Helios plasma instruments overview

David Stansby

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Abstract

An overview of the in-situ plasma instrumentation on board the Helios spacecraft. Information is taken from the translated technical manuals.

1 Plasma instruments

Each spacecraft has 4 plasma instruments. I1a, I1b and I3 measure positive ions, and I2 measures electrons. The instruments point in the ecliptic, and the spin of the spacecraft is used to build up resolution in azimuth. In addition to resolution in azimuth, instruments I1a and I3 have a built in angular resolution in elevation out of the ecliptic. Instruments I1b and I2 in effect provide measurements integrated over given ranges of elevation.

A measuring cycle is defined as the 32 spins needed to build up distributions at each of the 32 energies measured by I1a and I1b. For proton measurements either I1a or I3 provides data. Most of the time I1a is used, but near perihelion I3 provides data.

During each complete spin of the probe the plate voltage on each instrument is kept constant, and 32 energies sampled over 32 spins of the satellite. Specific bin directions for each instrument can be found in tables 9 and 10 (pages 71 and 72). Every other measuring cycle the energy bins are swapped by half a spacing, and the azimuth bin directions are also swapped by half a spacing. This can provide higher angular resolution measurements over longer time periods.

1.1 I1a

The I1a instrument measures count rates of positive ions as a function of E/q, and reports a distribution function as a function of E_p, which is the energy assuming all the particles are protons.

- E/q range: 0.155 - 15.32 kV (32 channels)
- Azimuth range: -54.5° - 32.7° (16 channels)
- Elevation range: -20° - 20° (9 channels)

1.1.1 Correcting non-proton particle measurements

For a particle of mass m, charge q, travelling at speed v, energy per charge bin it will fall into is

$$\frac{E}{q} = \frac{mv^2}{2q} \tag{1}$$

eg. for an α particle travelling at the same speed as a proton, the ratio between the two bins will be

$$\left(\frac{E}{q}\right)_\alpha \left(\frac{q}{E}\right)_p = \frac{m_\alpha}{q_\alpha}\frac{q_p}{m_p} = \frac{q_p}{q_\alpha}\frac{m_\alpha}{m_p} = 2 \tag{2}$$

so the α particles lie in bins twice as high as protons with the same speed. This means when a velocity of α particles is calculated assuming that all the particles are protons, it is incorrect

$$\left(\frac{E}{q}\right)_{\alpha,actual} = \frac{1}{2}\left(\frac{E}{q}\right)_{\alpha,measured} \tag{3}$$

$$v^2_{\alpha,actual} = \frac{1}{2}v^2_{\alpha,measured} \tag{4}$$

$$v_{\alpha,actual} = \frac{1}{\sqrt{2}}v_{\alpha,measured} \tag{5}$$

1.2 I1b

The I1b instrument measures the ion current. Similarly to I1a the bins are E/q bins, but instead of couting particles I1b counts current. The distribution is effectively integrated over 80° of elevation and $\sim$ 180° of azimuth (towards the sun).

- E/q range: 0.145 - 14.32 kV (32 channels)
- Azimuth range: -56.25° - 118° (1 channel)
- Elevation range: -40° - 40° (1 channel)

1.2.1 Correcting non-proton particle measurements

The velocity and energy bin correction is the same as in the I1a correction. Because I1b measures current, if a particle with charge q enters the instrument it will contribue an extra factor of q/q_p to the distribution function.

1.3 I2

The I2 instrument measures electrons. It can run in two different modes (A or B), toggled by manual commands sent to the spacecraft. The only difference between the modes is the energy channel spacing. There is only 1 elevation bin, so effectively a 2D cut through the electron distribution is measured in the ecliptic.

- E/q range (mode A): 0.5 - 15.5 V (16 channels)
- E/q range (mode B): 10.7 - 1660 V (16 channels)
- Azimuth range: 360° (8 channels)
- Elevation range: -9° - 9° (1 channel)

1.4 I3

The I3 instrument measures positive ions. It can select for m/q and velocity. Further details about how the selection is done are given below.

- Velocity range: 199 - 767 km/s (16 channels)
- Azimuth range: -53.2° - 30.8° (16 channels)
- Elevation range: -20° - 20° (9 channels)
- m/q range: 1 - 5.33 (15 channels)

2 Plasma data processing

The organisation and transmission of data is described in pages 77-82. Channels are described in the format Energy x Azimuth x Elevation.

2.1 Normal data mode (NDM)

2.1.1 I1a

During each spin period instrument I1a produces 144 readings in all 9 elevation and 16 azimuth channels. Over an entire measuring cycle the channel with the highest counts is noted. During the following measuring cycle only the channels in the range 9 x 5 x 5 around the maximum are transmitted (255 values), whilst a new maximum is determined from the entire measurement. In addition a total count rate is transmitted for each energy from integrating over angles on board the spacecraft. This gives an idea of how much is missed by the reduced distribution.

2.2 I1b

All 32 integrated energy counts are transmitted.

2.2.1 I2

All 16 energy channels in 8 azimuth directions are transmitted.

2.2.2 I3

A similar selection process to I1a is used - during the first 16 spins of each measurement cycle the instrument is set to $m/q = 1$ and a maximum count rate bin noted, which is used to select transmission channels 9 x 5 x 5 in the next measurement cycle. During spins 17-32 of each cycle the previously measured speed maximum for $m/q = 1$ is set, and sequentially m/q values are stepped through. The distribution at each spin is integrated over all angles, to provide an estimate of the density of different species at the saved proton speed. Essentially this measures the integrated distribution over a shell in velocity space for each m/q value.

If the measured proton maximum is at a velocity higher than the 10th velocity channel, less than 9 proton angular distributions at constant energies are measured. The m/q program is still stepped trough, but on spins 17, 18... etc. angular distributions at v_{max} are measured for different m/q values until the avialable 9 energies are full. The order that m/q measurements are made in is given in table 7 (page 61).

The data transmitted in NDM is as follows (Fig 21, page 79):

- 32 I1b integration counts
- 32 I1a/I3 integration counts
- 128 I2 distribution measurements
- 225 I1a/I3 distribution measurements

2.3 High data mode (HDM)

2.3.1 I1a

A fixed grid of proton measurements is transmitted in a 32 x 7 x 7 grid, from AZ 5 to AZ 11 and EL 2 to EL 8 (see tables 9 and 10 for bin directions). Sometimes EL 8 is omitted due to a low transmission bit rate.

The 32 energy channels are divided into 4 blocks (HDM1 to HDM4), each of which contains 392 (or 336) values. At the highest data rate each block is sent every 10.125 s, giving a full distribution every 40.5 s. If the bit rate is not maximal, the blocks are sent over longer periods.

2.3.2 I3

Each cycle meaures the proton distribution for the first 16 spins, and then measures an angle resolved spectrum for a given speed and each m/q in the second 16 spins. Each cycle steps through speed, so after 16 cycles a full 3D spectra is available for each m/q as well as 16 3D proton spectra.

In HDM a single data frame is sent every 10.125 seconds. A complete distribution is build from 4 individual frames. The data transmitted in a HDM frame is as follows (Fig 22, page 82):

- 8 I1b integration counts
- 8 I1a/I3 integration counts
- 64 I2 distribution measurements
- 336 or 392 I1a/I3 distribution measurements