Energetic particles and their detection in situ
(particle detectors)
Part III

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Energy Analyzers

- To measure (select) the energy of low energy ($\leq \sim 100$ keV/charge) charged particles, electrostatic and magnetic energy analyzers are used in space instruments.

- Magnetic analyzers are bulky and heavy compared to electrostatic analyzers, and require magnetic shielding to prevent interference with magnetic field measurements on the same spacecraft.

- Electrostatic analyzers often use high voltages that require special care to prevent discharge.

- Incorporating UV suppression is essential since most detector systems (SSDs, CEMs, MCPs) placed behind energy analyzers are sensitive to UV.

- Three types of electrostatic analyzers are discussed:
  - Retarding Potential Analyzer (RPA) for low energies (few eV to $\sim$ few keV/e).
  - Spherical and Cylindrical Section Analyzers (ESA) for medium energies ($\sim 0.1$ to $\sim 20$ keV/e).
  - Small-Angle Deflection Analyzers (SADA) for high energies (up to a few MeV/e).

- Many different configuration of analyzers are used, but they all operate by using various electric field configurations to allow only particles in a selected energy/charge ($\varepsilon$) window ($\varepsilon_1 < \varepsilon < \varepsilon_2$) to pass through the system.
• The RPA consists of three highly transparent metal grids, an aperture stop (to define the acceptance geometry) and support structure.

• It is a simple device with a large acceptance area and geometrical factor.

• Its disadvantage are:
  - upper energy range is limited to ~6 to 8 keV/e
  - UV suppression is very difficult

• The energy of incoming ions is determined by applying to the central metal grid a time-varying, dc-biased square wave potential that varies from \( V_1 \) to \( V_1 + \Delta V \) (\( V \) and \( \Delta V \) can be changed).

• Ions with 'perpendicular' energies, \( \frac{1}{2} m v_1^2 < q V_1 \), are rejected, those with \( \frac{1}{2} m v_1^2 > q V_2 \) are accepted and ions with energies in between are either accept or reject depending on whether the modulating voltage is in its high or low step.
**Spherical and Cylindrical Section Analyzers (ESA)**

- Charged particles are deflected by the electric field between the inner and outer concentric spherical (or cylindrical) section electrodes.

- Only particles having the right energy per charge $\varepsilon$ and arrival directions will pass through the entrance aperture and ESA to be detected without first hitting one of the electrodes.

- The mean energy per charge $\varepsilon$ of the particle arriving at the detector is

  $$\varepsilon \approx 0.5\left(\frac{V_{\text{out}} - V_{\text{in}}}{\ln(R_{\text{out}}/R_{\text{in}})}\right) \approx 0.5\Delta V/(\Delta R/<R>)$$

- $\Delta R = R_{\text{out}} - R_{\text{in}}$ and $<R> = (R_{\text{out}} + R_{\text{in}})/2$

- The energy per charge resolution is

  $$\Delta \varepsilon / \varepsilon \approx \Delta R/<R>$$

- The acceptance angle $\alpha$ is also

  $$\alpha \approx \Delta R/<R>$$

- The analyzer constant $K$ is

  $$K = \varepsilon / \Delta V \approx 0.5<R>/\Delta R$$

- An analyzer constant of 20 can be achieved with $<R> = 20$ cm and a gap between the plates $\Delta R = 0.5$ cm.
Small Angle Deflection Analyzer (SADA)

- Charged particles pass through a multi-slit collimator (which defines their incoming directions) and are then deflected by the electric field between the upper and lower deflection plates.
- Only particles having the right energy per charge $\varepsilon$ will pass through the narrow slit and are detected (alternatively, a position-sensitive detector could be used to measure $\varepsilon$).
- The mean energy per charge $\varepsilon$ of the particle arriving at the detector is
  \[ \varepsilon \approx (V_{\text{up}} - V_{\text{lo}}) L^2 / (4 h \delta) \]
  where $L$ and $h$ are average length and separation of deflection plates.
- The energy resolution is $\Delta \varepsilon / \varepsilon \approx \Delta \delta / \delta$ where $\Delta \delta$ is the slit width.
- The analyzer constant $K = L^2 / (4 h \delta)$ and the acceptance angle $\alpha \approx h / (2L)$.

The main advantage of a SADA is that particles up to several MeV/charge can be deflected since $K$ can be large and large deflection voltages can be supported.

UV trapping is effective.
**Time-of-flight (TOF) – Energy detector**

- Measure time-of-flight, $\tau$, between foil and detector separated by $L$ (typically $\sim 10$ cm)
- Measure energy $E$ of particles in the detector

Particle mass: $m = 2E \cdot (\tau/d)^2$

Mass resolution: $(\Delta m/m)^2 = (\Delta E/E)^2 + (2\Delta \tau/\tau)^2 + (2\Delta d/d)^2$

Typical resolutions: $\Delta E = 35$ keV; $\Delta \tau = 150$ ps