View from the Inside: The Solar System's Particle Environment

Christina M. S. Cohen

*Caltech*
Space Observations

- NASA’s Heliophysics System Observatory (HSO)
Space Observations

- NOAA’s Observatory System
Space Observations

- Remote Sensing
- Coronal holes, active regions, flares, Coronal Mass Ejections (CMEs)
Space Observations

• Remote Sensing
  • Coronal holes, active regions, flares, Coronal Mass Ejections (CMEs)
  • Solar wind structures - shocks
Space Observations

- Remote Sensing
  - Coronal holes, active regions, flares, Coronal Mass Ejections (CMEs)
  - Solar wind structures - shocks
  - Open field lines

Radio observations
Space Observations

• In-situ
  • Solar wind parameters
    • Shocks, CMEs, CH wind
Space Observations

• In-situ
  • Solar Energetic Particles (SEPs)
Space Observations

- In-situ
  - Solar Energetic Particles (SEPs)
    - Intensities
Space Observations

- In-situ
  - Solar Energetic Particles (SEPs)
    - Intensities
    - Spectra
Space Observations

- In-situ
  - Solar Energetic Particles (SEPs)
    - Intensities
    - Spectra
    - Composition

![Graphs showing Helium Isotopes and Silicon Fluence](image_url)
SEP Variability

- SEP events are hugely variable – what might they depend on?
SEP Variability

Acceleration

Transport
SEP Variability

**Acceleration**
- Processes
  - shock acceleration, reconnection

**Transport**
- Process
  - Charged particles in magnetized plasma
SEP Variability

**Acceleration**
- **Processes**
  - shock acceleration, reconnection
- **Details**
  - Conditions
  - What is being accelerated
  - Escape

**Transport**
- **Process**
  - Charged particles in magnetized plasma
- **Details**
  - Scattering – turbulence
  - Solar wind conditions
  - Intervening structures (e.g., CMEs)
# SEP Variability

## Acceleration
- **Processes**
  - shock acceleration, reconnection
- **Details**
  - Conditions
  - What is being accelerated
  - Escape
- **Observations**
  - Flares
  - CMEs
  - Radio bursts

## Transport
- **Process**
  - Charged particles in magnetized plasma
- **Details**
  - Scattering – turbulence
  - Solar wind conditions
  - Intervening structures (e.g., CMEs)
- **Observations**
  - Solar wind
  - CMEs
Observational Limitations
Observational Limitations

- You don’t know what you can’t see
- Dark side of the Sun
Observational Limitations

• You don’t know what you can’t see
• Dark side of the Sun - illuminated
Observational Limitations

• You don’t know what you can’t see
• Dark side of the Sun - illuminated
• 2014 lost STEREO-B
Observational Limitations

• You don’t know what you can’t see
  • Dark side of the Sun
  • 2014 lost STEREO-B
  • 2023 STEREO-A near Earth
New Assets

• Parker Solar Probe
  • Closest spacecraft to Sun

Perihelion: Sept. 27, 2023
4.5 million miles from Sun's surface
New Assets

- Parker Solar Probe
  - Closest spacecraft to Sun

- Solar Orbiter
  - Close to Sun
  - Out of ecliptic
Solar Cycle and Pre-Space-Age

• SEP events vary over solar cycle
Solar Cycle and Pre-Space-Age

- SEP events vary over solar cycle
- In-situ measurements only over short period
Solar Cycle and Pre-Space-Age

• SEP events vary over solar cycle
• In-situ measurements only over short period
• Biggest events – Ground Level Enhancement (GLE) events
  • Interact with atmosphere to create cosmogenic isotopes (CI):
    • $^{14}$C, $^{10}$Be, $^{36}$Cl – long halflives
Solar Cycle and Pre-Space-Age

- SEP events vary over solar cycle
- In-situ measurements only over short period
- Biggest events – Ground Level Enhancement (GLE) events
  - Interact with atmosphere to create cosmogenic isotopes (CI):
    - $^{14}$C, $^{10}$Be, $^{36}$Cl – long halflives

Tree rings & Ice Cores
Solar Cycle and Pre-Space-Age

- $^{14}$C from tree rings
- Reconstruction of SSN
Solar Cycle and Pre-Space Age

- $^{14}$C from tree rings
- Reconstruction of SSN
- & $^{10}$Be/$^{36}$Cl ice cores
  - 5 extreme events + 3 possibles

Only 16.5% examined
Solar Cycle and Pre-Space-Age

- $^{14}$C from tree rings
  - Reconstruction of SSN
- $^{10}$Be/$^{36}$Cl ice cores
  - 5 extreme events + 3 possible
  - All much bigger than space-age
  - No current events have Cl sig.
- Carrington event (1859) also no
Solar Cycle and Pre-Space-Age

- $^{14}$C from tree rings
  - Reconstruction of SSN
- & $^{10}$Be/$^{36}$Cl ice cores
  - 5 extreme events + 3 possible
  - All much bigger than space-age
  - No current events have Cl sig.
  - Carrington event (1859) also no
- Aurora records (maybe help?)

Babylonian ©Hisashi Hayakawa 567 BCE

1582 CE
We have a lot of data... but

• Everything varies – so ‘typical’ is hard to define
• Connecting in-situ details to remote sensing details is difficult
  • Lot of unmonitored space
  • Conditions for acceleration / transport not observed
• Space-age may not be typical or even extreme
  • What is the limit?
  • What governs the limit?