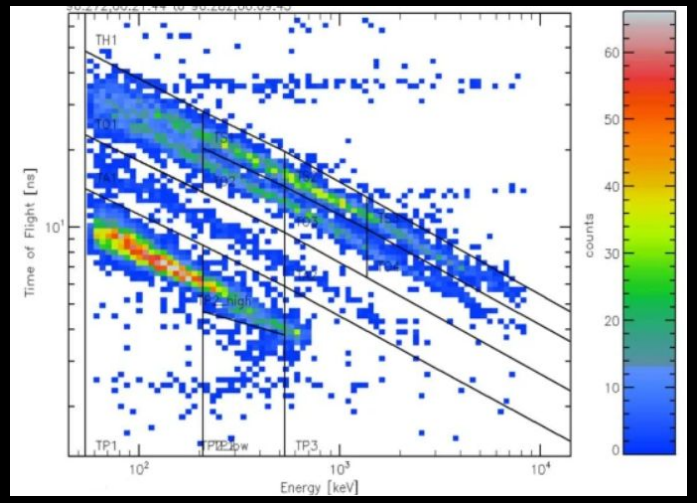
What it Took to Get These Measurements: An Engineer's Perspective

EPD: Energetic Particle Detector

Steve Jaskulek (EPD System Engineer)



Energetic Particle Detector (EPD) Science Overview

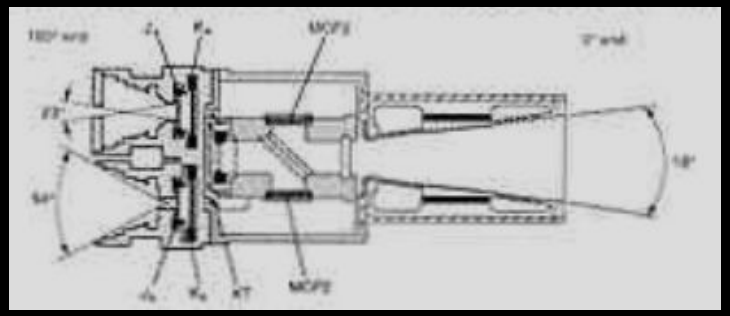
The main scientific goals of EPD were:

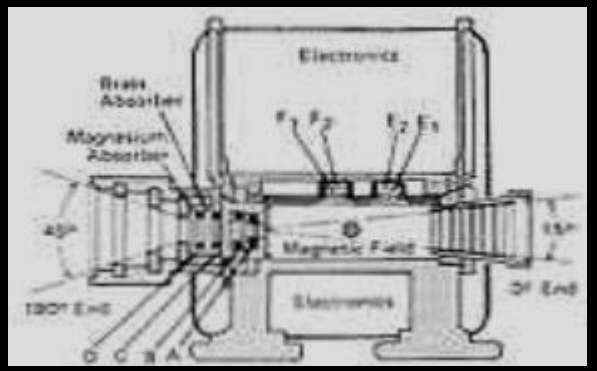
- **Measure the energy and angular distribution, composition, and stability of trapped radiation at Jupiter.**
- **Study the interaction of these energetic particles with the Galilean satellites and the solar wind.**
- **Derive thermal plasma flow velocities and temperatures.**
- **Examine adiabatic and non-thermal processes in the trapped radiation.**

EPD measured the detailed energy and angular distribution of the following over 4 pi:

- **Ions (Z >= 1) from 20 keV to 55 MeV**
- **Electrons from 15 keV to > 11 MeV**
- **Ion composition from 10 keV/nuc to > 10 MeV/nuc**

EPD Overview





Follow-on to APL's Voyager LECP instruments

The EPD weighed 10.5 kilograms and used 10.1 watts of power on average.

Our major partner was the Max Planck Institute for Solar System Research

There were two bi-directional sensors:

- **Low-Energy Magnetospheric Measurements System (LEMMS)**
  - **Stacked detectors and magnetic deflection**
- **Composition Measurement System (CMS)**
  - **Stacked detectors and time-of-flight**

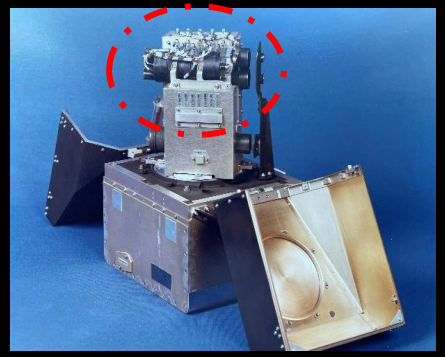
First APL instrument with a microprocessor

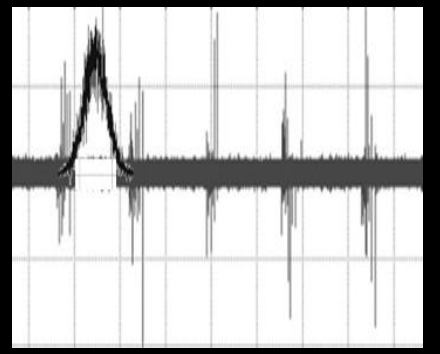
Early Years

"How did you became the EPD System Engineer…..?"

- **At APL for 6 months, much of that in a training program**
- **I was offered the opportunity to work on Galileo**
  - **But commit to 4.5 year mission assignment ????**
- **I was supposed to be the junior system engineer, and eventually transition take over, but….**
- **Thus began my trial by fire, where everything was new to me**
  - **Team was very experienced and very supportive**
  - **Particular nod to Don Williams (PI), Barry Tossman (PM), and Ray Thompson (Tech), and Dick McEntire (Co-I) - they set the bar**
- **Still, it was like drinking from a firehose**
- **Despite my EE degree, my real education was about to start…**

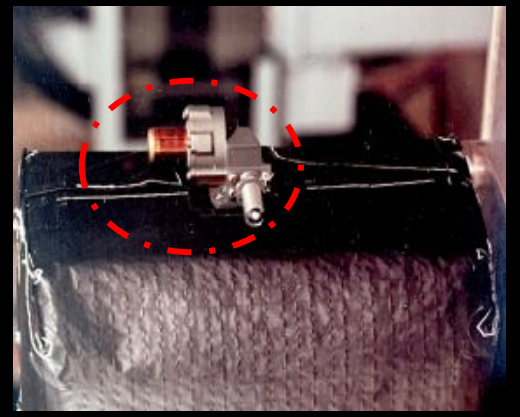
My Education





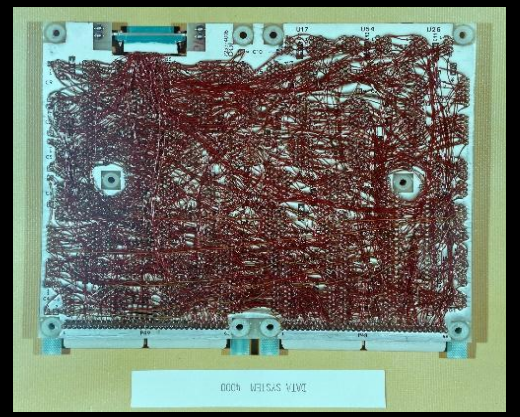
Electrical Problems

- **NOISE !!!! - mV and nsec**
  - **Mentored by Bob Martin**
  - **Peeling back the layers of the onion**
  - **Oh yeah baby – touch me right there**
    - ***"Steve- If you don't figure out how to make the noise go away without your finger touching that circuit, you are going to end up with 9 fingers"***



Mechanical Problems –

- **Cover release vibration failure**
- **AC-Delco car thermostats make great actuators**



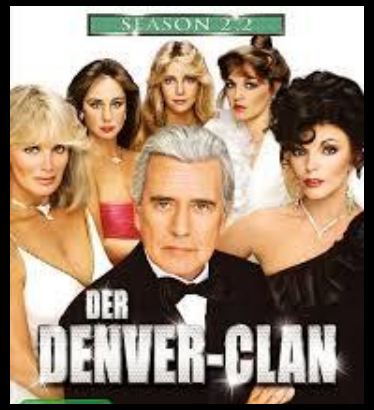
Thermal Problems

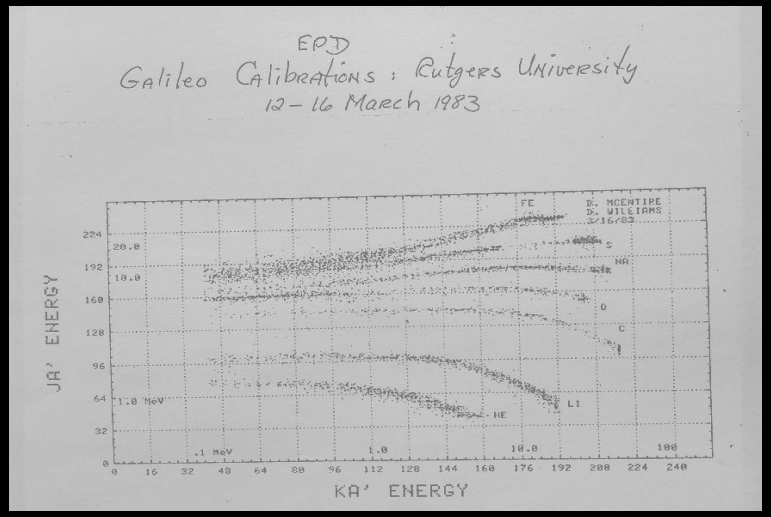
- **Why does data stop when we go cold???**
  - **A blessing in disguise**

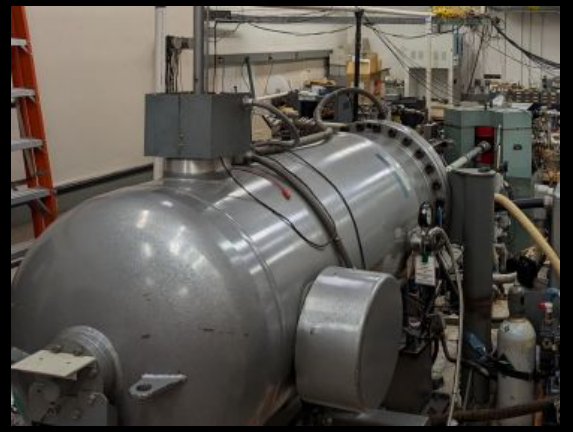
My Education

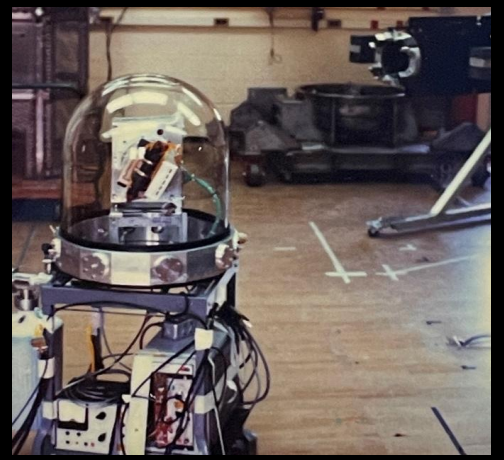
Calibration

- Many visits to the GSFC accelerators
- High energy runs at Rutgers
  - 24/7
- RTG test at Mound Ohio
- Many days at Max Planck
  - 9-5 (at first)
- There is nothing as rewarding as seeing real data from the assembled instrument !!









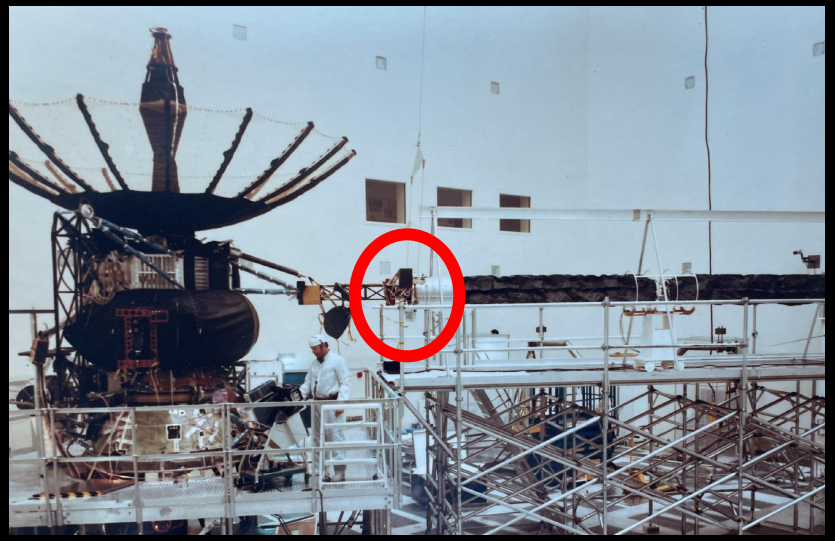
The Hard Work is Done - Delivery

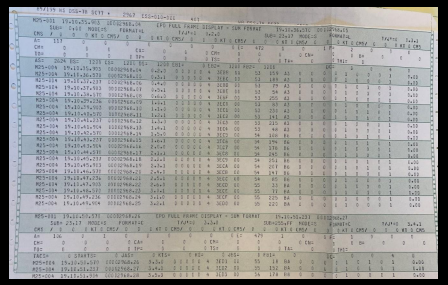
It's the only way to fly..

- **Hand carried on plane – 1st class seats ☺**
- **Mr. Box…. Mr. A Box**
- **Steve and Eydie Gorme are sitting in my seats!!**

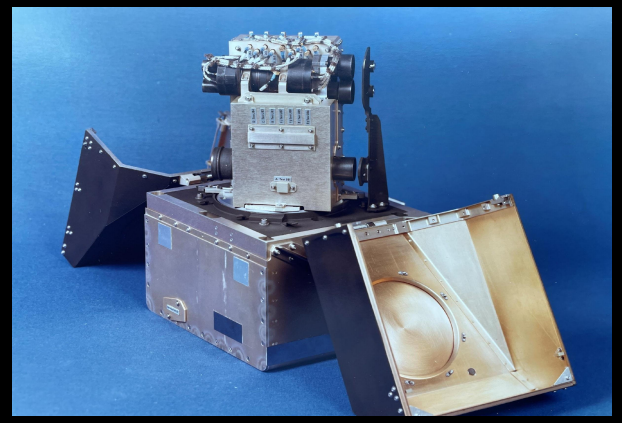
Arrival at JPL

- **All roads lead through Al Whittlesey's EMC area**
  - **Magnetic testing**
- **Great feeling to walk into S/C cleanroom and install our instrument**
- **Testing**
  - **No displays, just a large room full of giant, noisy line printers (3 trees/day)**
- **Spent so much time at JPL, local waiters would recognize my 'wife' and I at restaurants**



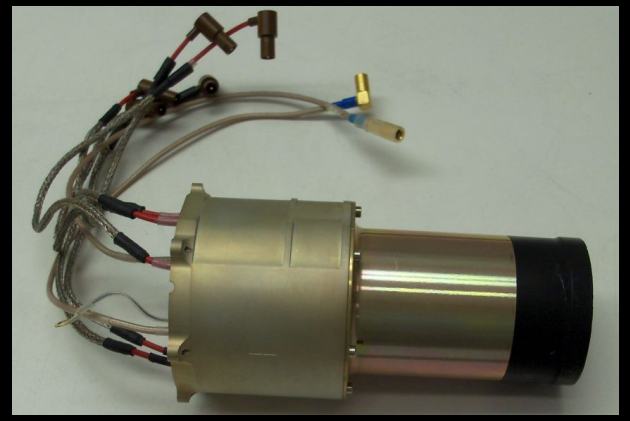


But Wait – The Fun has Just Started

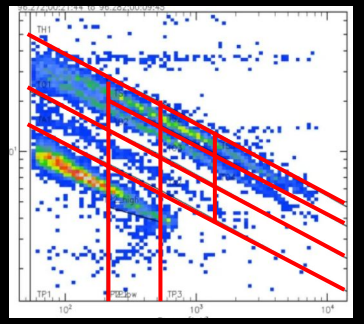


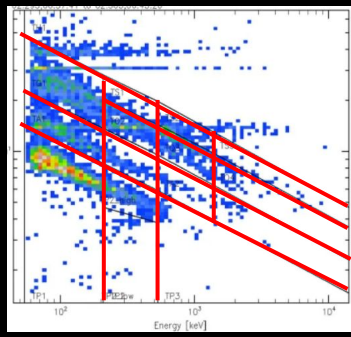
Challenger #1: Challenger

- Given the delay, the Project asked if new technology was available
- We just had to swap out our existing ΔE x E head with a new TOF x E head
  - By "just" - we needed to add in a high voltage supply, new sensor, new timing circuitry, mechanically fit it where the old hardware had been, and hide it all from the ROM-based software
- Incredible team effort
  - Max Plank designed and provided most of the new hardware (sensor, HVPS, TOF board)
  - APL modified main electronics, software
- This lowered low energy threshold for ion species determination from hundreds of keV to 20 keV



More Fun



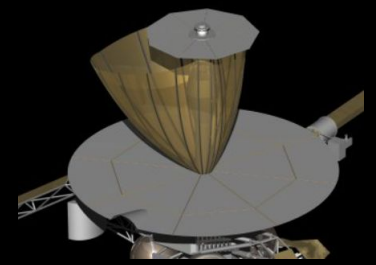


Challenge #2: Late breaking news

- At the daily status meeting from the Cape, our PI, Don Williams said we needed to make a change to our instrument.
  - We had learned that energetic oxygen was going to degrade our thin silicon detectors much more than thought, leading to high leakage currents (-> noise + energy losses).
- Plan A or Plan B
  - I was tasked with installing the flux reducer
- Phone home
  - "I'm going up in the shuttle…"
- Found: mid Sept
  Fixed: Oct 3
  Launched: Oct 19

My Favorite Shot

Oy Vey – Now What Do We Do?



Challenge #3: The Antenna

- Reduce our telemetry rate by >50X - This seemed impossible.
- BUT - the majority of Voyager papers actually used ground-processed 15 minute spin-sectored averages.
- Our EPD telemetry was time based (4/3 seconds), producing 912 bps, and we needed to reduce to something more like 15 bps
- Needed two new software modes, even though we were still limited by the ROM code
  - Existing high rates during flybys
  - Spin-based collection summed to 15 minute averages for S-band
- A few "small" issues to work
  - Needed to synchronize our motor stepping to spacecraft spin
    - Our instrument had no idea where the spacecraft was pointing!
  - The EPD didn't have enough memory to buffer this new 15-minutesectored data

Not So Fun

```
                Address   Assem.          Hex Opcodes

HVCTRL:         1B05      LDI  A1 (HVCNT)F8   18        TEST HIGH VOLGAGE CONTROL INTERVAL
                1B07      PHI  RA        BA              MODULE 64 COUNTER
                1B08      LDI  A0 (HVCNT)F8   7C        THIS COUNTER ROLLS OVER EVERY
                1B0A      PLO  RA        AA              64*(2/3)=42.67 SECONDS
                1B0B      LDN  RA        0A              INCREMENT THE COUNTER
                1B0C      ADI           1FC   1         BY ONE
                1B0E      ANI  X '3F'    FA   3F        MODULO 64
                1B10      STR  RA        5A              HVCNT
                1B11      LBNZ CRTI9+4   CA   08 5F     SKIP TO REMAINING RTI9 TAASKS IF NOT 0
                1B14      INC  RA        0A              POINT TO SLOT FOR HVLIMIT

                                    NEW Code
                Address   Assem.          Hex Opcodes

HVCTRL:         1B05      LDI  A1 (MOD91)F8   1C        TEST MOD91 COUNTER TO SEE IF COUNT
                1B07      PHI  RA        BA              EQUALS 0.
                1B08      LDI  A0 (MOD91)F8   D5
                1B0A      PLO  RA        AA
                1B0B      LDN  RA        0A              ONLY EXECUTE HV CODE IF MOD91=0.
                1B0C      LBNZ CRTI9+4   CA   08 5F     ELSE BRANCH BACK TO RTI 9 CODE
                1B0F      LDI  A1 (HVLIMIF8   18
                1B11      PHI  RA        BA
                1B12      LDI  A0 (HVLIMIF8   7D
                1B14      PLO  RA        AA              POINT TO SLOT FOR HVLIMIT
```

Challenge #3 (cont):

- We had three things going for us:
  - DMA (direct memory access) interface between the spacecraft and EPD
  - ROM-based code was written to support patching
    - An extra 256 bytes of SRAM we installed in the EPD during the rework after Challenger.
  - Tal Brady and the CDS team at JPL
- We engineered a constant dance of data exchanges between the EPD and CDS memories that allowed us to synchronize our data collection and motor movement with the spacecraft spin and to pass our 4/3 second data buffers to the CDS for summing.
- This beautiful kludge was tested at JPL, along with cobbled-together EM hardware from all the other instrument teams.
- It worked!!
- This was one of most rewarding tasks I’ve worked in my career

What A Ride !

- The EPD continued to work well throughout the mission.
- I supported the EPD through the end.
  - It was a great training ground to learn my craft
- I have since led work on Jupiter-bound particle instruments
  - Cassini, New Horizons, Juno, JUICE, plus Europa Clipper missions
- It is truly satisfying to know that in addition to the great science, the EPD measurements have helped define the Jovian radiation environment these missions would see
- I’ve enjoyed them all, but Galileo was my first love, and still holds a special place in my heart
- p.s. I still have the spacecraft simulator in my office, just in case we need to fire up the EM 😊

What a Team !

- **It's all about the people**
- **APL**
  - **J. Crawford, J. Dassoulas, D. Fort, S. Gary, J. Heiss, B. J. Hook, J. Kohl, H. Malcom, R.W. McEntire, R. Moore, T. Mueller, M. Puntz, S. Purwin, N. Rothman, P. Schwartz, R. Thompson, B. Tossman, J. Townsend, Jr., D.J. Williams, C. Wingate, and H. Wong**
- **Max Planck Institute fur Aeronomie**
  - **W. Boeker, E. Buble, W. Klemme, H. Sommer, W. Weiss, B. Wilken, and H. Wirbs**
- **NOAA Space Environment Laboratory and Bell Labs**
  - **J. Cessna, T. Fritz, R. Dayhoff, C. Holmes, L. Lanzerotti**
- **JPL**
  - **Tal Brady, W. Fawcett, R. Gibbs, G. McSmith, N. Murphy, R. Parrish, J. Taylor, J. Willett, and A. Whittlesey**
- **Others**
  - **T. Armstrong, S. Brown, J. Burke and R. Martin**

What a Team !