/O/9/batnto1
 file  ft11,  number  11 opened on file
/nfs/faraday/d9/vgr/data/v2/shortsedr/v2_shortse form formatted   ,
iostat =  0
 file  ft31,  number  31 opened on file
/nfs/faraday/d9/vgr/data/const/redart.data       form UNformated  ,
iostat =  0
    CUP RESPONSE AT NORMAL INCIDENCE     66.10     56.24

 openxwins WIN_X_0, :0.0, 600x500+0+0
 Plot option [cdefghIilmnoPpqrSstwx?]: 1, 3, EVENT 21
```

g

At this point an x-term window opens

```
 file  ft17,  number  17 opened on file trec
form formatted   , iostat =  0

Cruise SEDR = GETDATA 78001 78002 2 shortsedr |
SEDR file covers the time range:    1977 232 00 1979 186 00

Cruise DATA = GETDATA 78001 78002 2 vgr |
Mission file covers the time range: 1978 001 06 1978 120 23

 DEBUG   111     1
Do joint ion/electron analysis? 2=M, E1, E2; 1=L, E1, E2; 0=NO
```

0

```
 Select Data Mode:
 1 = Plasma, 2 = DC Return, 3 = MODCAL and CURCAL, 4 = All
```

1

```
Integrate Plasma Data? (Analysis Skipped)  2=YES for DC return spectra
1=YES for plasma spectra  0=NO
```

0

```
 Select Spectral Type:
     0 = all, 1 = ions only, 2 = electrons only
     3 = L only, 4 = M only, 5 = E1 only, 6 = E2 only, 7 = LS, E1S, E2S
only
```

4

```
 DEBUG  0
 INPUT START TIME: IYR, IDAY, IHR, IMIN, ISEC, IMSEC
 DEBUG  1
```

1978 1 0 0 0 0

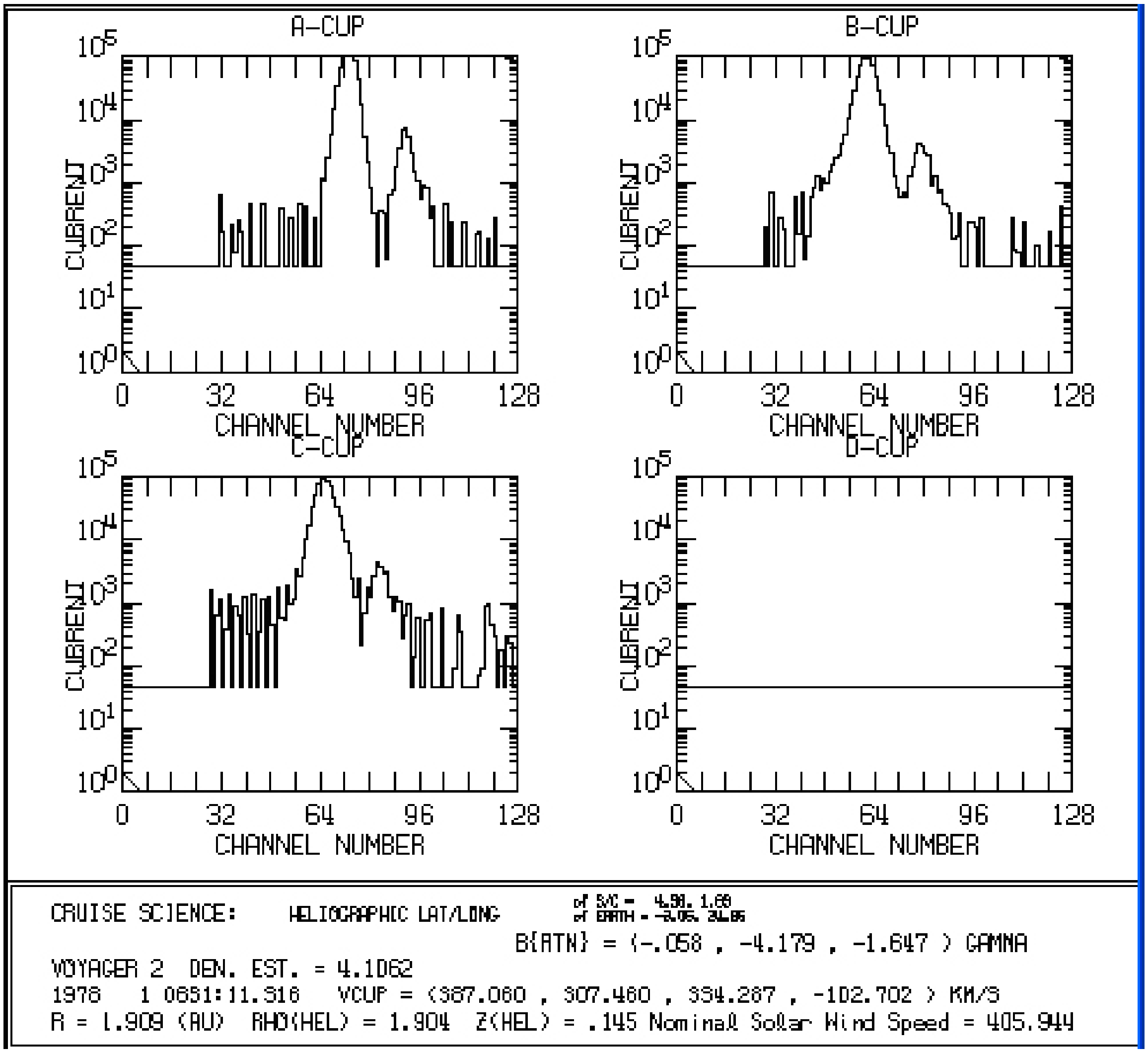
```
 DEBUG  2       1978  1  0  0  0  0
 Input number of spectra to average (0= no ave.)
```

0

```
 file  ft02,  number   2 opened on file
/nfs/faraday/d9/vgr/data/const/cntrl.data        form formatted   ,
iostat =  0
 file  ft30,  number  30 opened on file
/nfs/faraday/d9/vgr/data/const/conrd.data        form UNformated  ,
iostat =  0
 VOYPRT
01978   1  631:11.316       1  EFEF   0       0.0       0.0       0.0
65535  2  CR-1  29              0              0
    1   1 128       0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0   72
                   36    0    0   41   15   47   36    0    0   64    0
0    0   63    0    0
                    0    0    0   59    0    0   48    0    0   63    0
61    0    0   49    0
                   90   86  110  133  159  183  202  216  224  226  221
209  189  165  132  105
                   80   53    0   57   53    8   72   78  100  120  138
141  132  114   95   86
                   68   81   79   49   60    0    0    0   63    0   44
0    0    0   44    0
                    0    0   33   36    0    0   29    0   48    0    0
0    0    0    0    0
    2 129 256       0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0   40    0   74    0
                    0   48   37    0    0    0   71   32   74    7   31
71   79   91   77   89
                   84   97  103  111  112  125  133  150  163  179  193
203  210  212  210  204
                  193  179  163  143  123  114   92   80   70   76   71
91  101  114  125  122
                  116  112   82   92   75   78   64   62   55   28   30
54    0    0   45   45
                   40    0   48    0    0    0    0    0    0    0    0
0   48   16   15    0
                   45    0    0    0   20    0    0    0   34    0    0
0   61    0    0    0
   3 257 384      0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0   97    0   73   88
                    0   57   93    0   81   73    0   92   54    0   93
0   55   88    0   92
                   62    0  101   69   67  103   84   89  118  113  130
149  163  182  195  205
                  211  212  209  203  193  182  173  160  147  135  109
92  110   42   74  101
                   90  113  126  122  114  117   91   78   91   86   48
71   84    0   30   70
                    0    0   68   75    0    0    0   79    0    0    0
18   71   56    0    0
```

```
                    0    0    0   10   19   81   84   62   51    0   38
0   51   43    0    0
    4 385 512       0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
                    0    0    0    0    0    0    0    0    0    0    0
0    0    0    0    0
TIME OF CURRENT SPECTRUM IS 1978   1 0631:11.316
CURRENT SPECTRUM IS AN M-MODE
PROJECTION OF Magnetic Field ALONG CUP NORMALS (Gamma)
           BA          BB          BC          BD          B mag
        -0.152       1.232       2.404       4.227       4.493

MODULATOR ON, PLASMA, NORMAL SUPPRESSOR
PLOT DATA? 1=YES, 0=NO

1

THRESHOLD  IS   9.4703E+01 FEMTOAMPS.
SATURATION IS   9.1357E+05 FEMTOAMPS.

MINIMUM AND MAXIMUM CURRENTS (IN FEMTOAMPS) ARE:
    9.470E+01    3.218E+05 IN CUP     1
    9.470E+01    1.945E+05 IN CUP     2
    9.470E+01    1.945E+05 IN CUP     3
    9.470E+01    9.470E+01 IN CUP     4

WRITE OUT ALL CURRENTS? 1=YES, 0=NO

0

 THE SCALE STARTS AT 1.00E-01 FEMTOAMPS AND GOES UP 6 DECADES  CHANGE
CURRENT SCALE FROM CURRENT VALUE? 1=YES 0=NO

1

 YB (MUST BE A POWER OF 10),IDEC (NUMBER OF DECADES)

1 5

 Plot option [cdefghIilmnoPpqrSstwx?]:

g
```

At this point you have the plot of the currents versus channel number for all cups, as below.



```
CRUISE SCIENCE:     HELIOGRAPHIC LAT/LONG    of S/C =  4.98, 1.68
                                             of EARTH = -2.05, 24.85
                                       B{ATN} = {-.058 , -4.179 , -1.647 } GAMMA
VOYAGER 2  DEN. EST. = 4.1062
1978   1 0651:11.316   VCUP = (387.060 , 307.460 , 334.287 , -102.702 ) KM/S
R = 1.909 (AU)  RHO(HEL) = 1.904  Z(HEL) = .145 Nominal Solar Wind Speed = 405.944
```

11.3 Conversion of analysis from Solaris

11.3.1 First email

Wed, 3 Jul 2013 21:43:10 -0400 [03/07/13 21:43:10 EDT]
From: gsgordonjr <gsgordonjr@comcast.net>Add to Address book (gsgordonjr@comcast.net)
To: John Richardson <jdr@space.mit.edu>Add to Address book (jdr@space.mit.edu)
Cc: "John W. Belcher" <jwb@space.mit.edu>Add to Address book (jwb@space.mit.edu)
Subject: Re: Voyager
Headers: Show All Headers
John(s)

I have tried several clever ideas.
None have worked!
So now I am trying to just brute force it.
i.e. I will first just recompile the code on solaris,
fixing where it does not compile for obvious reasons.
This will be done by commenting out the offending code,
with double 'c's in Fortran and something similar in c'
For the non obvious I will comment out the offending ci=ode and insert a warning that it must be fixed later.
How we have illegal code in the official library
I do not know.
After be get the Solaris code to compile, link
I will have to set up a small set of test cases to ensure
that the code does the same as the official code.
Then the code will have to be compiled in Linux,
and run, making sure that we get the same results.
In this process, the Solaris code will have to be changed, and verified
that it performs the same as the official code.
In this the programs that read the data files will have to be modified to correct for the "big end", "little end" problem
One problem that worries me is to make
sure that we have a history of what is done
so that we can correct errors that were not found
and corrected now.
I am setting up an account 'lvgr' which will mimic
'vgr' but it will have two versions one to run on Solaris
and one to run on Linux.
This will require some rewriting of the default files,
e.g. .cshrc and the procedure in ~vgr/bin.

At present I am running all of the Linux work on my machines in Concord, as We have none
at MIT.
I hope to delay having to purchase a Linux machine
as long as possible, but that time is getting near.

As for us getting together,
This week I will be in Concord Tues & Wed , 9, 10.
My \phone numbers are
MA (978) 369-2527
NH (603) 763-4167
cell (617) 800-3184
I usually return to Concord MA once a week
to clean things there and am fairly flexible then.
We will probably have to negotiate timing on the phone
but e-mail is a good starter.

George
-----Original Message----- From: John Richardson Sent: Wednesday, July 03, 2013 11:27 AM
To: George S Gordon Jr Cc: John W. Belcher Subject: Voyager

Hi George,

Voyager made the news again - the science papers
for the V1 event last August finally got published.
And the most recent Senior Review came out yesterday,
Voyager was ranked #1 for science.

John Belcher and I would like to talk about the
progress/problems with migrating the programs sometime.
Are you around the week of July 15? If there is a time
you are coming to MIT we could meet here, or else we could
come out to Concord. Or up to NH.

Best, john

11.3.2 Second email

Fri, 5 Jul 2013 14:25:56 -0400 [05/07/13 14:25:56 EDT]
From: gsgordonjr <gsgordonjr@comcast.net>Add to Address book (gsgordonjr@comcast.net)
To: John Richardson <jdr@space.mit.edu>Add to Address book (jdr@space.mit.edu)
Cc: "John W. Belcher" <jwb@space.mit.edu>Add to Address book (jwb@space.mit.edu)

Subject: Re: Voyager
Headers: Show All Headers
John(s)
Below is a listing of the source code subdirectories
with the return code and number of subroutines with compile errors.
These were gotten running make in each subdirectory on carrington.

```
bev   1       4
dl    0            gi    0            im    1       1     imp   1
  13     directory   return    # compile
              code      errors   jwb           1          0     mjs
        1         3      nrc          1          2      nrf
 1          0      nrpc          0             nwin          0
   pls           1          5      plt           1          1      rsh
           1          0      run           1          2      sedr
      1          0      so            1          0      tek
1          0      vec           0             vgr           1
 20     xwin         1          0
```

I would appreciate a statement as to the
importance of the different subdirectories,
so I can do the most important first.
A lot of the compile errors are simple things such
as changes in Fortran's format statement.
These are easy. Others are statements, that I
do not see how they ever compiled. Especially where
I do not know/remember what the routine is suppose to do
is more difficult. Any suggestions?
I will correct some of the warning, where
doing so are not too tricky/dangerous, as they
will cause trouble down the road.
When I have gotten enough of the code to compile/link/run
under Solaris, I will start making the same change to compile/link/run
under Linux. Here I will have to change the Solaris code to agree
with the Linux at least in functionality. In any case we must get the same result as we
get in the 'official' version.
Fairly soon in this stage I will have to tackle the
'Little End' / 'Big End' problem. Here I will need your help
to decide which data sets to do first and to check
that we are getting the same results.

George

11.3.3 Third email

Sat, 6 Jul 2013 17:41:40 -0400 [06/07/13 17:41:40 EDT]
From: gsgordonjr <gsgordonjr@comcast.net>Add to Address book (gsgordonjr@comcast.net)
To: John Winston Belcher <jbelcher@mit.edu>Add to Address book (jbelcher@mit.edu), John Richardson <jdr@space.MIT.EDU>Add to Address book (jdr@space.MIT.EDU)
Subject: Re: Voyager
Headers: Show All Headers
John(s)
Wed the 17th at 0900 is good for me.
My address is
100 Newbury Court
suite 305
Concord MA 01742

exit route 2 at Emerson Hospital
on "old Road to nine acre corner
then it is the third left turn
(first is Hospital parking second Deaconess Rd.
third is Newbury court (one sign lists it as Newbury Court Rd.)

George

11.4 Leslie/John emails regarding location

11.4.1 Answer Array definition

http://space.mit.edu/home/gsg/doc/Voyager/vgranl.html

11.4.2 Voyager 1 Data files

```
cd /nfs/plas7/d2/vgr/v1/sum

ls -lt
total 26
lrwxrwxrwx   1 vgr          49 Feb  1  2007 1980_oldlink ->
/nfs/debye/d3/plasma/dw/vgr/data/v1/sum/1980_save
lrwxrwxrwx   1 vgr          49 Feb  1  2007 1979_oldlink ->
/nfs/debye/d3/plasma/dv/vgr/data/v1/sum/1979_save
lrwxrwxrwx   1 vgr          49 Feb  1  2007 1978_oldlink ->
/nfs/debye/d3/plasma/du/vgr/data/v1/sum/1978_save
lrwxrwxrwx   1 vgr          49 Jan 25  2007 1977_oldlink ->
/nfs/debye/d3/plasma/dt/vgr/data/v1/sum/1977_save
dr-xr-xr-x   5 vgr        3584 Mar 20  1997 1980
dr-xr-xr-x   5 vgr        3072 Mar 20  1997 1979
dr-xr-xr-x   5 vgr        6656 Mar 20  1997 1978
```

```
dr-xr-xr-x   5 vgr         3072 Mar 20  1997 1977
-rwxr-xr-x   1 vgr          501 Mar 20  1997 RRRR


-rw-r--r--   1 vgr          331 Mar 19  1997 RRR
-rw-r--r--   1 vgr          322 Mar 19  1997 RR
-rw-r--r--   1 vgr          468 Mar 19  1997 R
-r--r--r--   1 vgr          586 Mar 10  1997 README
```

Hi John -

They are all in those two directories ($vgrV2ALL/v2all_files and $vgrV2ALL/v2all_plots):

```
setenv vgrV2ALL   /nfs/plas7/d9/vgr/v2/vgr_staging/v2all_dir
cd $vgrV2ALL/v2all_files
pwd
/nfs/plas7/d9/vgr/v2/vgr_staging/v2all_dir/v2all_files

ls -lt v2all_197* | head

-rw-r--r--   1 vgr     41168057 May  1  2012 v2all_1979_063_065.txt
-rw-r--r--   1 vgr     15847162 May  1  2012 v2all_1979_064_064.txt
-rw-r--r--   1 vgr     71974912 Nov  4  2011 v2all_1978_041_050.txt
-rw-r--r--   1 vgr     71983104 Nov  4  2011 v2all_1978_001_004.txt
-rw-r--r--   1 vgr     18078124 Feb  3  2010 v2all_1979_190_190.txt
-rw-r--r--   1 vgr     76657237 Jan  6  2010 v2all_1977_341_365.txt.gz
-rw-r--r--   1 vgr     60159677 Jan  6  2010 v2all_1977_321_340.txt.gz
-rw-r--r--   1 vgr     49803440 Jan  5  2010 v2all_1977_301_320.txt.gz
```

specifically, the ascii files from 1977:

```
ls -lt v2all_1977*
-rw-r--r--   1 vgr     76657237 Jan  6  2010 v2all_1977_341_365.txt.gz
-rw-r--r--   1 vgr     60159677 Jan  6  2010 v2all_1977_321_340.txt.gz
-rw-r--r--   1 vgr     49803440 Jan  5  2010 v2all_1977_301_320.txt.gz
-rw-r--r--   1 vgr      6394793 Jan  5  2010 v2all_1977_281_300.txt.gz
-rw-r--r--   1 vgr      6661218 Jan  5  2010 v2all_1977_261_280.txt.gz
-rw-r--r--   1 vgr     12270473 Jan  5  2010 v2all_1977_233_260.txt.gz
```

Are you going to be able to "uncompress" the files as you need them, or should I do it for you?

- Leslie

John Winston BelcherReply All
Sent ItemsTuesday, September 02, 2014 2:50 PM

thanks leslie, could you point me towards earlier files as well, e.g. just after launch?

11.4.3 Voyager 2 Data files

Leslie A. Finck [laf@space.mit.edu]Reply All
Tuesday, September 02, 2014 11:50 AM
Hi John -

I think this is what you want:

```
setenv vgrV2ALL   /nfs/plas7/d9/vgr/v2/vgr_staging/v2all_dir

ls -lt $vgrV2ALL/v2all_files | head
ls -lt $vgrV2ALL/v2all_plots | head
```

```
[laf@tsessebi:~]> ls -lt $vgrV2ALL/v2all_files | head

total 5134552
-rw-r--r--   1 vgr      7892484 Jun  5 15:20 v2all_2014_051_100.txt.gz
-rw-r--r--   1 vgr      7287744 Jun  5 14:57 v2all_2014_001_050.txt.gz
-rw-r--r--   1 vgr      9928620 Jun  5 14:36 v2all_2013_301_365.txt.gz
-rw-r--r--   1 vgr      9079453 Jun  5 14:16 v2all_2013_251_300.txt.gz
-rw-r--r--   1 vgr     11313186 Jun  5 13:41 v2all_2013_201_250.txt.gz
-rw-r--r--   1 vgr     12470265 Jun  5 13:15 v2all_2013_151_200.txt.gz
-rw-r--r--   1 vgr     10289806 Jun  5 12:49 v2all_2013_101_150.txt.gz
-rw-r--r--   1 vgr      5574036 Jun  5 12:32 v2all_2013_051_100.txt.gz
-rw-r--r--   1 vgr      4348538 Mar 18  2013 v2all_2013_001_050.txt.gz
```

```
[laf@tsessebi:~]> ls -lt $vgrV2ALL/v2all_plots | head
total 582816
-rw-r--r--   1 vgr       209703 Jun  5 15:30 v2_2014_051_100_Dcup_E2mode.jpeg
-rw-r--r--   1 vgr       299787 Jun  5 15:29 v2_2014_051_100_Dcup_E1mode.jpeg
-rw-r--r--   1 vgr       266420 Jun  5 15:29 v2_2014_051_100_Dcup_Mmode.jpeg
-rw-r--r--   1 vgr       269360 Jun  5 15:29 v2_2014_051_100_Ccup_Mmode.jpeg
-rw-r--r--   1 vgr       179861 Jun  5 15:27 v2_2014_051_100_Bcup_Mmode.jpeg
-rw-r--r--   1 vgr       248939 Jun  5 15:26 v2_2014_051_100_Acup_Mmode.jpeg
-rw-r--r--   1 vgr       251735 Jun  5 15:25 v2_2014_051_100_Dcup_Lmode.jpeg
-rw-r--r--   1 vgr       201955 Jun  5 15:25 v2_2014_051_100_Ccup_Lmode.jpeg
-rw-r--r--   1 vgr       106169 Jun  5 15:25 v2_2014_051_100_Bcup_Lmode.jpeg
```

11.4.4 John's Heliosheath Fits

ftp://space.mit.edu/pub/plasma/vgr/v2/key/v2_keys_2007.241-now

12 Tasks

12.1 Survey calibrations throughout mission

12.1.1 Print out calibrations

Directory /nfs/carrington/h1/jwb/2015_voyager
See program readdata.f

```
    DATA kstat1/239/, kstat2/111/, kstat3/47/, kstat4/175/
```

12.2 Document new data format

http://space.mit.edu/home/gsg/doc/Voyager/vgranl.html

/nfs/carrington/h1/jwb/src/test

From /nfs/carrington/h1/jwb/src/storage/ansTEST.f

```
c  this is the time
        WRITE(29,5) JTB,JTLMOD,jne,JCLK,kstat,ipls,ityp,lstat
 5    format(12I5,Z10)
c   write out answer array
        write(29,8) ANS,temp
 8    format(5E15.5)

     INTEGER*2 JDAT(512) ,JTB(6),JNE,JTLMOD,JCLK
      REAL  ANS(200)

      KSTAT = L1X(LSTAT)
      IPLS = MOD(KSTAT/2,2)
      ITYP = MOD(KSTAT/4,4)
```

12.3 Make galactic coordinate plot of voyager trajectories

References

8

Bridge, H. S., J. W. Belcher, R. J. Butler, A. J. Lazarus, A. Mavretic,G. L. Siscoe, J. D. Sullivan, and V. M. Vasyliunas: The PlasmaExperiment on the 1977 Voyager Mission, *Space Science Reviews*, **21**, 259-287, 1977 9

Lallement, R, J. L. Bertaux, E. Chassefiere, and B. R. Sandelin, *Lyman-Alpha observations from Voyager (1-18 AU)* in Physics of the Outer Heliosphere, edited by S. Grzedzielske and D. E. Page, Cospar Colloquia Series, Pergamon Press, 1990, p 74. 28

13 Index