14 Years of Spacecraft Charge Monitor Development

Luke Goembel

Goembel Instruments

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Spacecraft Charging Facts

- “The largest cause of mission failures related to the space environment is surface ESD.” [Koons, et al., 1999.]
- 200 annoying to serious and 10 critical operational anomalies due to electrostatic surface discharge are expected over the lifetime of a S/C in GEO. [Wrenn, et al., 1993.]

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Why should we monitor S/C charging?

- Mission Safety - placing S/C in safe mode
- Post-Failure Analysis
- Evaluate charging mitigation techniques
- Study the S/C charging phenomenon

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Monitoring Spacecraft Charge

- Few S/C are equipped with charge monitors
- Why don't we have more?
  - Uncertainty?
  - Denial?
  - Ignorance?
- What is the cost/benefit analysis of placing monitors on S/C?

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Methods Currently Used to Measure Spacecraft Potential			
Instrument	**Method**	**Major Limitations**	**Comments**
Double Probe	Spacecraft Electric field measured by potential difference between two probes mounted on booms	Biases due to changes in probe work function, probe photoemission, etc. Booms needed [Maynard, 1998]	**100 Meter Boom**
Langmuir Probe	Volt-Ampere characteristic of probe immersed in space plasma is measured	Biases due to changes in probe work function, magnetically induced probe potentials and so on [Brace, 1998]	**Will not work in GEO**
Retarding Potential Analyzer (RPA)	A current voltage curve from instrument is analyzed to determine ion drift velocity	Biases due to uncertainty in expected ion drift for spacecraft at zero potential. [Anderson, 1994]	**Will not work in GEO**
Ion Energy Analyzers	Ion Spectra of space plasma are analyzed for 'low energy cutoff'	Biases due to uncertainty in the 'low energy cutoff' from such measurements [Moore, 1996]	**Crude and slow as done today**

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Today…

- **‘Commercial off-the-shelf’ devices for monitoring charge do not exist**
- **Spacecraft charge has only been measured with unwieldy, one-of-a-kind, multi-million dollar, mission specific instruments**
- **Existing charge monitors return data of questionable accuracy and reliability**

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Spacecraft Charge Monitor (SCM)

- **14-year development effort…**
- **Far superior to anything that has flown before…**

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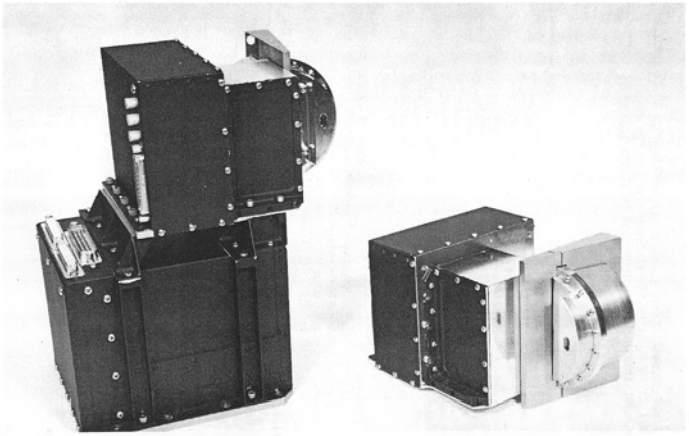
Pre-History of the SCM

- The Photoelectron Spectrometer (PES) Experiment on the Atmosphere Explorer satellites (1970's)



PES

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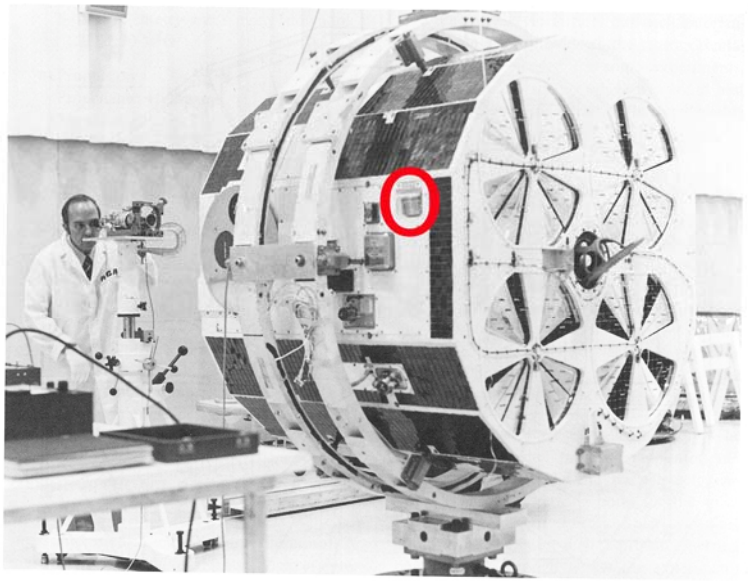

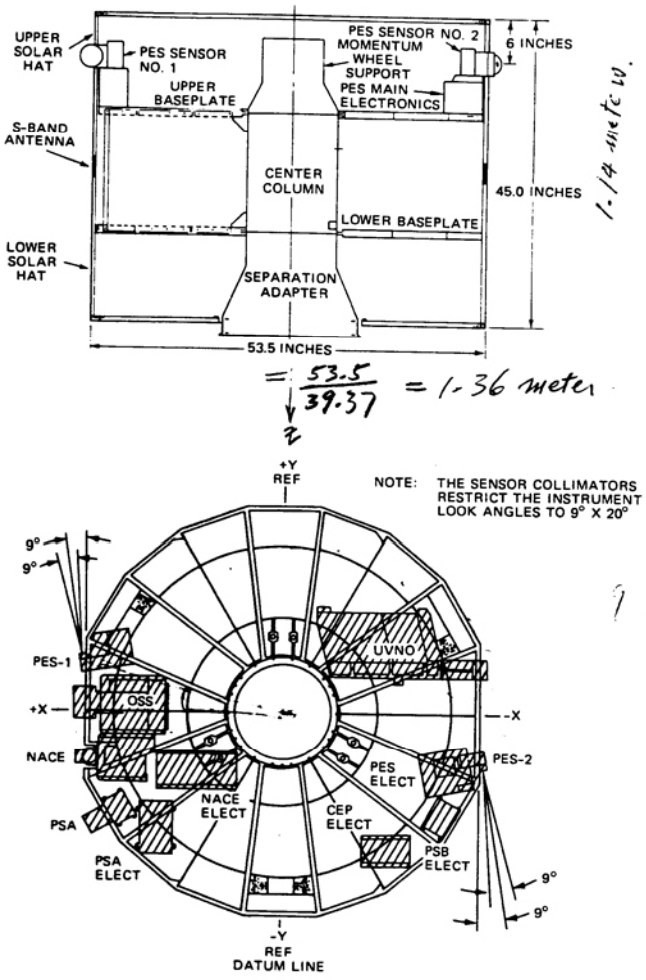

Fig. 1 LOCATION OF THE PHOTOELECTRON SPECTROMETER ON THE ATMOSPHERE EXPLORER-C UPPER BASEPLATE

PES (1970's)

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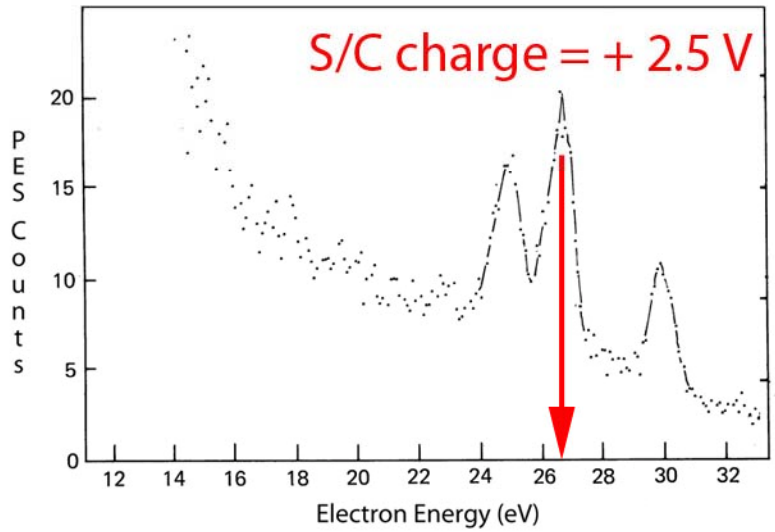

PES Charge Sensing

'Electron-spectroscopic Method'

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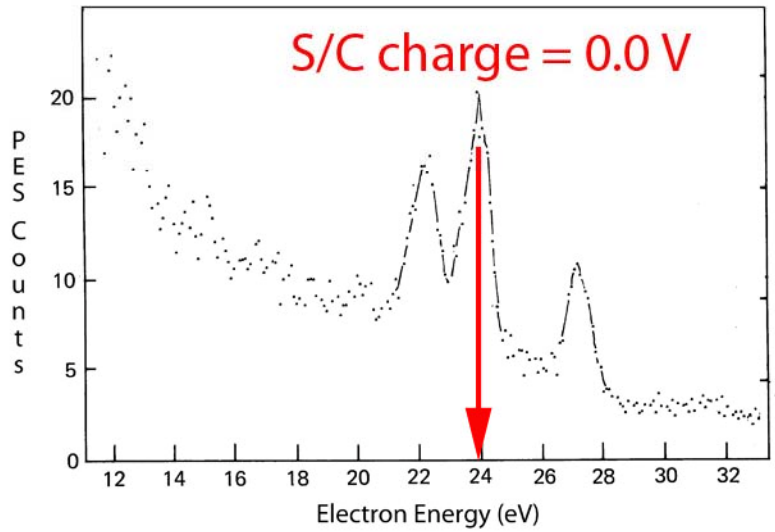

PES Charge Sensing

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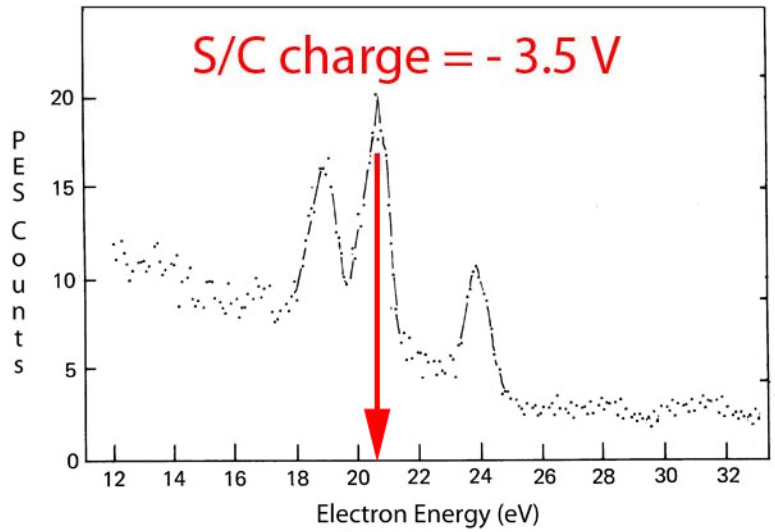

PES Charge Sensing

'Electron-spectroscopic Method'

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Goals for Goembel Instruments

- PES gathered data slowly
- A major goal for Goembel Instruments was to monitor charge more rapidly and accurately
- A fundamental design change to PES was needed

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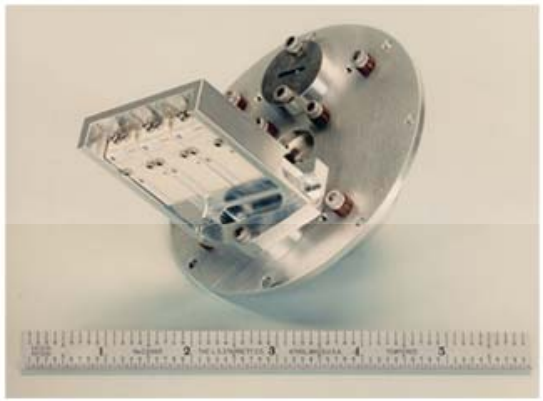
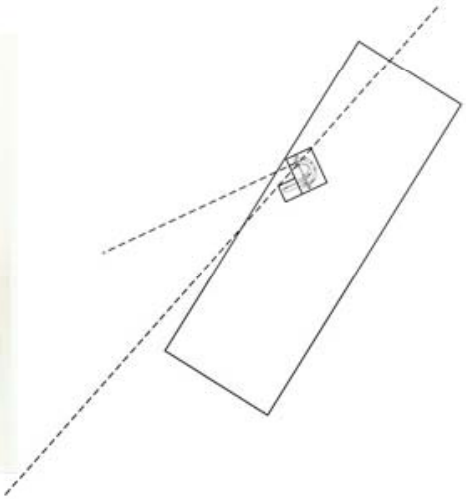
First Attempt at SCM (1996)

- Started at APL
- **3 times better than PES**





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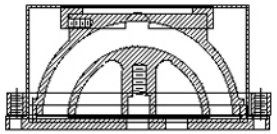
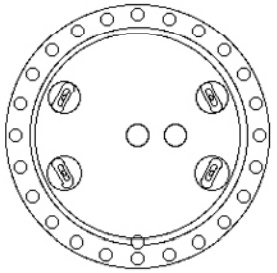
Second Attempt at SCM (1997)

- Addition of another aperture
- **6 times better than PES**





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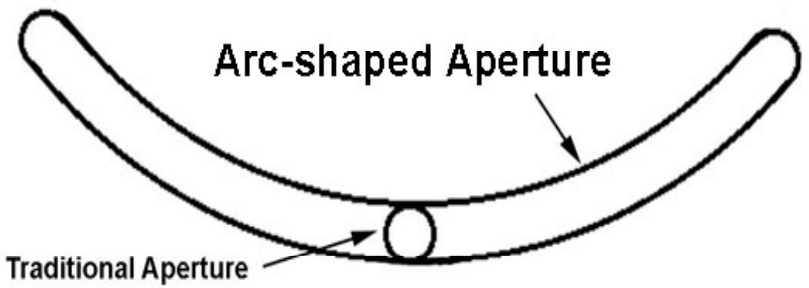
Third Attempt – A Breakthrough!

- If two apertures worked - why not more?



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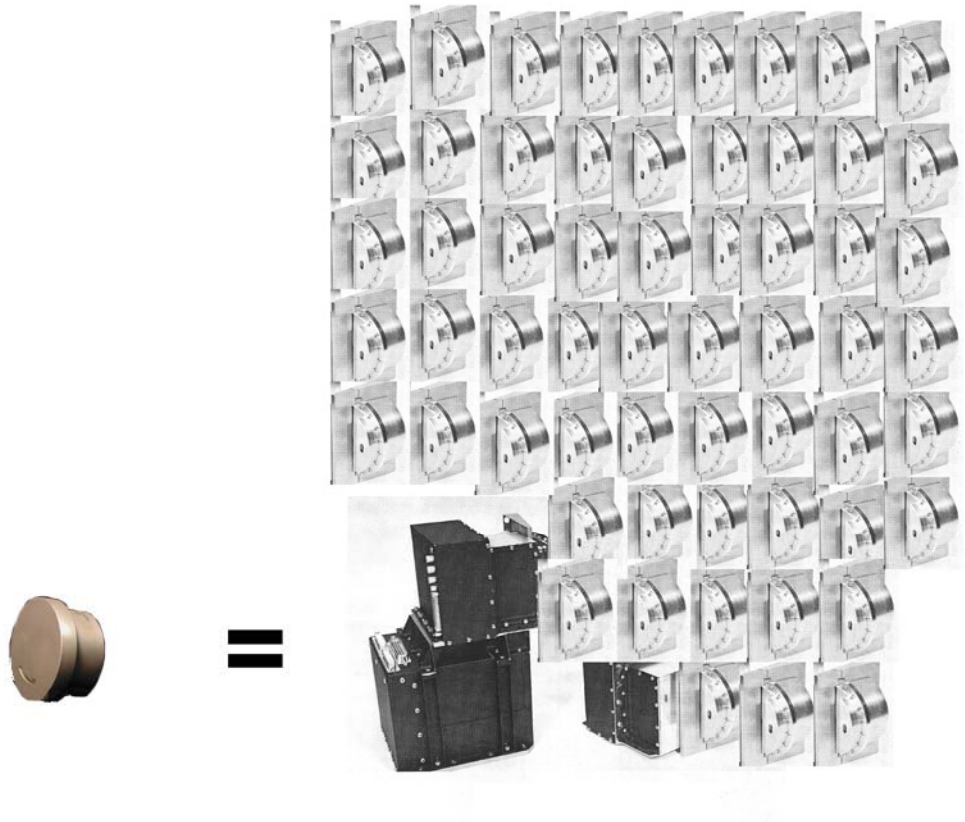
New design is 60 times better than PES!



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Applied for Patent in 2001

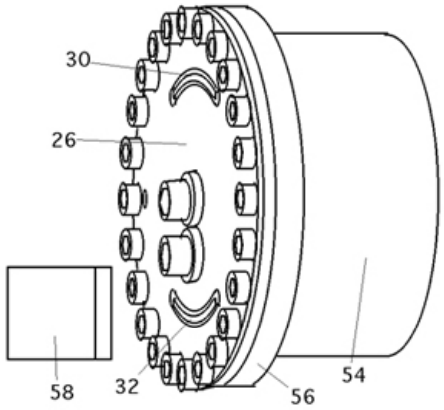

FIG. 1

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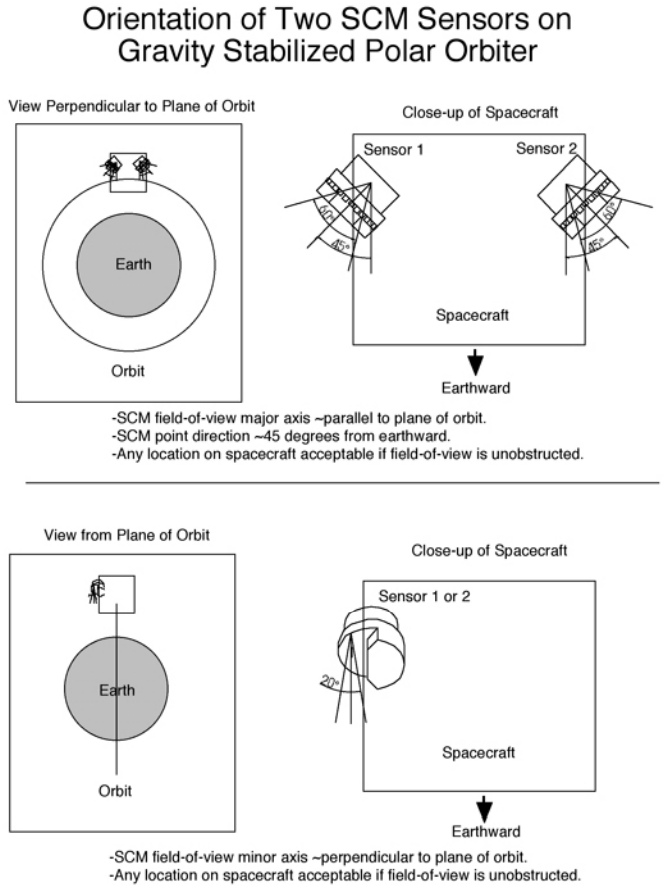
AFRL proposed using SCM on NPOESS in 2001



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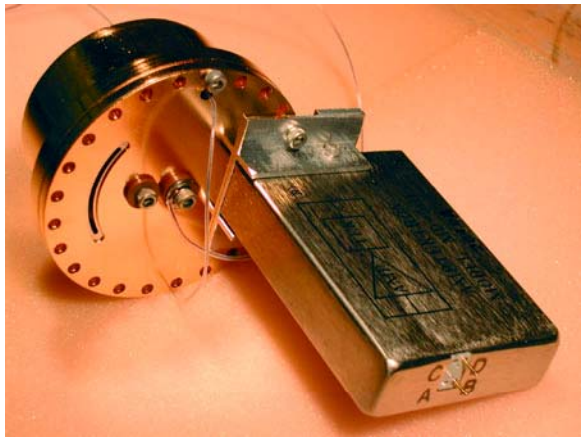
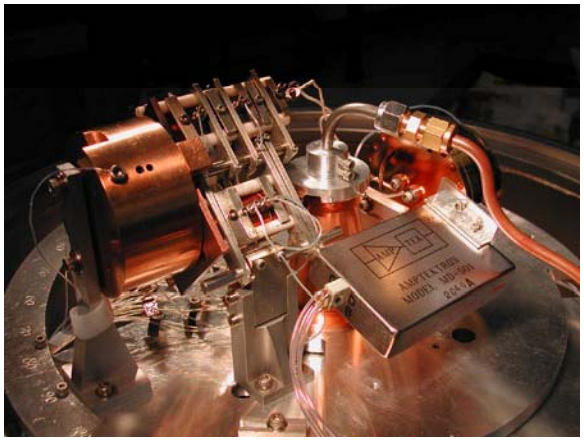
Lab Prototype SCM 2001-2





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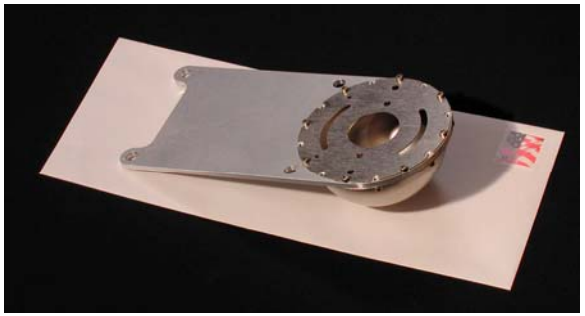
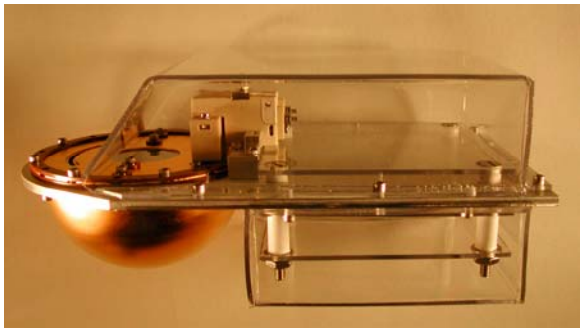
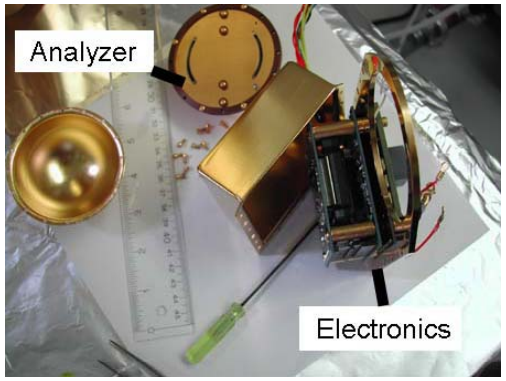
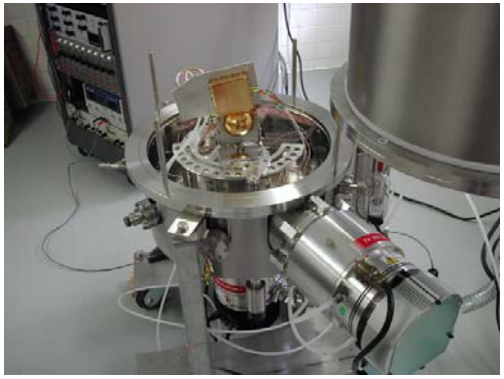
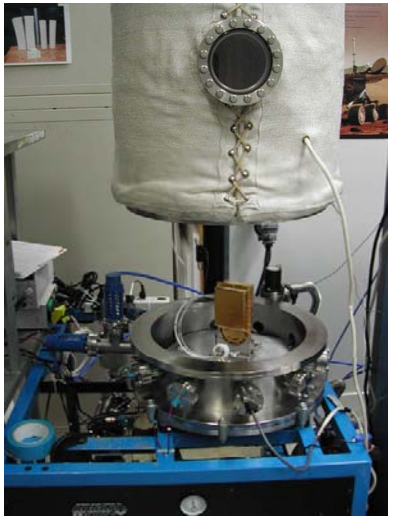
Flight Version SCM 2002-6











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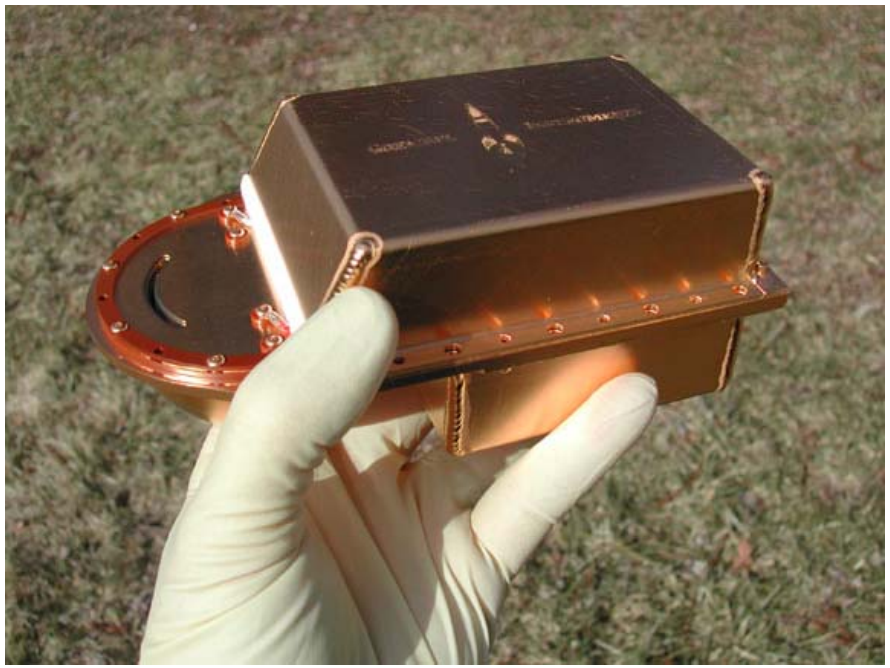
SCM Delivered 2006

- 650 grams
- 2 watts
- FPGA on board
- RS422 S/C interface
- Ready to fly today!



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SCM-2

- **2007-2009**
- Goembel Instruments was asked to design a charge monitor for GEO
- SCM-1 is for minor charging (+/- ~100V)
- Charging up to -10,000V expected in GEO
- SCM-2 is a modified SCM-1 for GEO

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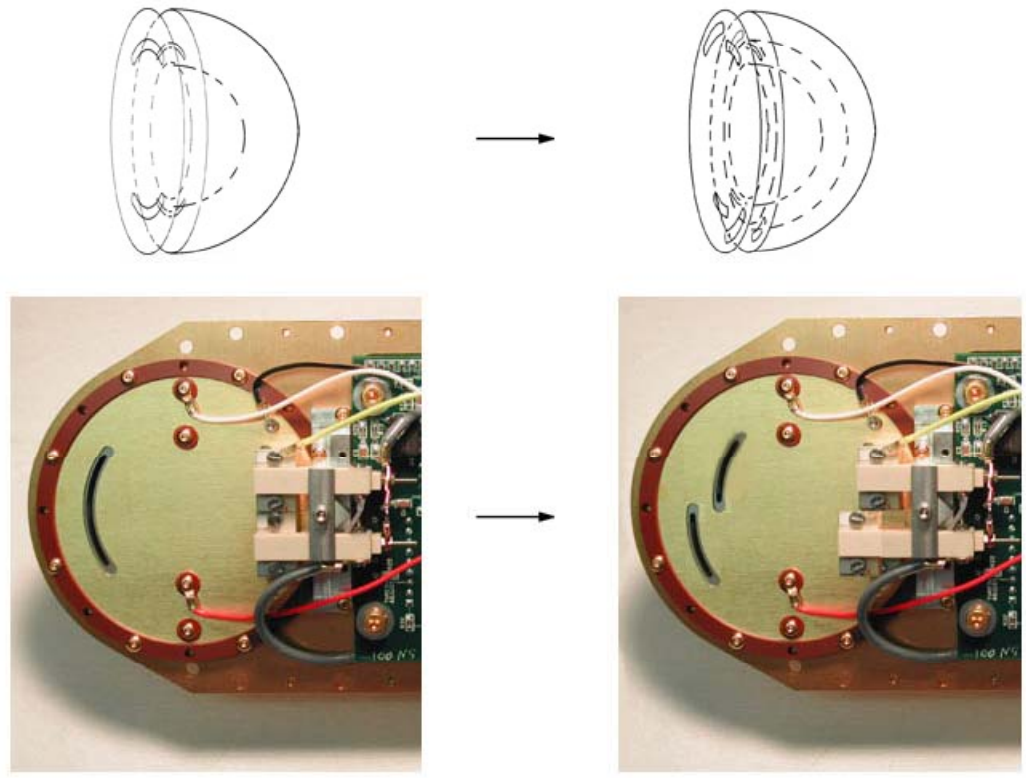
SCM-2

- **Two charge monitoring methods**
  - **Electron-Spectroscopic**
  - **Low Energy Ion Cutoff**



SCM-1 SCM-2

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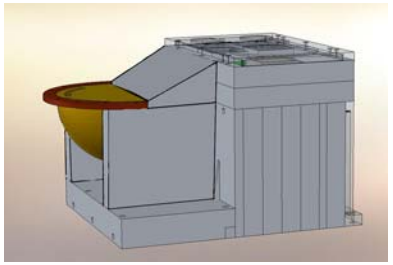
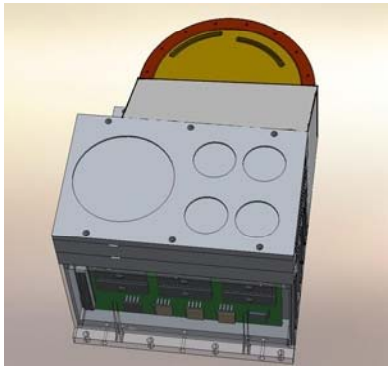
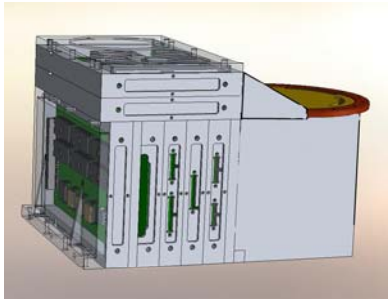
SCM-2







- Chosen by both prime contractors for their proposals to build DoD's TSAT in early 2009
- TSAT program cancelled in Spring 2009
- Development of SCM-2 continued into Fall 2009

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SCM-2 Performance

- Accurate, No Calibration Drift, No Booms Needed
- Compact: ~1kg, 2W
- Determine charge +500 to -10,000 volts
- Two methods used to validate measurements within 5% under all conditions
- Determine charge ~ once a minute

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SCM-3

- 2010
- Not for monitoring charge
- Spin-off of previous SCM technologies
- Designed to monitor solar wind
  - Speed
  - Direction
  - Temperature
  - Density

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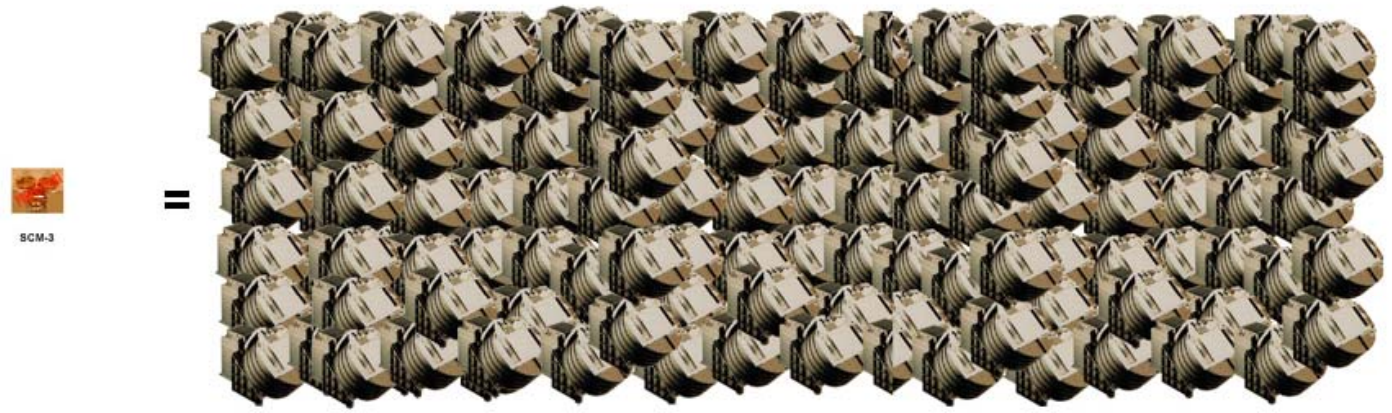

1 SCM-3 = 600 ACE SWEPAM-I

SCM-3 is 600 times better than the instruments used today to monitor the solar wind!

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Conclusions

- Over the last 14 years, Goembel Instruments has developed innovative spacecraft charge monitoring technology
  - **Outperforms Current Spacecraft Charge Monitoring Options**
  - **Costs are significantly less due to the minimal overhead and focused development of Goembel Instruments**

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Next Steps Ahead…

- SCM-2, for high level charging in GEO, is awaiting funds to be built
- **SCM, for accurately monitoring low level charge, is ready to fly today!**

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Thank You

For More Inquiries Please Contact

Luke Goembel

luke@goembel.biz

www.goembel.biz