Solar Probe Plus

A NASA Mission to Touch the Sun

Integrated Science Investigation of the Sun Energetic Particles

Preliminary Design Review

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EPI-Lo Calibration

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Outline

- Overview
- 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[cm2 -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)

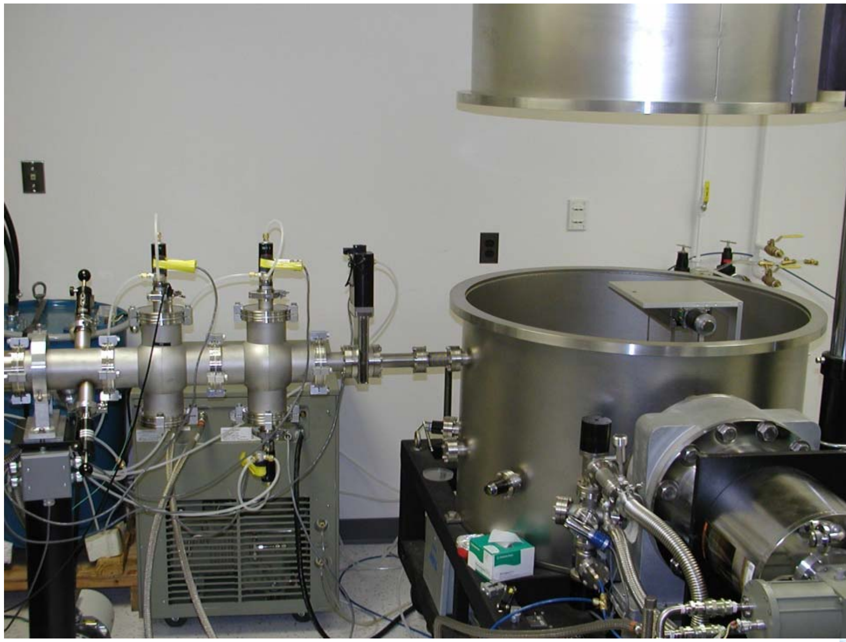
Background Calibration Requirement

- 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

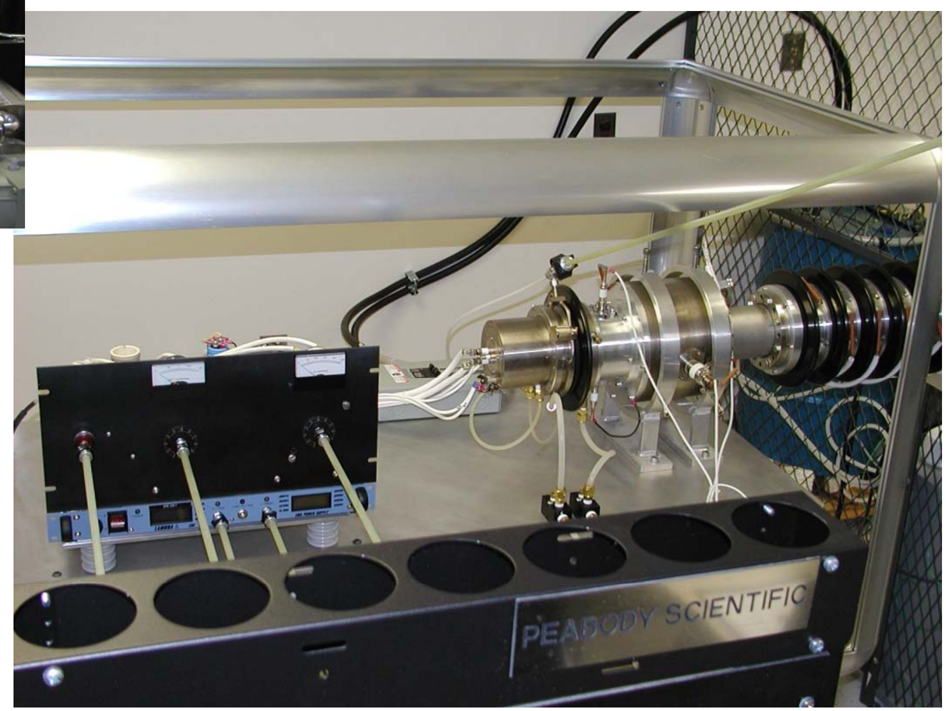
The JHU/APL Calibration Facility

- 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/cm2/sec at the target position (mm2 - cm2)
- 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 1010 ions/cm2/s
- Purposed built articulation stage



Beam Tests at GSFC

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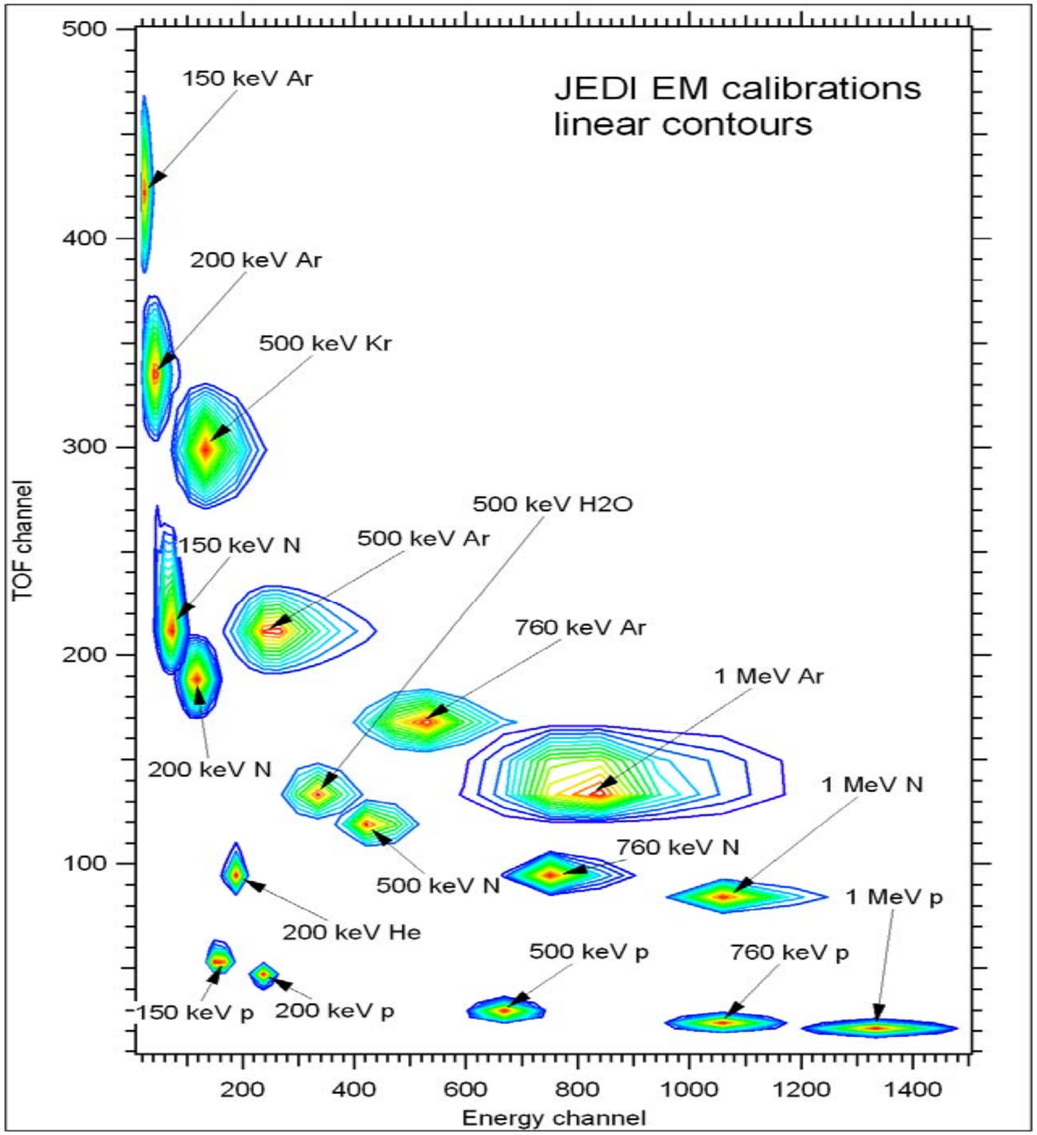
- It is planned to have four calibration sessions at the accelerator at the Goddard Space Flight Center. Each session starts with a one-day setup, check, and pump:
- Session 1: Exploratory run to characterize EPI-Lo
- Session 2: Use H beam to scan both angles to complete characterization of the transfer 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

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 understanding 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 to 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 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