Tests and Calibrations of the PLASTIC Entrance System: Design Verification for Flight Models on the STEREO Spacecraft

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1. Introduction

The PLasma and SupraThermal Ion Composition (PLASTIC) instruments will measure properties of solar wind ions and suprathermal solar ions in the framework of the Solar Terrestrial Relations Observatory (STEREO) mission (Fig. 1). Two identical instruments located on separate spacecraft will provide *in situ* plasma measurements at ~1 AU in order to understand processes low in the corona and in the inner heliosphere. The STEREO mission will provide a unique opportunity to investigate the 3-dimensional structure of the heliosphere; particularly the origin, evolution, and propagation of Coronal Mass Ejections (CMEs) through the heliosphere. This will be achieved with simultaneous measurements at two different heliocentric longitudes, utilizing both remote sensing and *in situ* instruments aboard spacecraft moving away from the Earth at 22.5°/yr. PLASTIC will measure bulk solar wind plasma parameters (density, velocity, temperature, temperature anisotropy, and alpha/proton ratio) and the distribution functions of major heavy solar wind ions (e.g. various charge states of C, O, Ne, Mg, Si, Fe). The PLASTIC instrument includes an electrostatic deflection analyzer, a time-of-flight section, and solid-state detectors (SSD's) for energy measurement. The instrument will provide a large instantaneous field of view (in-ecliptic and polar angles resolved) with measurements taken at high time resolution (1-5 minutes) spanning an ion energy range of 0.3-80keV/e. To handle a large range of particle fluxes, the PLASTIC Entrance System employs collection apertures with different geometric factors for the bulk solar wind (H ~96%, He ~4%) and for the heavier, less-abundant ions (<1%) and suprathermals. An Engineering Qualification Model (EQM) of the Entrance Sys-

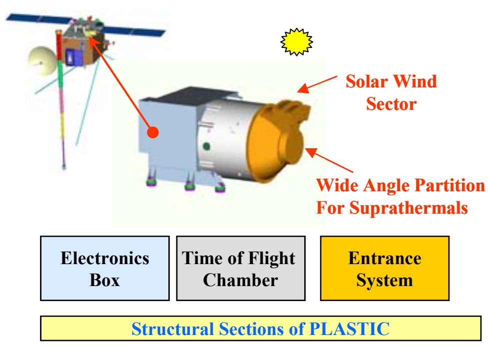


Fig. 1 *Diagram showing the PLASTIC instrument and its orientation on STEREO Spacecraft. Courtesy of T. Galvin, PLASTIC Critical Design Review, Goddard, Nov 2002.*

tem (ESEA) model has been constructed and has undergone tests and calibrations to verify functionality before proceeding to the flight model construction. The flight models (FM1, FM2, FS) are now under construction. Further detailed measurements with the EQM are proceeding, including integrated testing with the full PLASTIC EQM. In this paper, the measurement principles will be explained and the ion optic calibrations of the PLASTIC EQM Entrance System will be presented.

2. Entrance System and Operational Requirement

Solar wind ion are accepted by the PLASTIC Entrance System (ESEA) through different entrance apertures, which select the geometrical factor relevant for the collected ion fluxes. The electrostatic deflection analyzer (ESA) selects ions by energy per charge (*E/q*), while the entrance apertures ("duckbills") select ions by incident polar angle. Additionally, the ESEA must prevent the collection of other particles, which contribute spurious signals. Solar UV, scattered ions and solar wind electrons must be suppressed from passing through the ESEA, as they can generate false start and stop pulses on the MCPs in the Time-Of-Flight (TOF) section (direct conversion or carbon foil SEE).

The Entrance System consists of three different apertures employing different geometrical factors (Fig. 2). The Solar Wind Sector (SWS) spans a 45° azimuthal field-of-view in the sun-facing direction, thus receiving the bulk flow of the solar wind. The remaining azimuth (excluding spacecraft and internal blockage) is spanned by the Wide Angle Partition (WAP) for suprathermal ions. The SWS consists of the proton-alpha S-Channel (SC) and the heavy ion Main Channel (MC), which differ in active area. When the ESA is tuned to the high *E/q* range, corresponding to heavy ion collection, the Main Channel (A_{active} = 1 cm^2) is enabled. In scanning down the *E/q* range, the ion flux increases as the instrument begins to collect the abundant H and He ions. The instrument switches from the Main Channel to S-Channel at a set-point defined by a count rate maximum. The S-Channel steering electrodes (SCO-L, SCI-U) and the Main Channel Gate (MG) are activated. The S-Channel (A_{active} = 4.5E-3 cm^2) is thus enabled, collecting ions at a decreased count rate. The WAP (A_{active} = 1.3 cm^2) is continually active. At the entrance apertures of the SWS, the "duckbill" electrodes

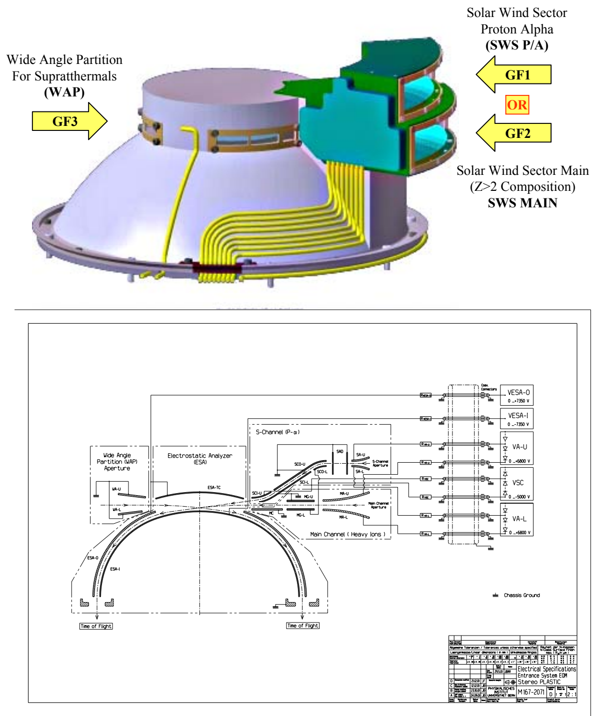
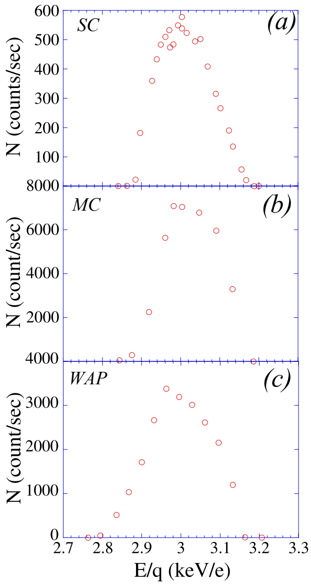
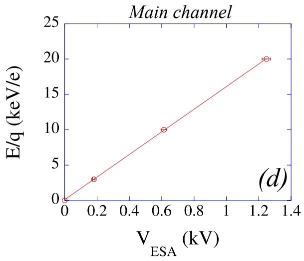


Fig. 2 *Design schematics of Entrance System show different entrance apertures and internal electrodes.*

Fig. 3 *E/q resolution for the (a) proton-alpha S-Channel, (b) heavy ion Main Channel, (c) suprathermal WAP. Slope of E/q(V_{ESA}) in gives Main Channel the analyzer constant (d).*





(SA-U/L, MA-U/L) are scanned in voltage to select ions by polar incident angle for up to +/– 20°. The toroidal deflection analyzers domes (ESA) [1] isolate ions by *E/q* with a resolution of ~6%. Ions then pass to the TOF section for measurement of velocity (*l/TOF*) and energy (*E*) resolved in azimuthal angle (θ), thus allowing for a full 3-D characterizations of the solar wind ions.

3. Calibration of the PLASTIC EQM Entrance System

The PLASTIC Entrance System concept was tested utilizing a Laboratory Prototype (LP) to verify the operation principle.[2] Design was aided by LP measurements in the CASYMS ion beam facility[3],[4] as well as ion-optical simulations (SIMION)[5]. These findings, along with further ion-optical simulations, facilitated the design of the EQM ESEA.[2]

Ion beam tests and UV tests have been carried out on the EQM ESEA in the CASYMS and MEFISTO [6] devices. Calibrations yield a relation between the *E/q* of the incident ions and the voltages on the ESA electrodes:

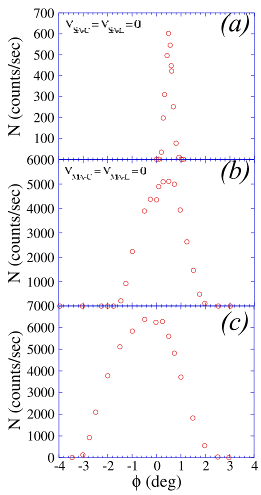
$$k = E/q\ V_{ESA}^{-1}$$

Because of the different geometries, each entrance aperture (SC, MC, WAP) will have a different analyzer constant (*k*) and *E/q* resolution, although the differences are only slight. The *E/q* resolution and ESA tuning are shown in Fig. 3. Additionally, a deflection constant is measured for the S-Channel steering electrodes. Similarly, a deflection constant can be attained for the relation between incident polar angle (ϕ), *E/q*, and "duckbill" electrode voltages:

$$k_{SA,MA} = \phi\ E/q\ V_{SA,MA}^{-1}$$

Polar angle resolution and the duckbill deflection relations are shown in Fig. 4. Table 1 gives a summary of the EQM calibration results from measurements and simulations.

In flight, the solar wind properties will be established by voltage scans of the electrodes and the pre-flight calibrations of the analyzer and deflection constants. The solar wind ion *E/q* will be derived from ESA voltage scans, while the



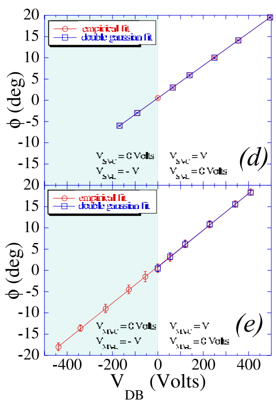


Fig. 4 *ϕ resolution for (a) S-Channel, (b) Main Channel, and (c) WAP. Linear relation between "duckbill" voltage and acceptance angle (for 3keV/e beam) give the deflection constant: (d) SC, (e) MC.*

***Tab. 1** Summary of analyzer and deflection constants, with E/q and ϕ resolution.*

entrance aperture	electrode	Analyzer Constant (keV/e kV^{-1}) simulations	Analyzer Constant (keV/e kV^{-1}) measurements	Energy Resolution (% FWHM) simulations	Energy Resolution (% FWHM) measurements	Active Area (cm^2) simulations	Active Area (cm^2) measurements
S-Channel	SCO-L	3.329	3.45		11%		
	SCI-U	3.803	3.68		12%		
	ESA ±	8.344	8.47	9.8%	5.8%	1.20E-02	4.53E-03
						real smaller slit than simulated	
Main Channel	ESA ±	8.127	8.35	6.5%	5.8%	1.400	0.988
WAP	ESA ±	8.127	8.23	7%	6.3% (-120°) 6.7% (-30°)	1.680	1.305

entrance aperture	Polar Angle Resolution (FWHM) simulations	Polar Angle Resolution (FWHM) measurements	Polar Deflection Constant (° keV/e V^{-1}) simulations	Polar Deflection Constant (° keV/e V^{-1}) measurements
S-Channel	0.55°	0.4°	0.0981	0.114
Main Channel	2.9°	1-2 °	0.125	0.129
WAP	-5°/+6°	3.5°	N/A	N/A

ion velocity distribution (v) will be established from *TOF* as a function of ϕ ("duckbill" voltage scans) and θ (MCP position measurements). *E/q* and *TOF* combine to give mass per charge (*m/q*) composition. The SSDs yield the ion energy (*E*) in SWS and a portion of the WAP. Measurements are then separated into *m*, *q*, and v(ϕ, θ). The calibrated geometric factor (angular acceptance for ion energy (*E*)) relates the measured count rate to the incident ion flux, thus giving the density (*n*) of different species.

To ensure signal purity, the ESEA has been designed to prevent solar UV, scattered ions and solar wind electrons from entering the TOF section. The ESA hemispheres select only ions in the desired *E/q* band. Electrons are deflected away from the measurement path. The Gate (MG) deflects ions entering the Main Channel aperture when the S-Channel is enabled. (EQM measurements show < 0.6% suppression factor.) Radiation from the solar photosphere is excluded from entering the ESA hemispheres. However, solar corona will be visible to the ESA entrance, thus a suppression factor of 10^9 is required to limit background signal in the TOF to < 1 count/sec. Photons must suffer one or more reflections to enter TOF. Serration of instrument surfaces reflect UV and particles away from the measurement path. A copper sulfide (Cu_2S) surface treatment also results in attenuation and diffuse reflection of UV and particles.

Acknowledgments

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