Solar Probe Plus

A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

05 – 06 NOV 2013

EPI-Lo Calibration

Don Mitchell

Outline

- Introduction
- Species and Energy Ranges
- Facilities
- Calibration Plan
- Test Flow
- In-Flight Calibration

EPI-Lo Calibration

- EPI-Lo measurements are intended to generate the information needed to derive differential intensities ($j[cm^2$ -sr-s-keV$]^{-1}$)
- The goal of EPI-Lo characterization and calibration efforts is to develop the quantitative procedures for converting the count rates (R [counts s^{-1}]) reported by EPI-Lo into estimates of j for the various defined ranges of energies, particle species, and arrival angles
- "Calibration" for a particle instrument like EPI-Lo means determining the following:
  - Transfer function from counts into flux (physical units)
  - Characteristic of "Rate-in" versus "Rate-out"
  - Response to visible and ultraviolet light
  - Response to high energetic particle backgrounds

Calibration Types

Foreground

Ions and Electrons in the energy range of interest to the instrument

Background

Electrons

Characterize the rates from penetrating radiation

Characterize response to Solar Wind and/or photoelectron impact

Light

Characterize rejection of UV background, primarily H-alpha

Characterize rejection of sunlight and glint

Foreground Calibration Requirements

Foreground Electrons

- **40 keV to 1000 keV (Needed for understanding backgrounds)**
  - 1 keV to 30 keV — Electron Gun at APL
  - 30 keV to 100 keV — Radioactive sources at APL
  - 125 keV to 1.6 MeV — Accelerator at GSFC

Foreground Ions (H, He3, He4, O, Fe)

- **40 keV to 15000 keV (Level 4 Requirements)**
- **(Goal: protons to 20 MeV)**
  - 3 keV to 170 keV — Accelerator at APL
  - 30 keV to 5 MeV — Degraded alpha sources
  - 125 keV to 1.6 MeV — Accelerator at GSFC
  - 1 MeV to 20 MeV — Accelerator at LBL

Test as You Fly

- The instruments will be tested in flight-like environments
- Since the instrument will need to operate in a high background environment, we will characterize response to high energy penetrating radiation, UV light, and low energy plasma (all potential sources of background counts for EPI-Lo)

Background Calibration Requirement

Background Electrons

- **2 eV to 10 MeV (from the expected environment)**
  - 1 eV to 100 eV — Hot filament at APL
  - 1 keV to 50 keV — Electron Gun at APL
  - 125 keV to 1.6 MeV — Accelerator at GSFC
  - 1 MeV to 10 MeV — Accelerator at Idaho

Background Ions

- **3 keV to 50 MeV (from the expected environment)**
  - 3 keV to 170 keV — Accelerator at APL
  - 30 keV to 5 MeV — Degraded alpha sources
  - 125 keV to 1.6 MeV — Accelerator at GSFC
  - 1 MeV to ~100 MeV — Accelerator at LBL

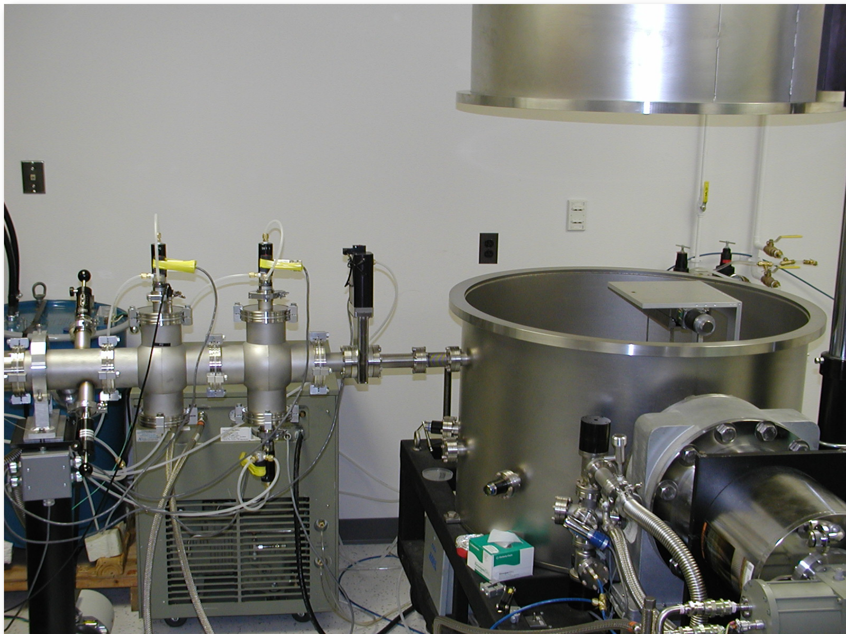
Photons

- UV and visible lamps at APL

The JHU/APL Calibration Facility

- The APL particle accelerator is a versatile system capable of producing a broad range of ion species at energies from 20 to 170 keV
- The system includes a electron-impact ionization source, extraction gap, Einzel Lens and Wien filter mounted in the insulated terminal structure along with all associated power supplies
- The system will produce beams of H, He, O, and noble gas ions with intensities over the range of 100's to 1,000,000 particles/cm^2/sec at the target position (mm^2 - cm^2)
- We also have a variety of radioactive sources as stimulus.

The JHU/APL Calibration Facility



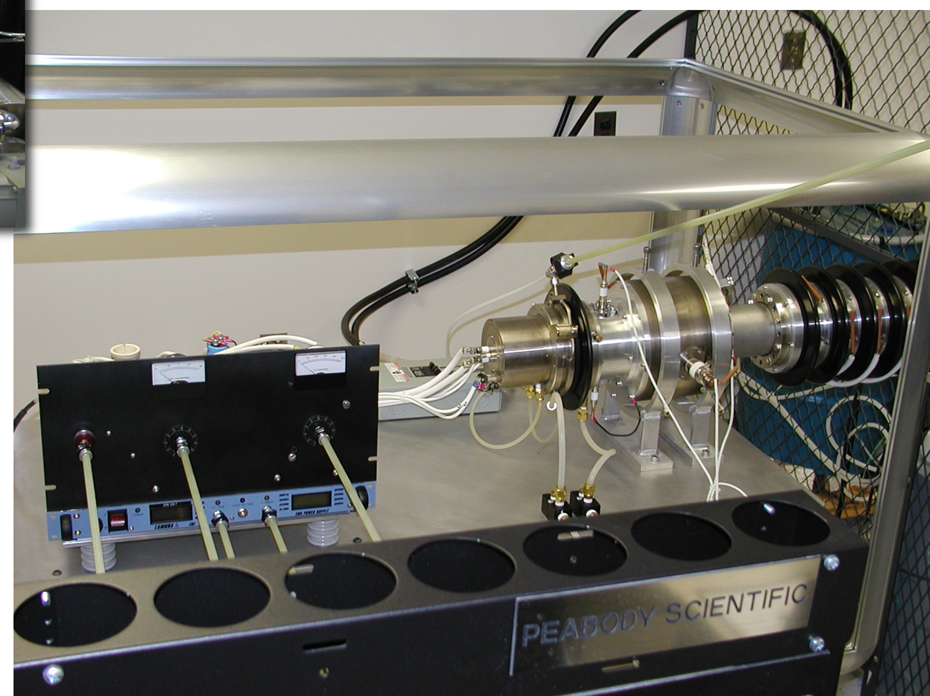
•All ions from a gas source

•Energy continuously tunable: 3 to 170 kV

•Wien filter

•Beam intensity between 10 and 10^{10} ions/ cm^2/s

•Purposed built articulation stage



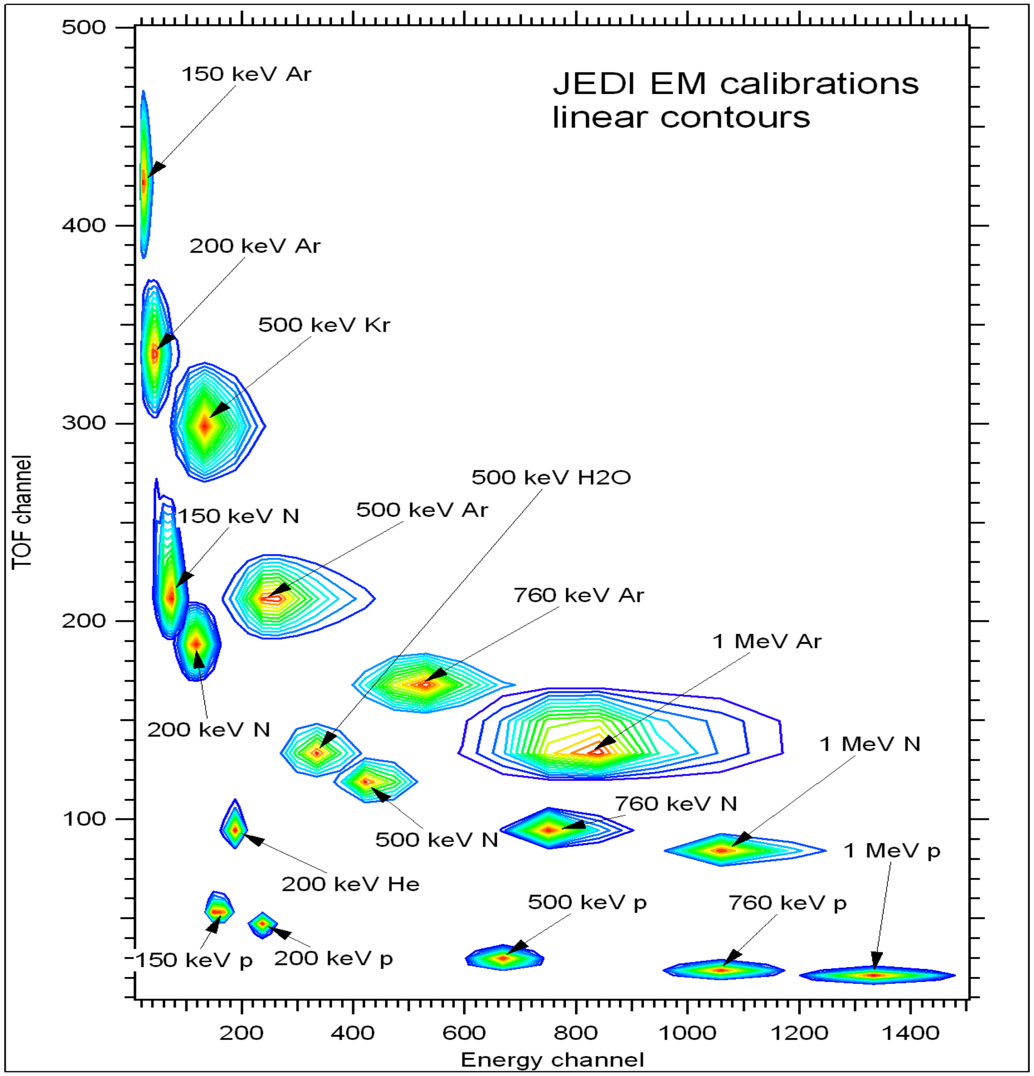
Beam Tests at GSFC

It is planned to have four calibration sessions at the accelerator at the Goddard Space Flight Center. Each session starts with a one-day setup, check, and pump:

- Session 1: Exploratory run to characterize EPI-Lo
- Session 2: Use H beam to scan both angles to complete characterization of the transfer function
- Session 3: Characterize sensor response with e- beam from ~100 keV to 1 MeV
- Session 4: Use heavy ions (He, O, and Ar) to characterize the instrument response

GSFC JEDI EM calibration results

Representative results from JEDI Cal.



EPI-Lo Test Summary

- Prototype "EM" Testing
  - Validate instrument design and performance
    - Energy response;
    - Instrument efficiency;
    - Instrument geometry factor
  - Establish testing procedures

- Flight Model (FM)
  - Verify instrument design and performance
    - Energy response;
    - Instrument efficiency;
    - Instrument geometry factor

Calibration Approach (Flight units)

- FM Unit
  - All instrument integration activities will be performed in a Class 5 clean room environment
  - Test in bell jar to characterize geometry, energy response, and sensitivity
  - Calibrate using particle sources and in Beam Facilities at APL to characterize energy response, sensitivity, dynamic range
  - Compare with EM results to cover gaps in energy coverage

- Test Philosophy:
  - FM will be extensively calibrated, and performance compared with more extended energy range EM calibrations (LBL, GSFC)
  - pre- and post-environmental qualification spot calibration
  - In-flight cross calibration between EPI-Lo and EPI-Hi

EPI-Lo Calibration Schedule

- Final calibration for FM slated for three weeks

- Major calibration efforts will be performed at APL facility
  - Substantial understandings of the instrument performance will be made with the EPI-Lo EM characteristics

Tests at Instrument Level

	Element	Property	Requirement*	Expected Performance	Calibration Accuracy
System Level	**Calibration mode without Collimator**	Energy-ToF plane characteristic	Verify simulation to 20%	Verify simulation to 5%	5%
		Input/output rate at system level	Known to 10%	Known to 2%	1%
		Background rejection	> 90%	> 95%	2%
		Mass resolution	Discriminate between $e^{=}$, H+, 3He+, 4He+, C, O+,	< 0.5 AMU (H+) < 1 AMU (CNO) < 2 AMU (Fe+)	0.5 AMU
		Absolute efficiency	Known 50% for $e^{=}$, H+, He+, CNO+	10%	10%
	Calibration mode with collimator	Scattering of ions	< 10%	< 5%	2%
		Scattering of electrons	< 10%	< 5%	2%
		Properties at octant boundaries	Known to 30%	Known to 5%	5%
		Efficiency as a function of entrance	Known to 20%	Known to 5%	5%
		Angular resolution	30°	25°	3°
		Geometric factor	> 0.05 cm^2-sr	0.061 cm^2-sr	0.01 cm^2-sr
		Full calibration: verify previous measurements			
	Flight mode	Input/output rate at system level	Known to 50% 30	Known to 10%	10%
		Verify all modes			
		Verify all timing windows			
		Throughput of event classification			
		Efficiency of counters			
		Energy-ToF plane characteristics			
		Threshold settings			
		Temperature dependent			

***Science requires relative/absolute accuracy: 20%/50%. Ground calibration 20% precision, reduced to 10% in flight.**

In-Flight Calibration

- On-orbit and cruise calibration achieves relative calibration to 10% precision
  - Uniformity confirmed by evolution of pitch angle distribution from onset to shock passage.
  - Such calibrations cover the entire energy and FOV coverage with linear instrument response (targeted rates, no pulse pileup)

- Built-in features to determine on-orbit instrument ion performance
  - Measure pulse-height spectrum of secondary electrons from incident protons as function of time-of-flight
  - Unit has built-in stimulus to inject known pulse through the front-end electronics

Summary

- Calibration plan satisfies all Level IV requirements
- Calibration facilities have been identified that meet EPI-Lo needs
- APL operates and maintains the key EPI-Lo calibration facility which allows maximum flexibility

Accuracy & Precision

Parameter	Required	Goal (Capability)	Comment/Heritage
Electron Energies	50 - 500keV	25 - 1000 keV	Electron capability from JEDI, RBSPICE
Ion Energies	50 keV/nucleon – 15000 keV Total E	40 keV/nucleon – 20000 keV Total E	Capability partially based on RBSPICE capabilities. Top energy ~250keV/nuc for Fe
Energy Resolution	45% for required energy range	40% for required energy range	Telemetry limited
Time sampling	5 sec	1 sec	Telemetry and/or statistics limited
Angle resolution	<30° x <30°	Ions, ~15° x 12° to <30° x <30° e-, 45°	Varies with elevation
Pitch Angle (PA) Coverage	0°-90° or 90°-180°, some samples in both hemispheres	0°-90° or 90°-180°, some samples in both hemispheres	
Time for Full PA	1 – 5 sec	1 – 5 sec	Telemetry limited
Ion Composition	H, He3, He4, C, O, Ne, Mg, Si, Fe	H, He3, He4, C, O, Ne, Mg, Si, Fe	He3/He4 ~50 to 1000 keV/nuc
Electron Sensitivity: I=Intensity (1/cm^2.sr)	j = 1E1-1E6/cm^2-s-sr	Sensor-G:0.144 (cm^2.sr) Pixel-G: ~0.02 (cm^2.sr) Up to 6E6 1/s counting	j=Intensity (1/cm^2-s-sr) G=Geom. Factor (cm^2-sr) 8 pixels/sensor
Ion Sensitivity	j = 1E1-1E6/cm^2-s-sr	Sensor-G:0.16 (cm^2.sr) Pixel-G: ~0.002 (cm^2.sr) Up to 3.5E6 1/s counting (TOFxE)	80 pixels/sensor