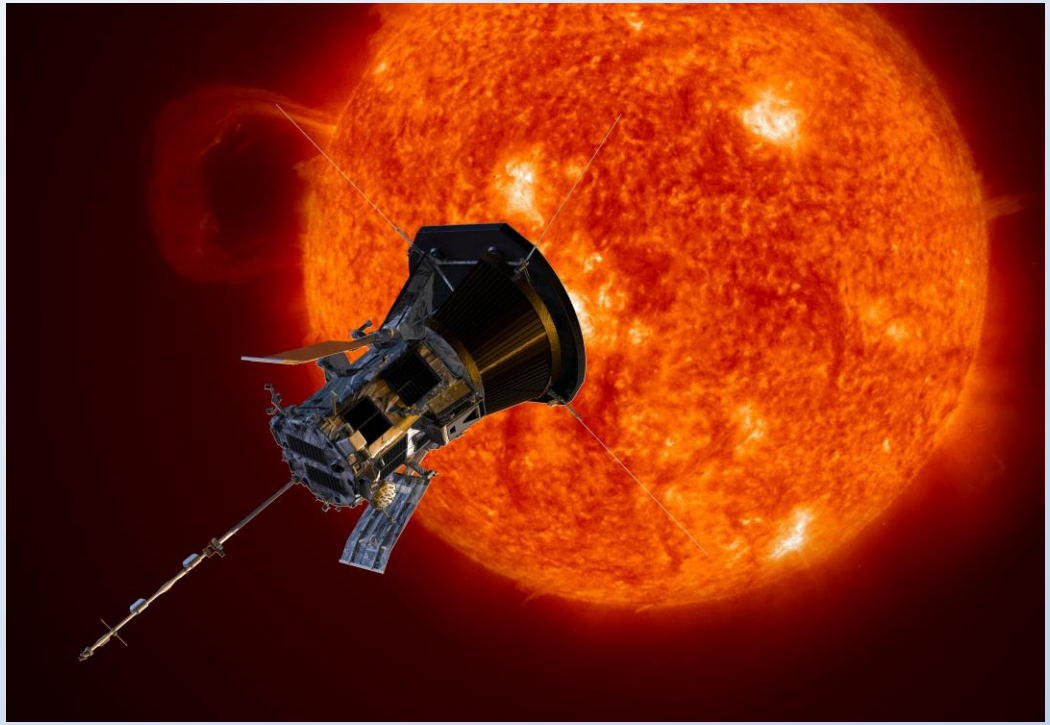
Credit: SA/Tony Case



Credit: NASA/Johns Hopkins APL/Steve Gribben

Environmental Testing of the Solar Probe Cup

K. H. Wright[1], T. A. Schneider[2], J. A. Vaughn[2], A. W. Case[3], J. C. Kasper[4]

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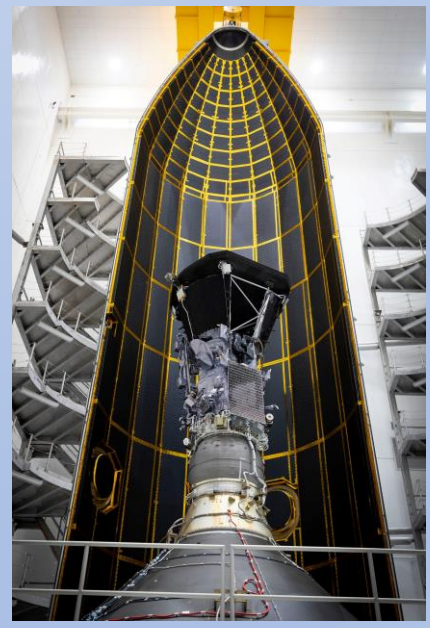
[4]BWXT, Inc.

Parker Solar Probe Mission

➢ Parker Solar Probe (PSP) Mission

- In the mid-1950s, Eugene Parker developed the theory for the solar wind
  - In 1958, the NRC Simpson Committee Report recommended a solar probe mission
- A key PSP mission goal is to study early evolution of the solar wind
- 4 hardware investigations: SWEAP, FIELDS, IS⊙IS, WISPR
- Launched on August 12, 2018 on a Delta IV-Heavy
- Nominal mission is 24 encounters with Sun at ever decreasing perihelion distance from 35.67 R_{sun} to 9.86 R_{sun}
  - 9 encounters to date with next perihelion on 11/21/2021 at 13.28 R_{sun}
  - No major issues with spacecraft or instruments



Credit: NASA/Johns Hopkins APL/Ed Whitman

SWEAP

➢ Solar Wind Electrons, Alphas, and Protons (SWEAP)

- Two types of instruments
  - Solar Probe ANalyzers (SPAN)
    - ✓ SPAN-A: ions (3D VDF + mass); electrons (3D VDF)
    - ✓ SPAN-B: electrons only (3D VDF)
    - ✓ Located behind spacecraft heat shield
    - ✓ UC-Berkeley heritage design - most recent flight on MAVEN
  - Solar Probe Cup (SPC)
    - ✓ Single Faraday Cup sensor outside the spacecraft heat shield looking sunward (1D VDF + energy-dependent flow angles)
    - ✓ electronics behind heat shield
    - ✓ MIT heritage design – AC operation
    - ✓ Flight history: Voyager I and II, Wind, DSCOVR
- Combined FOV of SPC and SPAN provides 100% coverage of proton core through out encounter phase of orbit

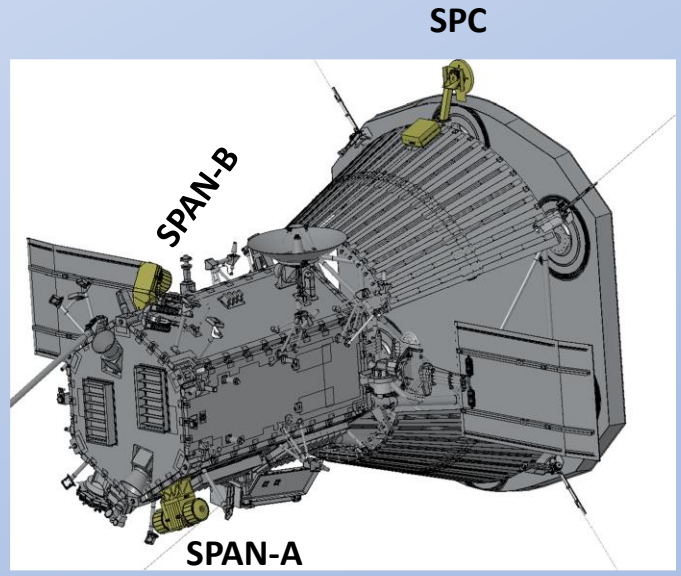


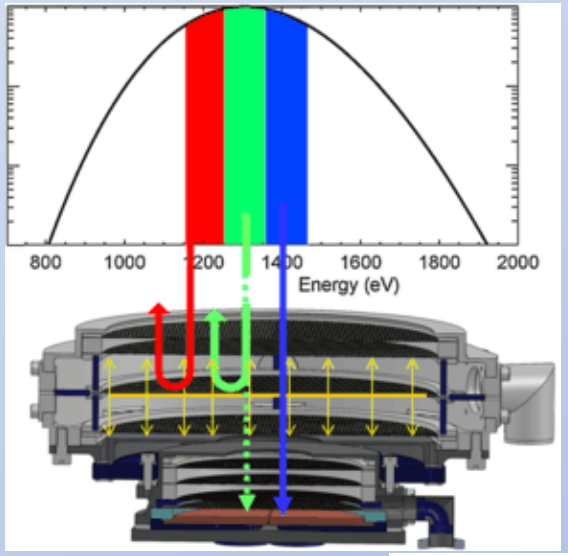
Fig. 12 in Kasper et al., Space Sci Rev, 204, 131–186 (2016). https://doi.org/10.1007/s11214-015-0206-3; open access

See Kasper et al., Space Sci Rev, 204, 131–186 (2016). https://doi.org/10.1007/s11214-015-0206-3 (open access) for details on SWEAP

SPC: Configuration & Operation

Configuration

- Sensor - Modulator section
- Sensor - Collector section
- Custom built Co-axial cables between sensor and electronics box
- 4-segment collector



Operation

- AC modulation of HV grid: HV up to +6 kV for ion mode and -1.5 kV for electron mode
- Suppressor voltage grid at -55 V
- Each signal from each collector plate has 4 gain ranges
- Various acquisition modes of energy, angle vs current that can be pre-programmed via ground command

See Case et al., ApJS, 246:43, 12pp (2020) https://doi.org/10.3847/1538-4365/ab5a7 (open access) for detailed SPC operational aspects

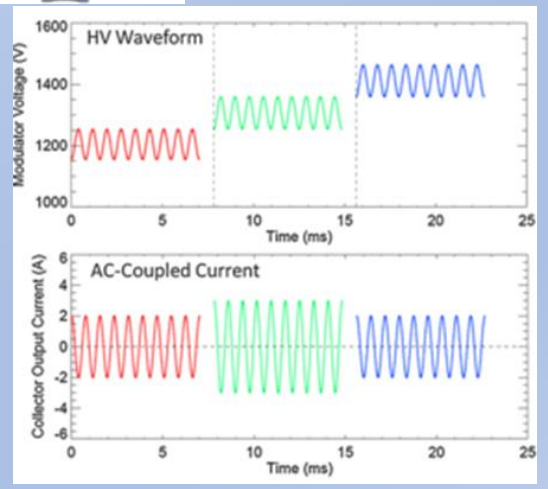


Fig. 14 in Kasper et al., Space Sci Rev, 204, 131–186 (2016). https://doi.org/10.1007/s11214-015-0206-3 ; open access

SPC: Development Approach

➢ Materials

- At closest perihelion, solar flux ~ 520 times that at 1 AU
- High temperature materials and novel construction required for success
  - Properties vs temperature: strength, CTE, thermo-optical, etc.
    - ✓ Consulted MSFC high-temp database
    - ✓ High-temperature thermo-optical properties derived from sample testing at the PROMES solar furnace in France
  - Housing - Molybdenum TZM, grids - tungsten, collector plates, wire and tubing for ICA, heat shield - niobium, insulators - sapphire
- Thermal modeling
  - Many iterations on modeling

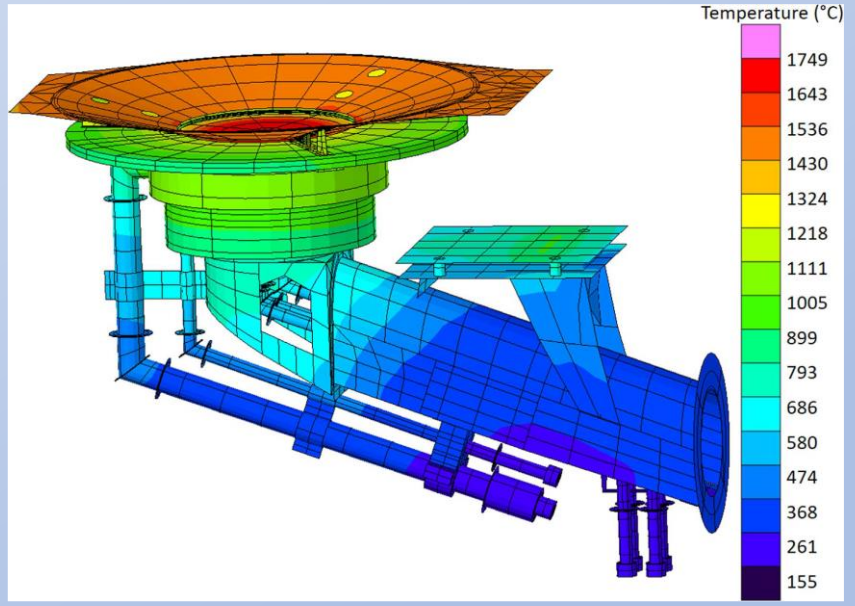


Fig. 2 in Case et al., ApJS, 246:43, 12pp (2020). https://doi.org/10.3847/1538-4365/ab5a7b reproduced by permission of the AAS

SPC: Development Approach

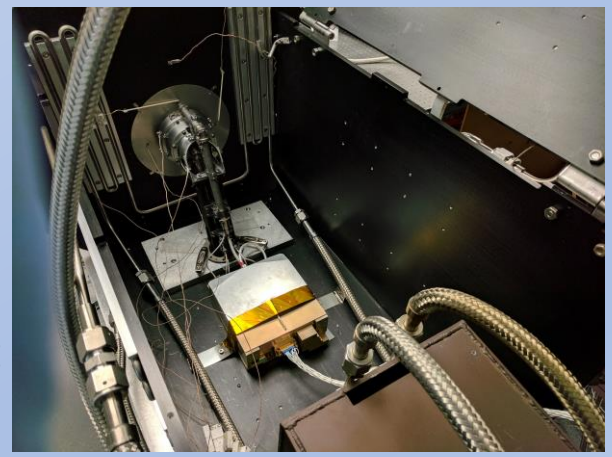
- **Testing**
  - Component and various sensor build model testing
  - Solar Environment Simulator (SES) at SAO
    - High fidelity photons from Xenon arc lamps
    - Off-axis Li ion gun to stimulate sensor while hot
  - Solar Wind Facility (SWF) at MSFC
    - High fidelity ion and electron sources
  - Thermal Vacuum (TV) chamber at MSFC
    - Quartz lamp configuration + cold plate to impose thermal gradient across sensor and repeat over several cycles

SES: Solar Environment Simulator

- **Facility**
  - Located at Harvard/SAO
  - Four 6.5 kW Xenon arc lamps
  - Various water-cooled optics to manage light beam size
  - Water-cooled window on vacuum chamber
  - Water-cooled beam block inside chamber
  - 13 deg illumination angle on target
  - Net output < 500 Suns
  - Off-axis Li ion source

Credit: SAO/Tony Case

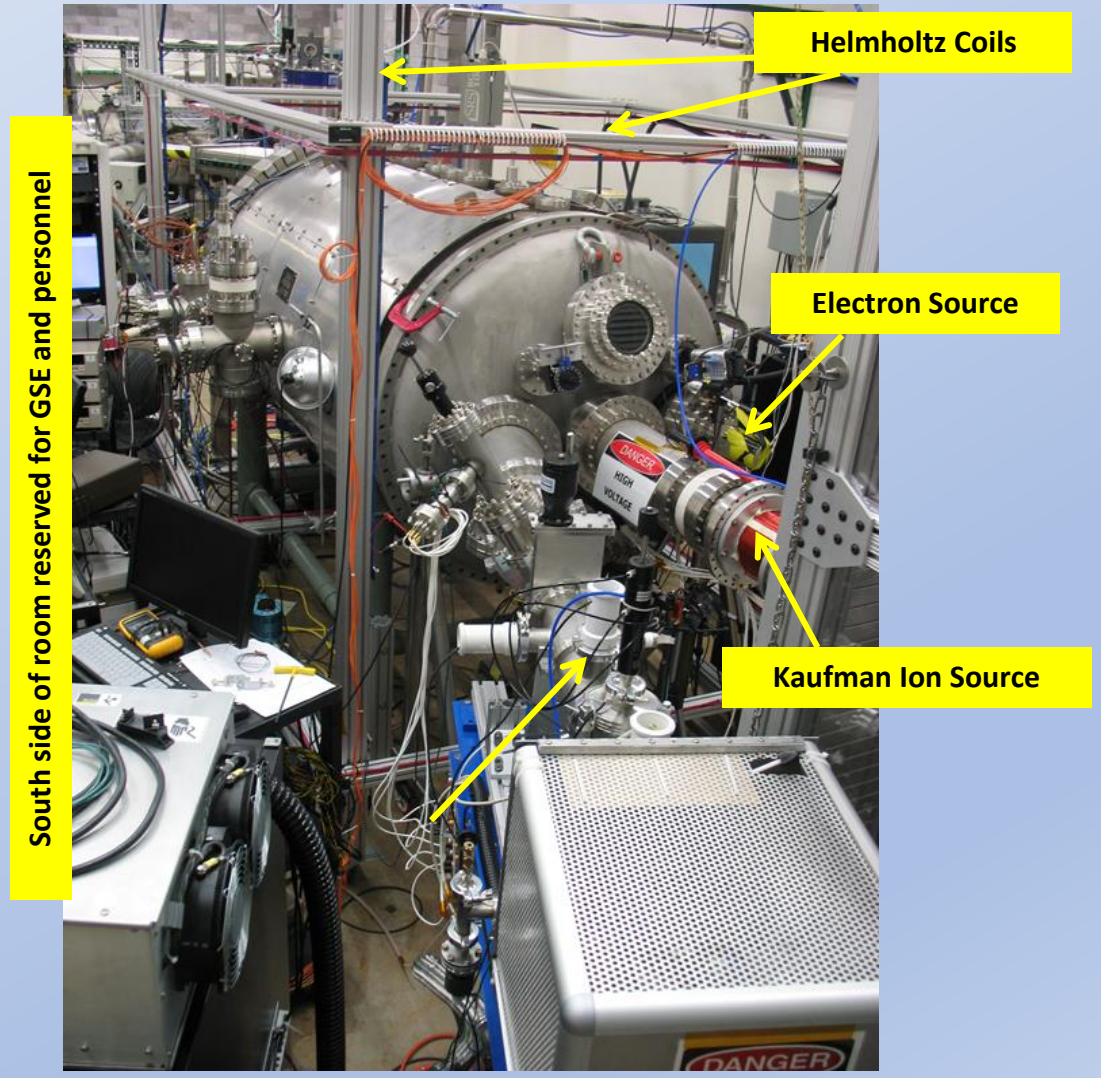
Qual Model SPC ready for test



Credit: SAO/Tony Case

SWF: Solar Wind Facility - MSFC

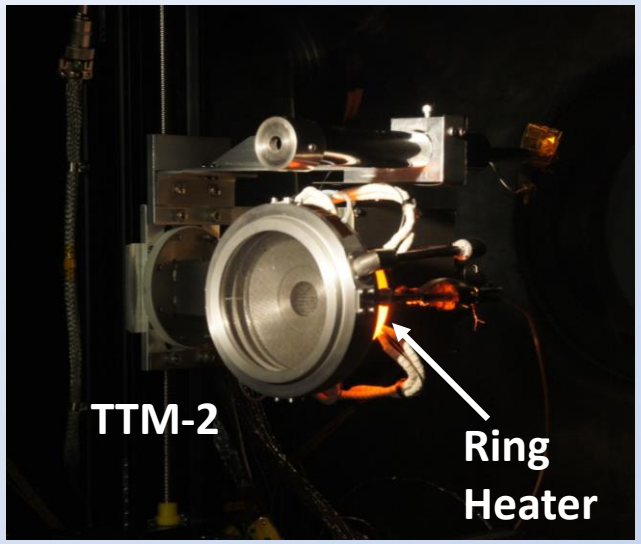
- **Facility**
  - 2.72 m long by 1.23 m inner diameter (shroud)
  - Oil-free roughing and high-vacuum cryopumps.
  - 2-D linear stage system and rotational stage
  - Broad-beam electron source, broad-beam ion source, and pencil-beam ion source.



Credit: NASA/MSFC/Todd Schneider

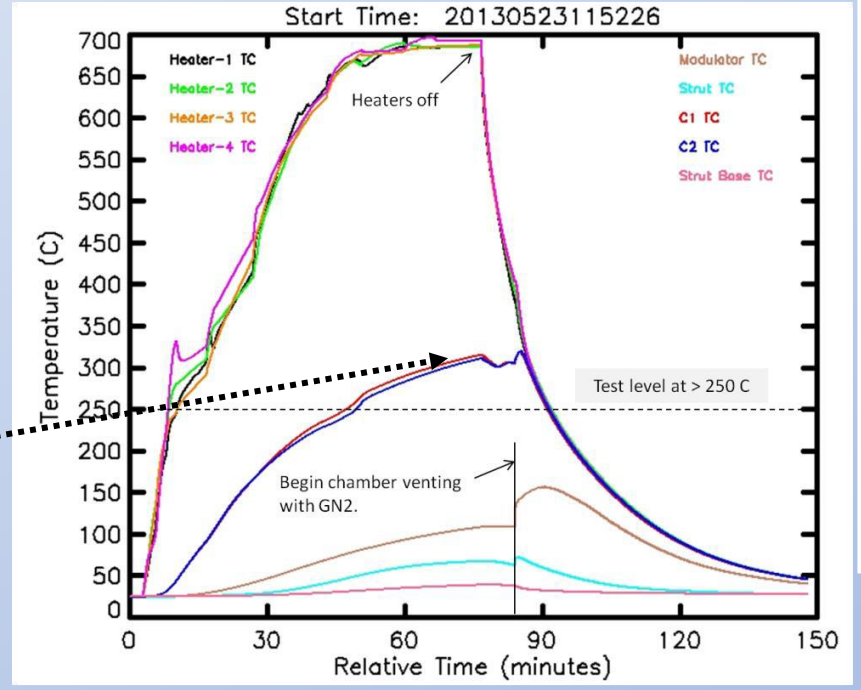
SWF: Solar Wind Facility

- **TRL-5 Test with Thermal Test Model (TTM)**
  - Verify that collector is not influenced by temperature



Credit: NASA/MSFC/Todd Schneider

Collector temperature



TTM exposed to ion beam

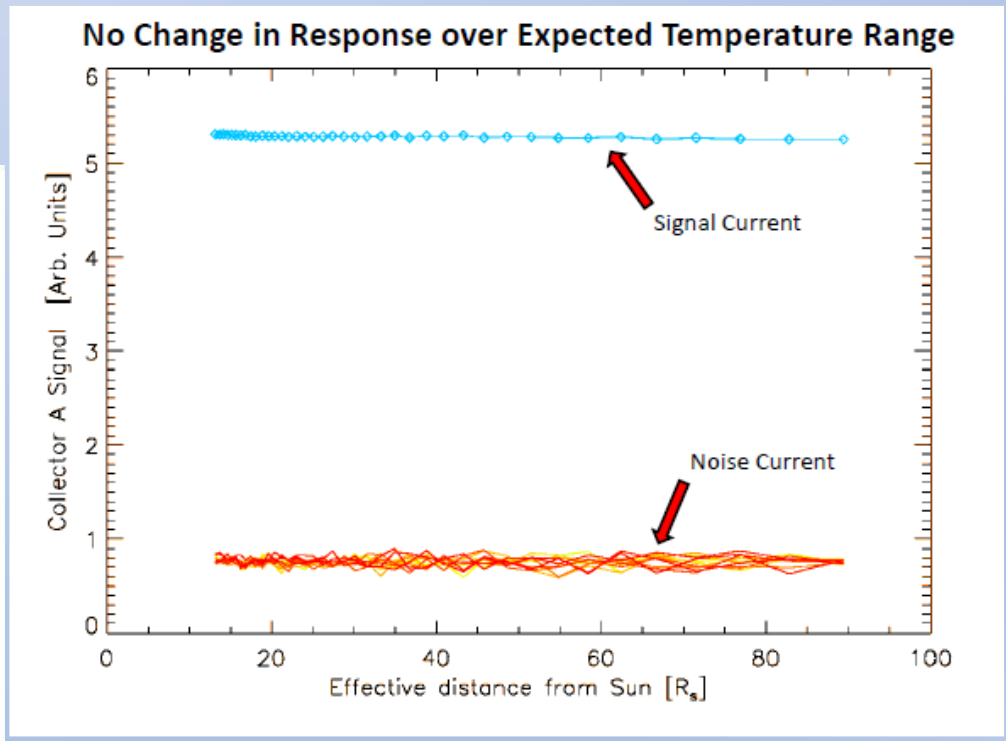
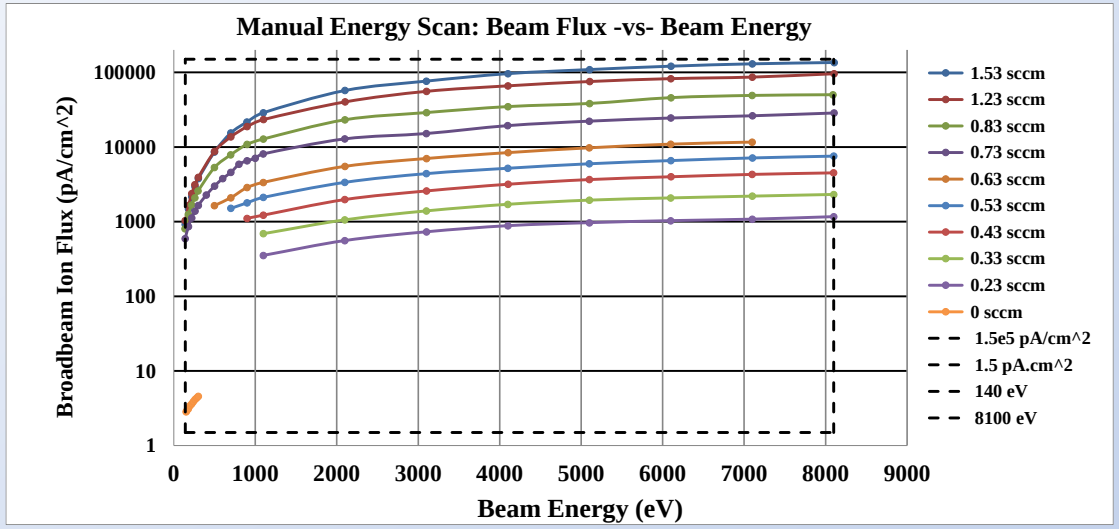


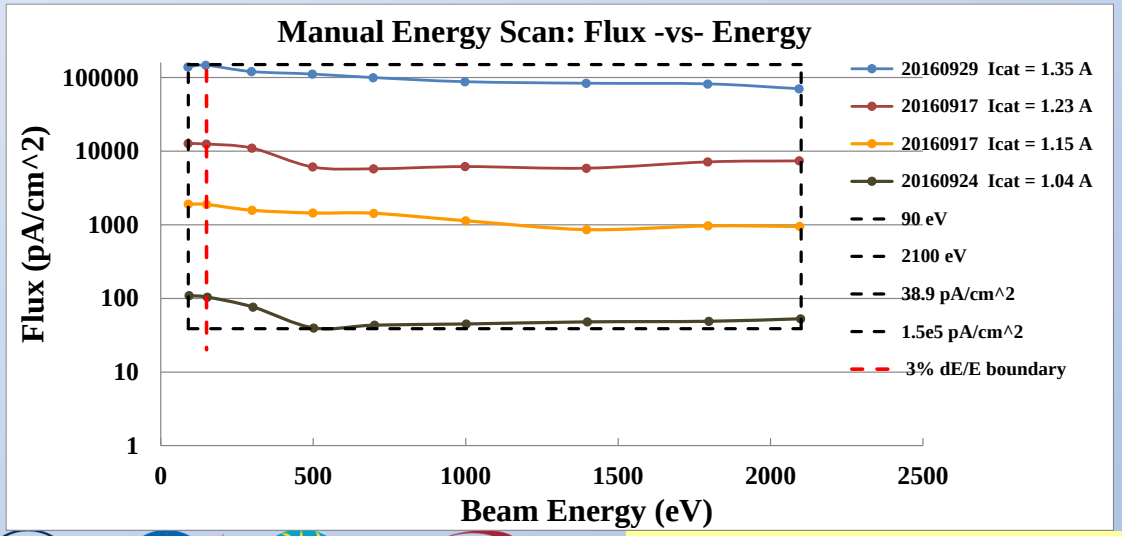
Fig. 23 in Kasper et al., Space Sci Rev, 204, 131–186 (2016). https://doi.org/10.1007/s11214-015-0206-3 ; open access

SWF: Solar Wind Facility

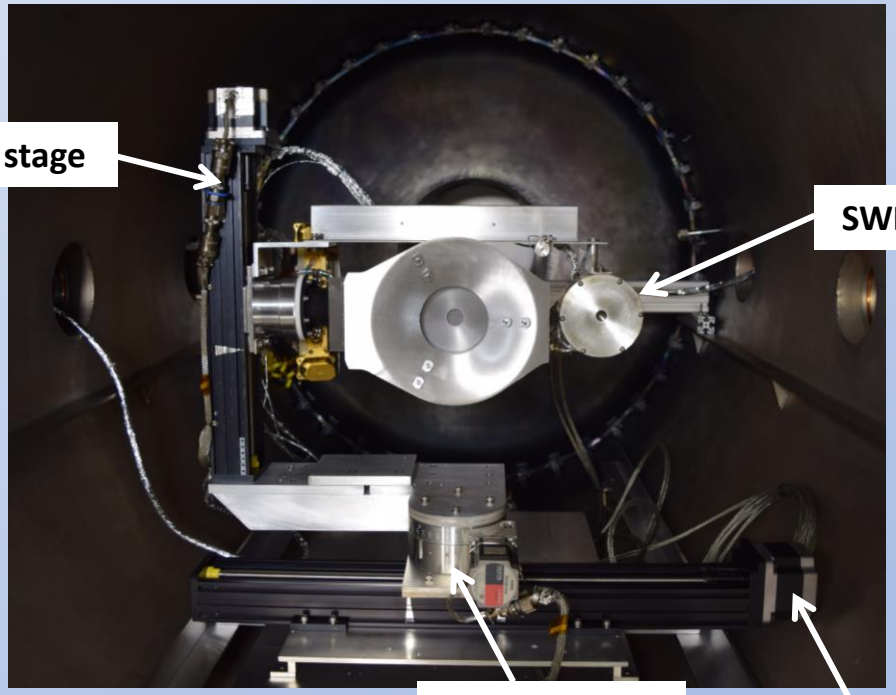
Kaufman Ion Source: Argon



Electron Source



Flight Model SPC in SWF

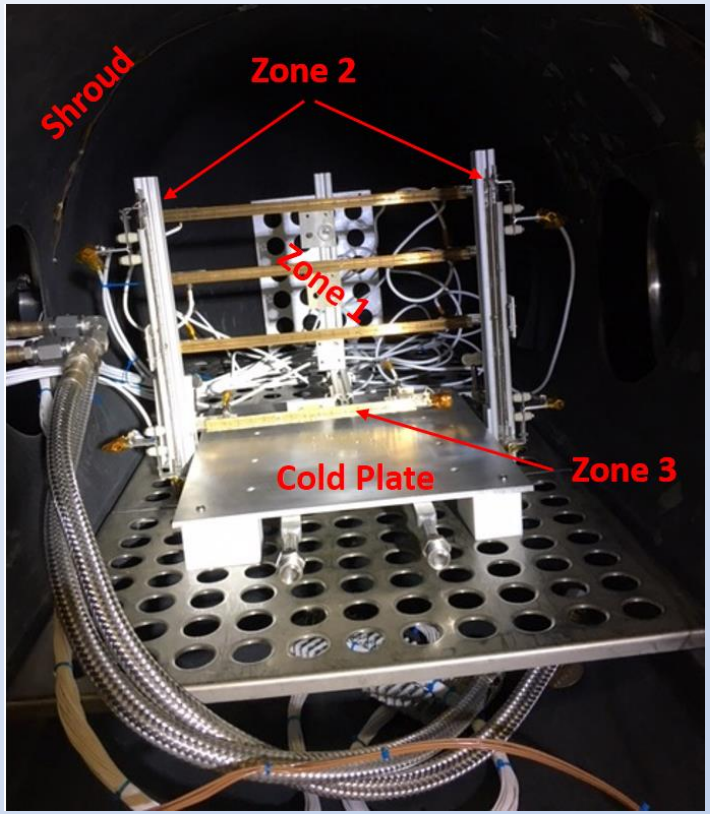


Credit: NASA/MSFC/Todd Schneider

- Various automated energy, flux, angle scans performed to exercise SPC operational modes
- H^+ beam used for FM SPC

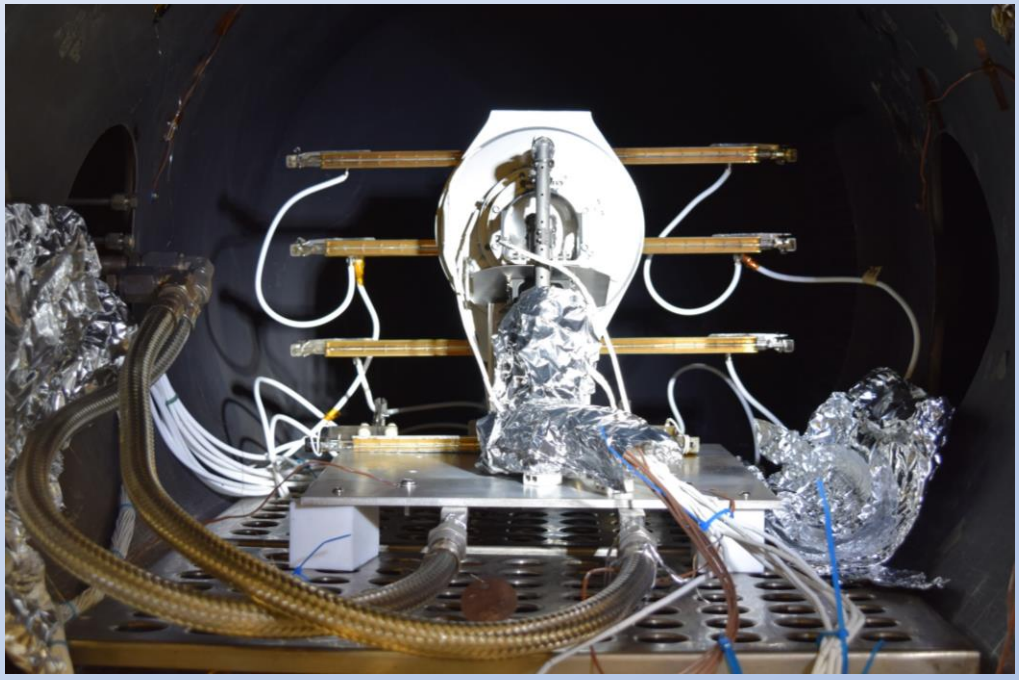
MSFC Thermal/Vacuum Test

3 quartz lamp arrays + cold plate



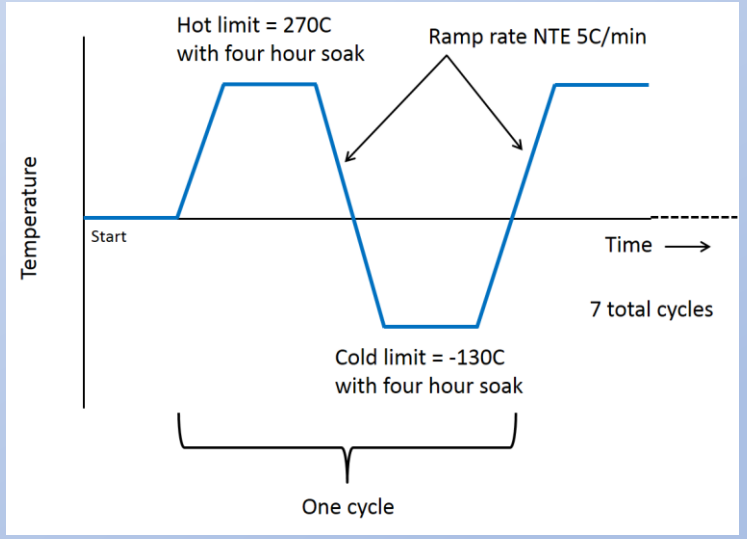
Credit: NASA/MSFC/Todd Schneider

Various thermocouples (TCs) mounted on sensor with TC1 on sensor base



Credit: SAO/Tony Case

Thermal profile: TC1



Isolation measurements:

- **Between each pair of collector plates**
- **HV cable center-to-shield**
- **LV cable center-to-shield**

Flight Data

- **In-Flight Calibration**
  - Performed on approach to Venus
- **Notable early results**
  - Proton velocity enhancements
  - Switchbacks in magnetic field

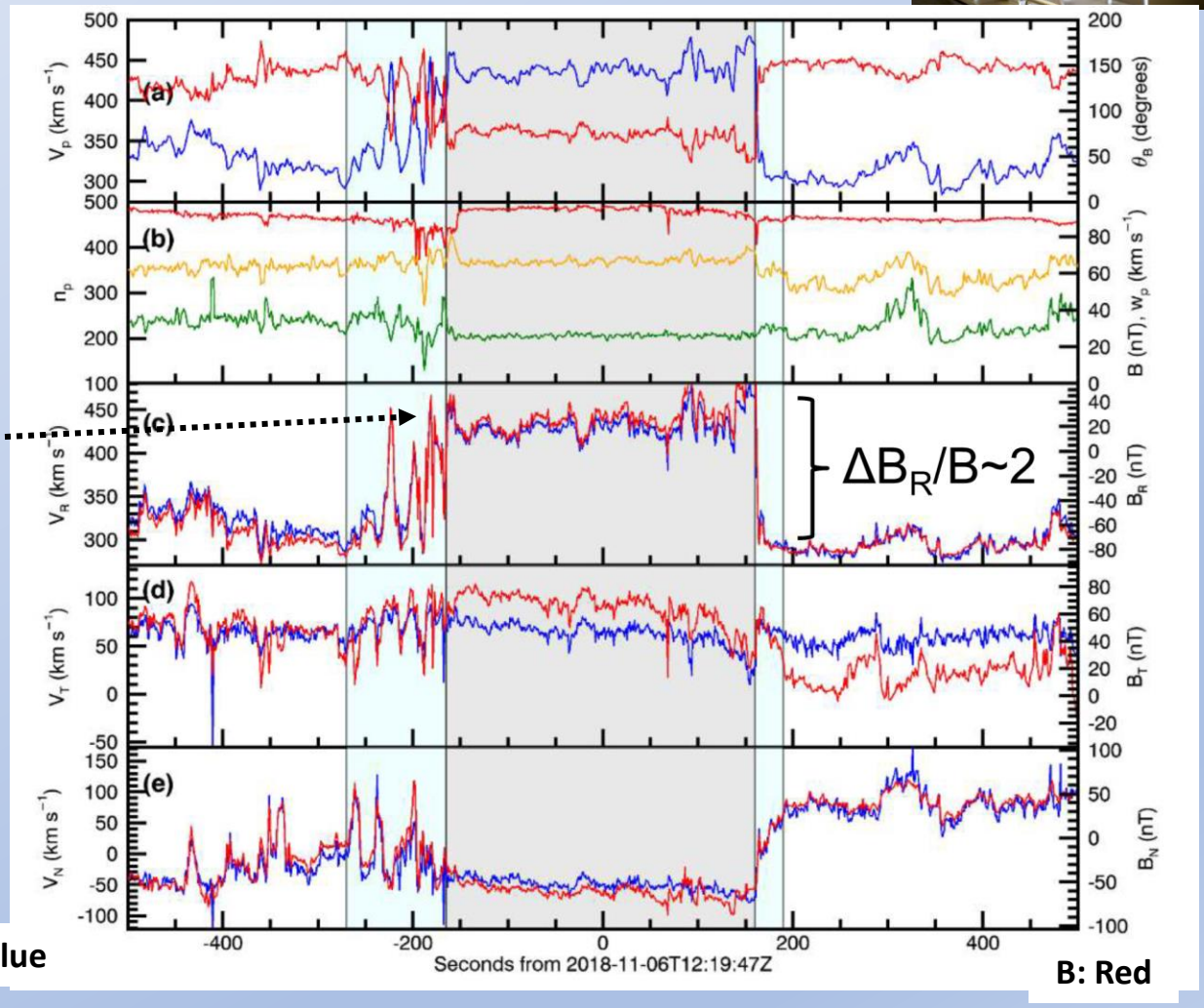
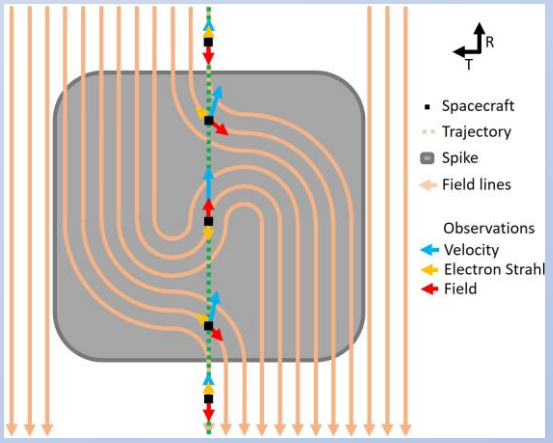


Fig. 2 in Kasper et al., Nature 576, pp 228–231 (2019). https://doi.org/10.1038/s41586-019-1813-z



Extended data Fig. 2 in Kasper et al., Nature 576, pp 228–231 (2019). https://doi.org/10.1038/s41586-019-1813-z

Summary

- **Rigorous Development Plan for SPC**
  - Unprecedented environment for the sun-facing SPC
  - Extensive material research and testing
  - Numerous tests performed in SES and SWF with various sensor builds to verify sensor operation in expected thermal and charged particle environments
  - Extensive thermal model informed by SES testing
- **Reward**
  - **SPC performing as designed returning new in situ data from a previously unexplored region of the heliosphere!**

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