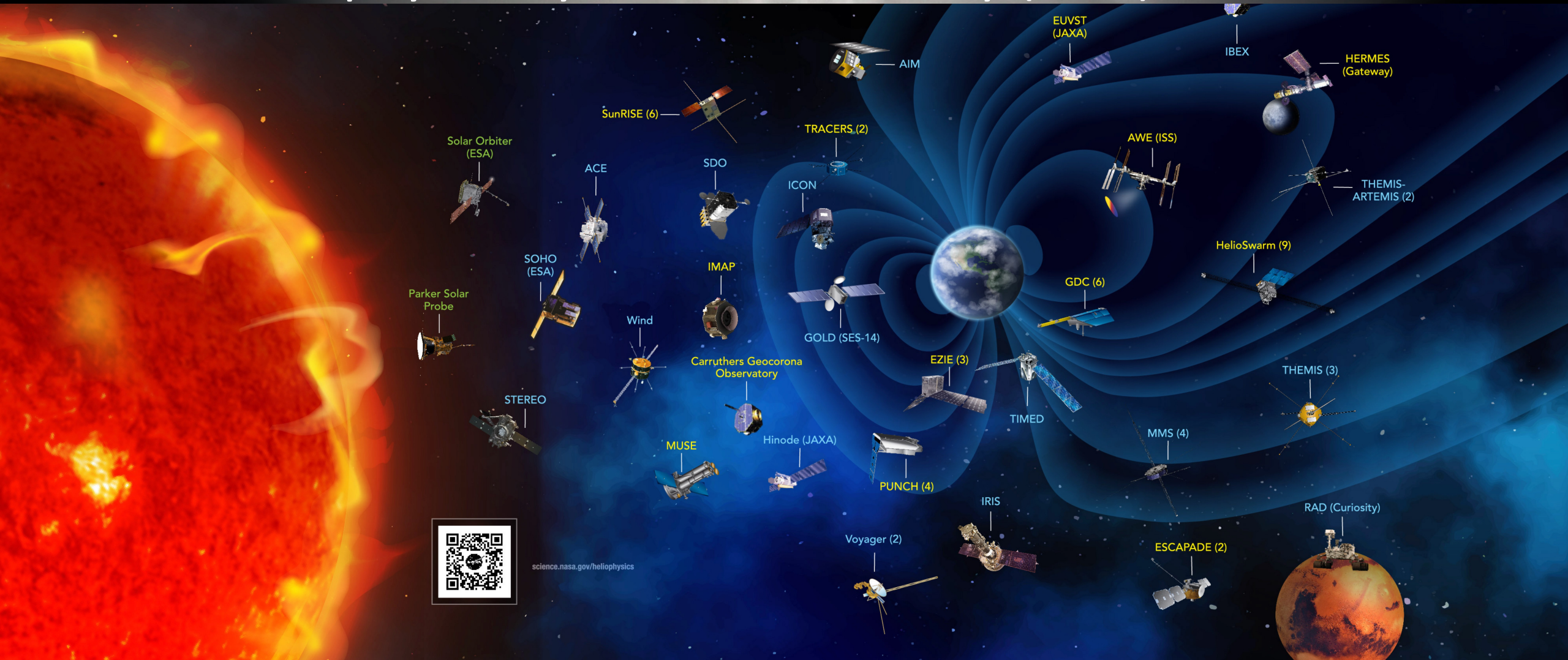
View from the Inside: The Solar System's Particle Environment

Christina M. S. Cohen

Caltech

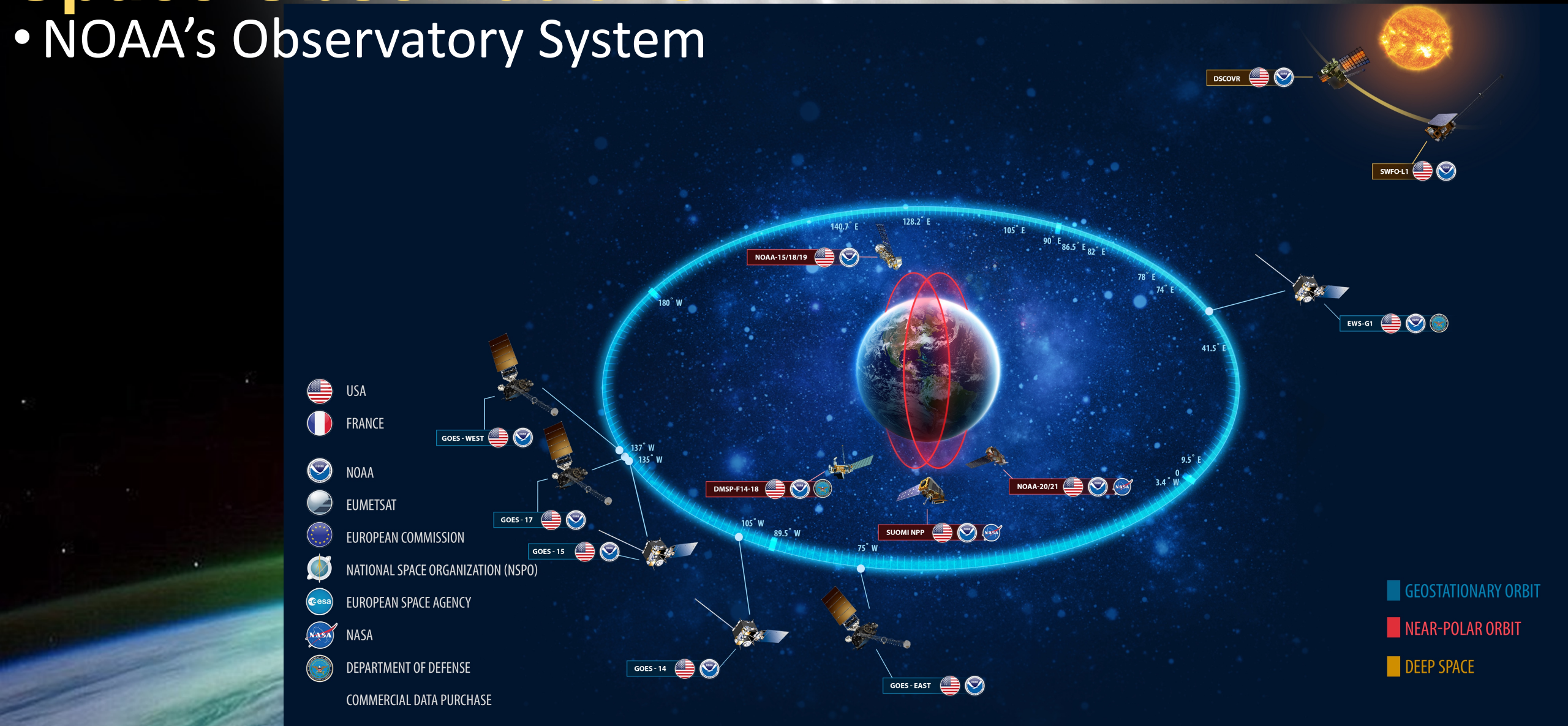
Space Observations

- NASA's Heliophysics System Observatory (HSO)



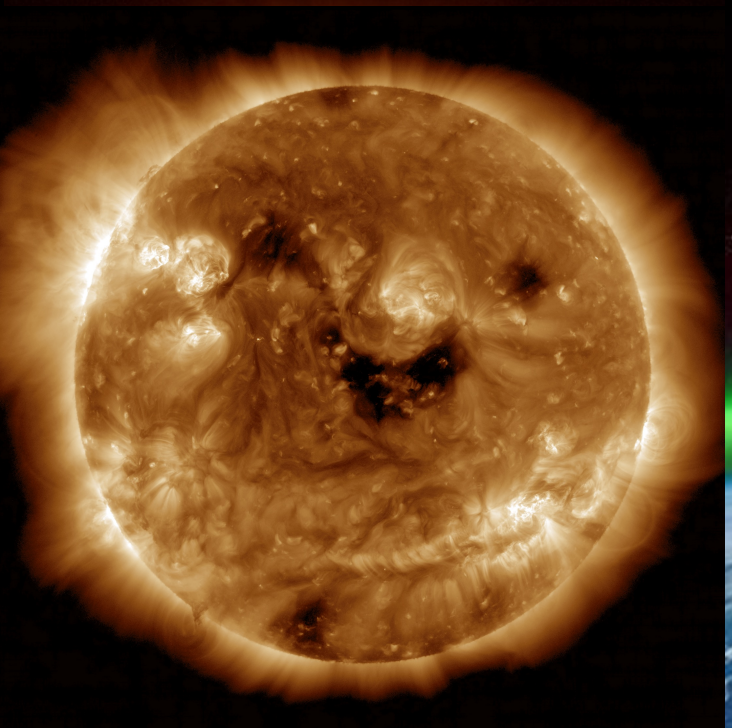
Space Observations

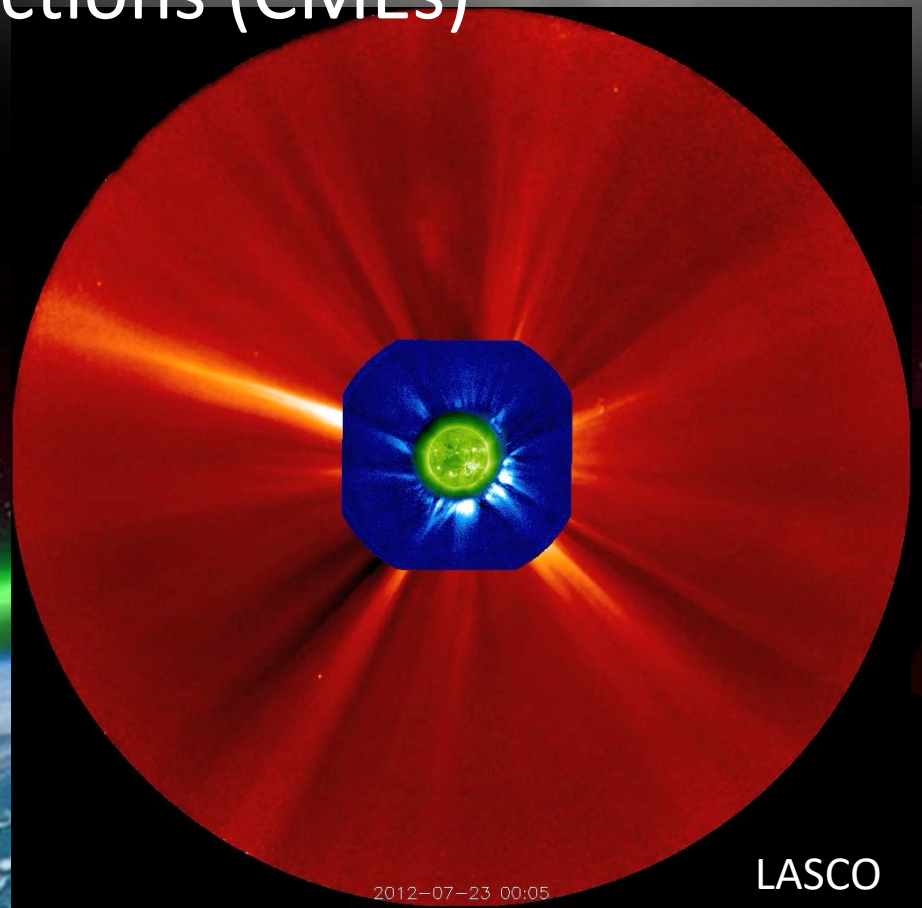
- NOAA's Observatory System



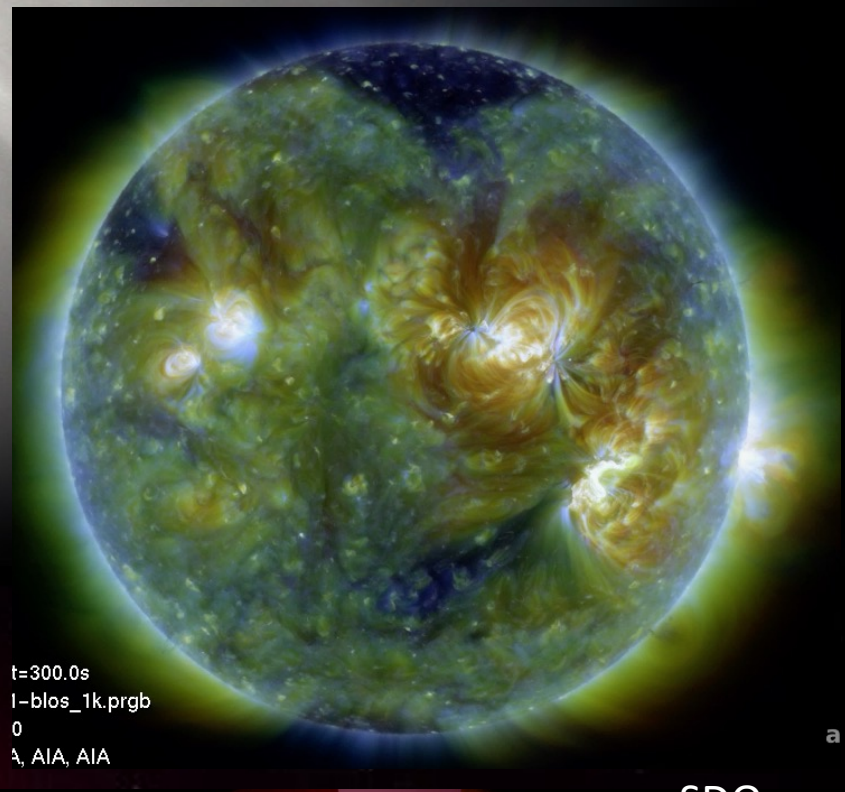
Space Observations

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





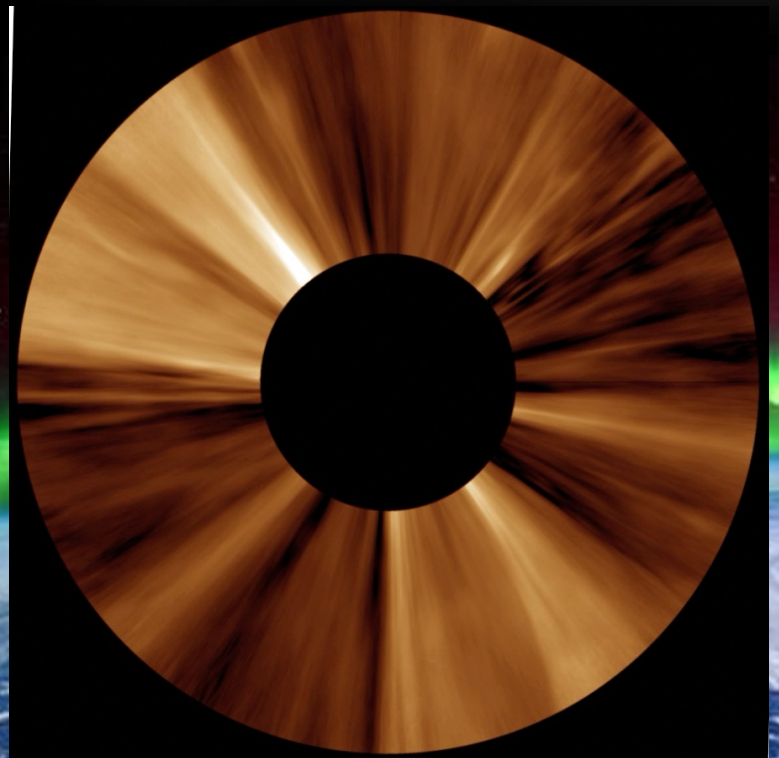
LASCO

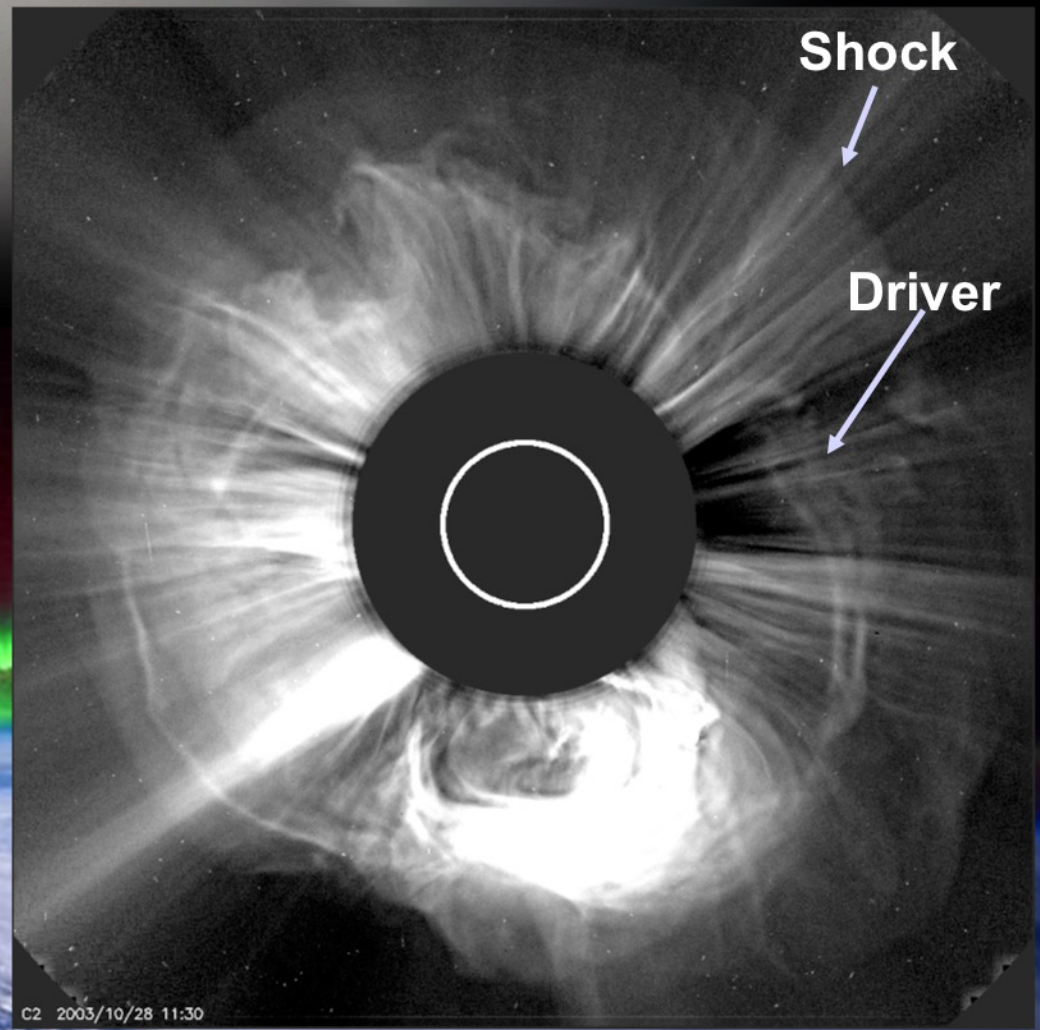


SDO

Space Observations

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

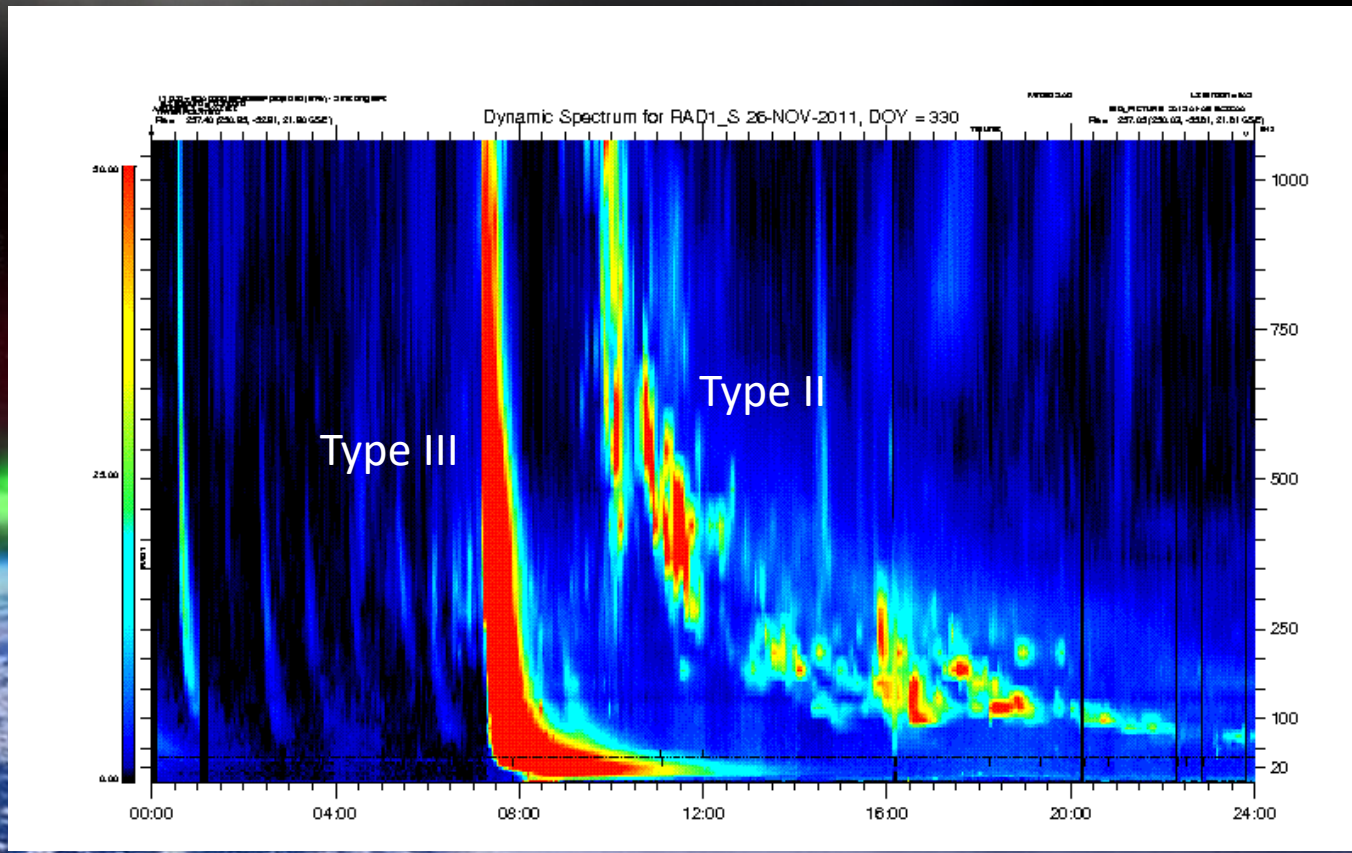




Space Observations

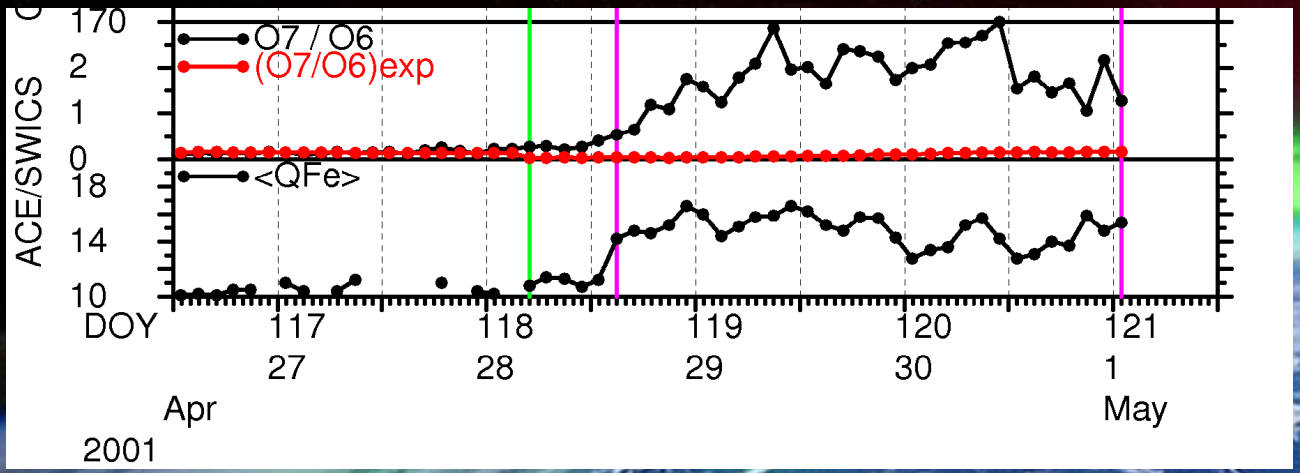
- Remote Sensing
  - Coronal holes, active regions, flares, Coronal Mass Ejections (CMEs)
  - Solar wind structures - shocks
  - Open field lines

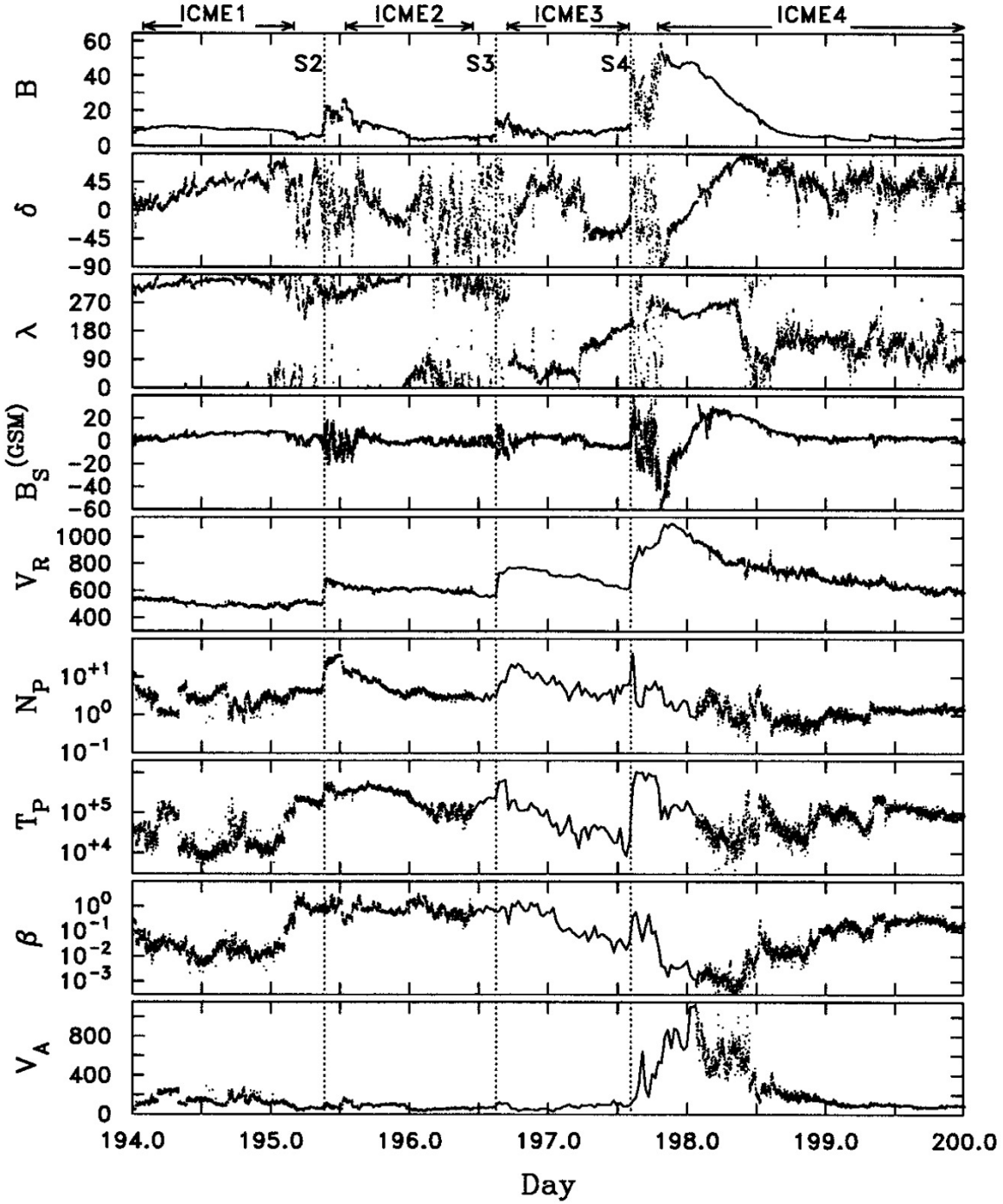
Radio observations



Space Observations

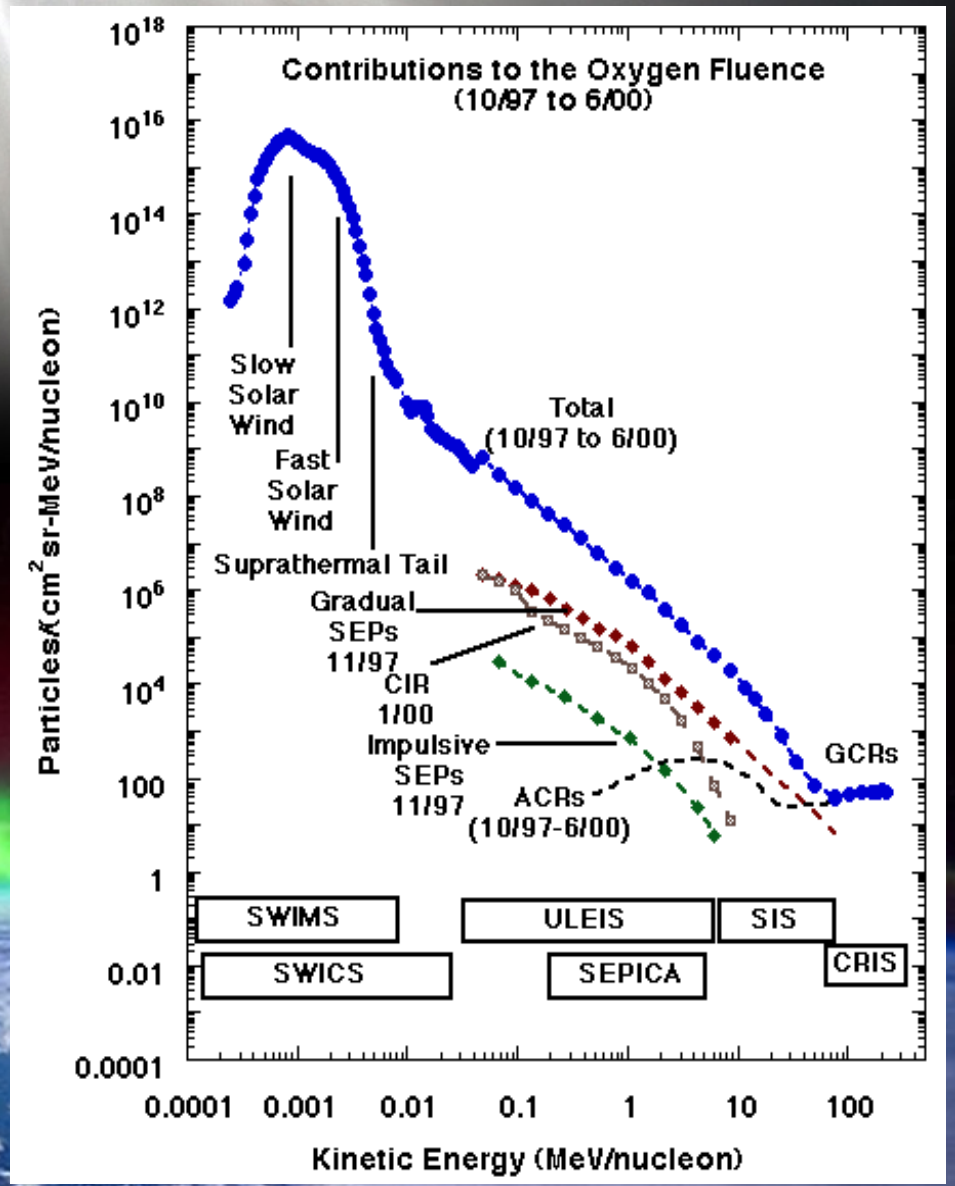
- In-situ
  - Solar wind parameters
    - Shocks, CMEs, CH wind





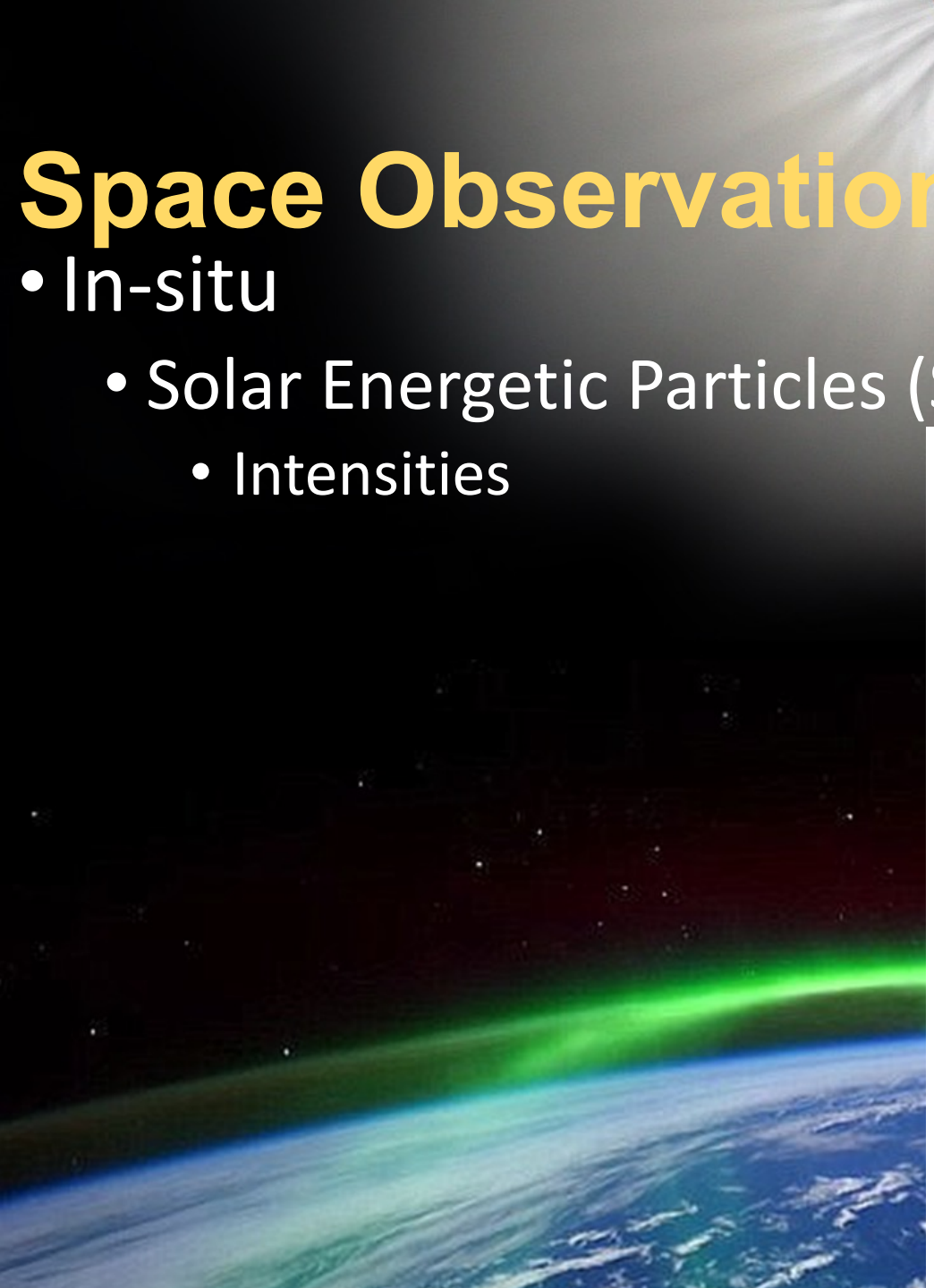
Space Observations

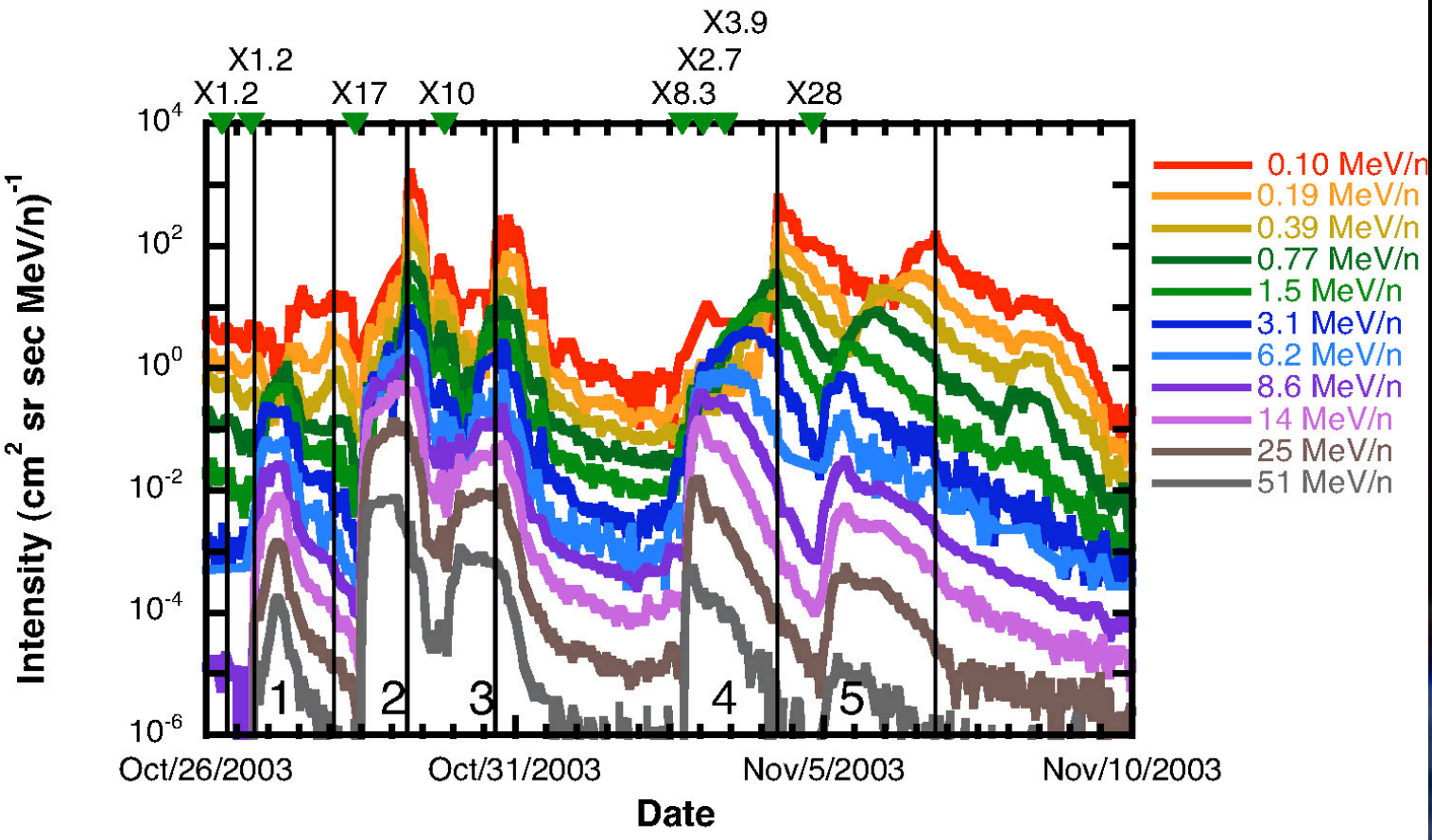
- In-situ
  - Solar Energetic Particles (SEPs)



Space Observations

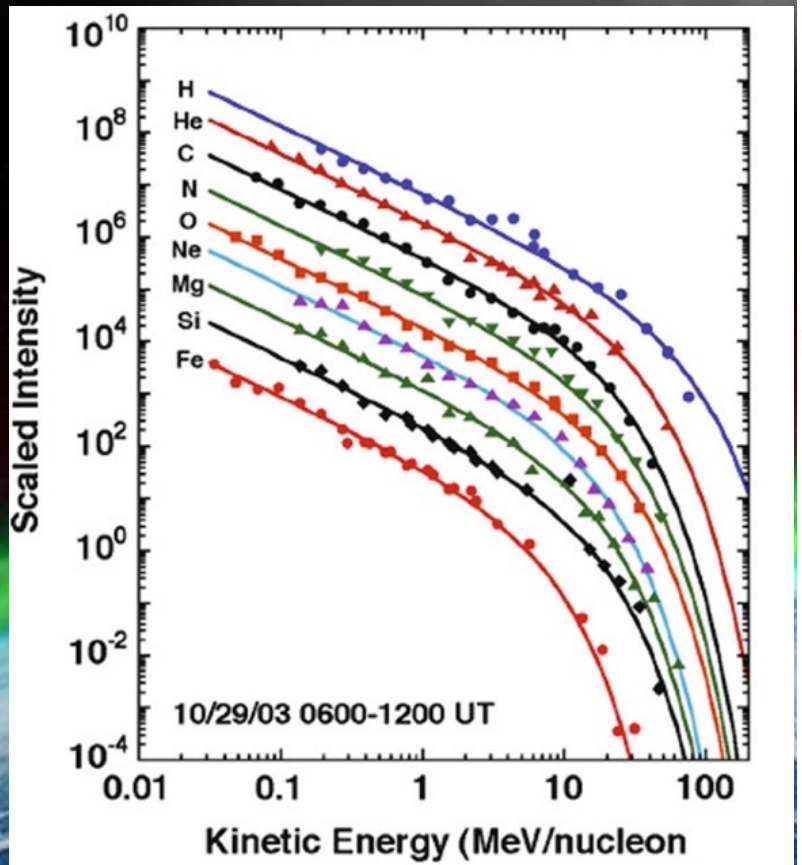
- In-situ
  - Solar Energetic Particles (SEPs)
    - Intensities

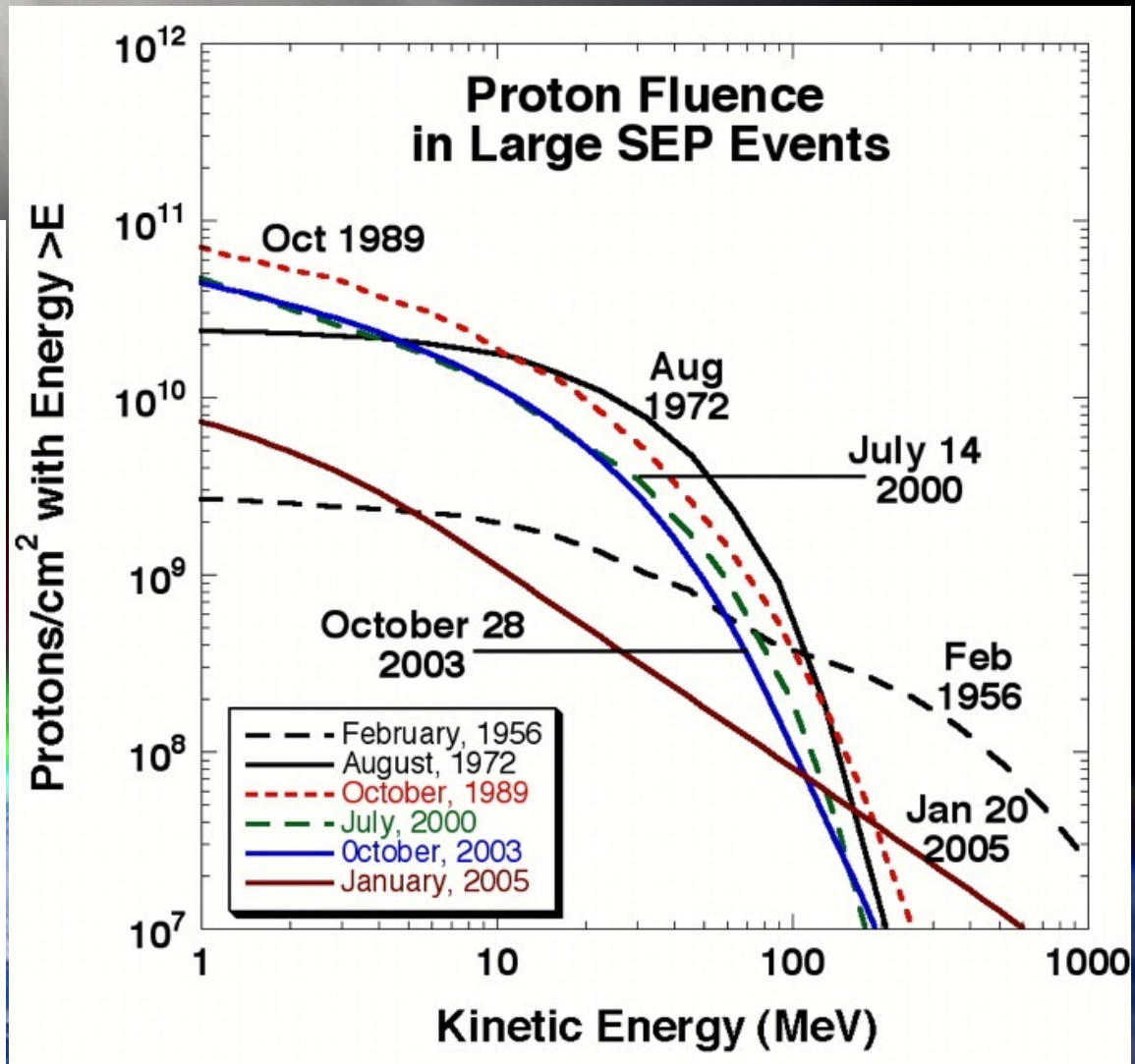




Space Observations

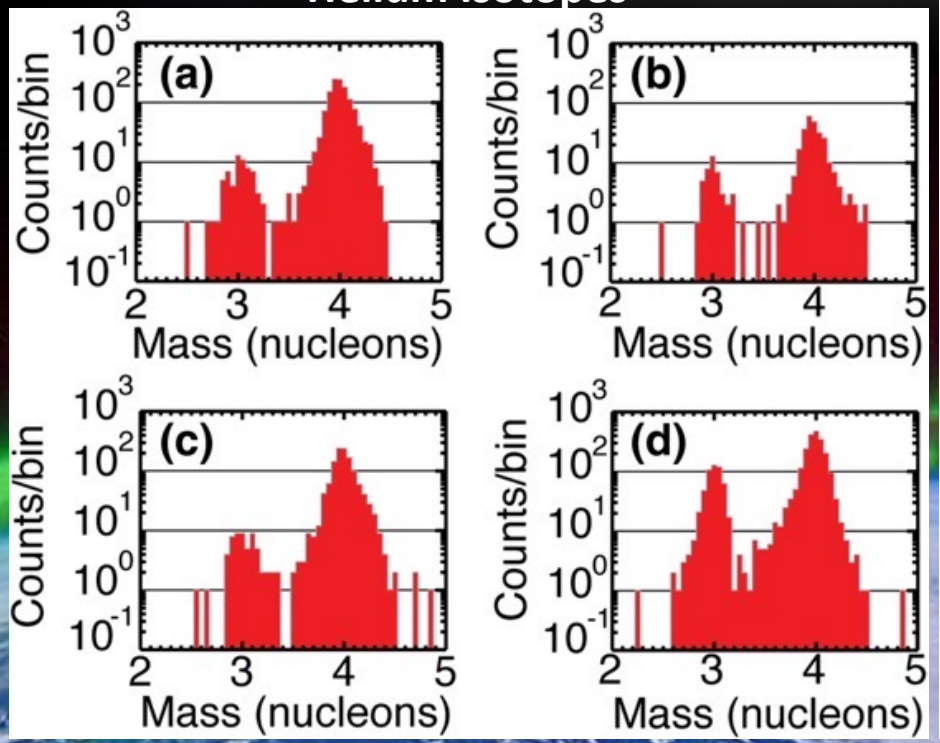
- In-situ
  - Solar Energetic Particles (SEPs)
    - Intensities
    - Spectra

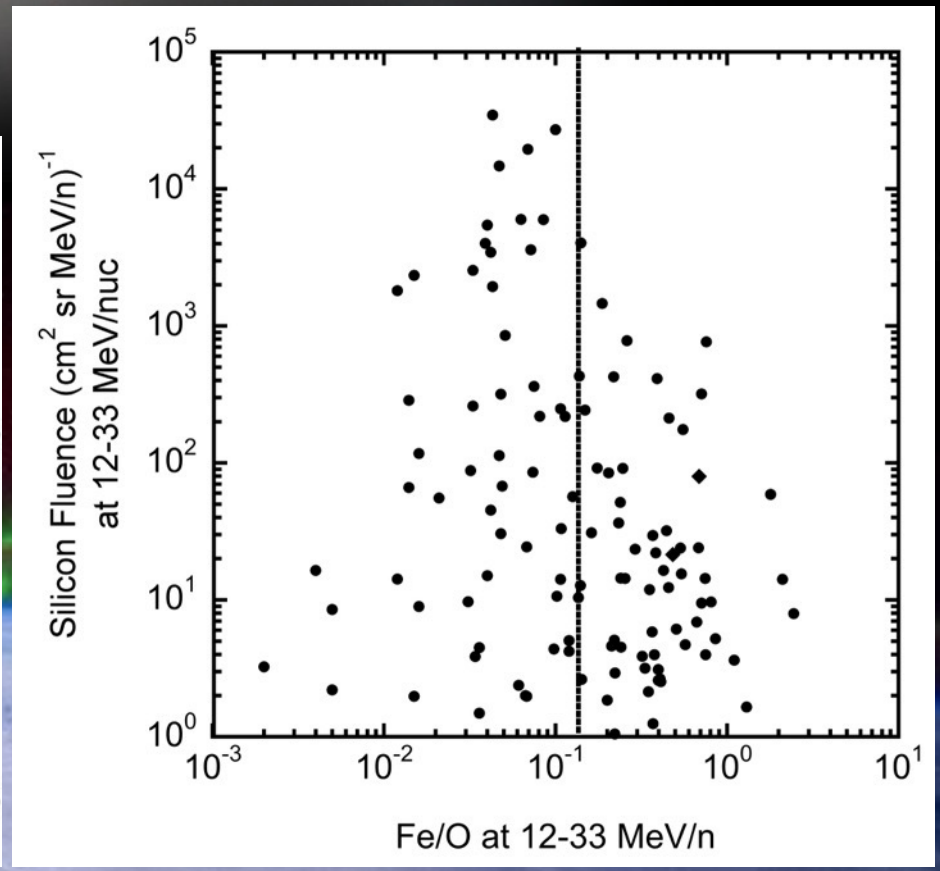




Space Observations

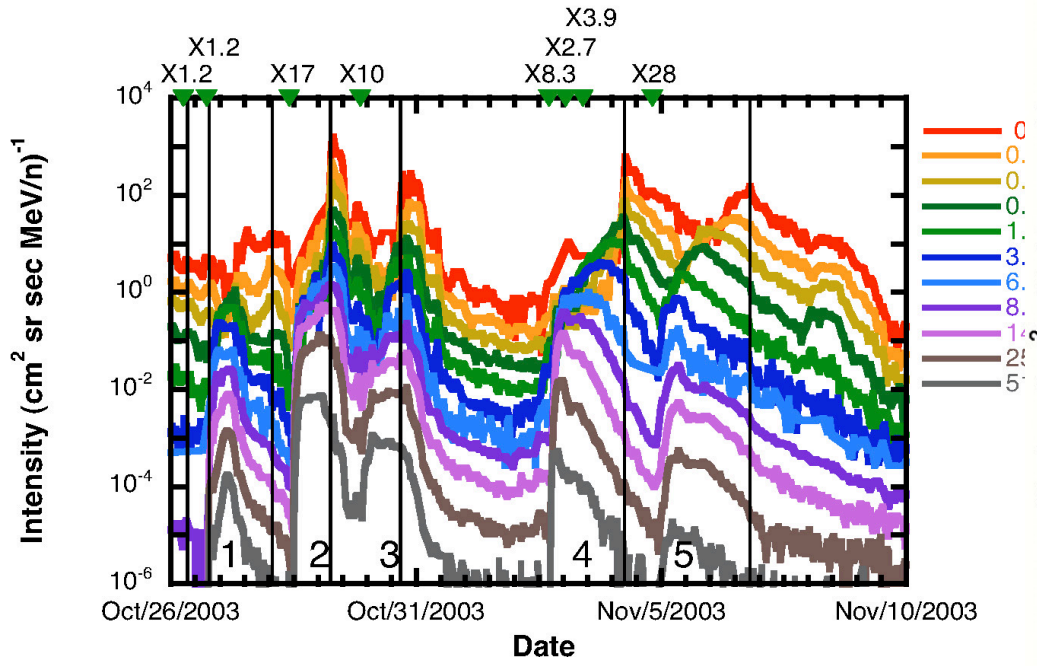
- In-situ
  - Solar Energetic Particles (SEPs)
    - Intensities
    - Spectra
    - Composition

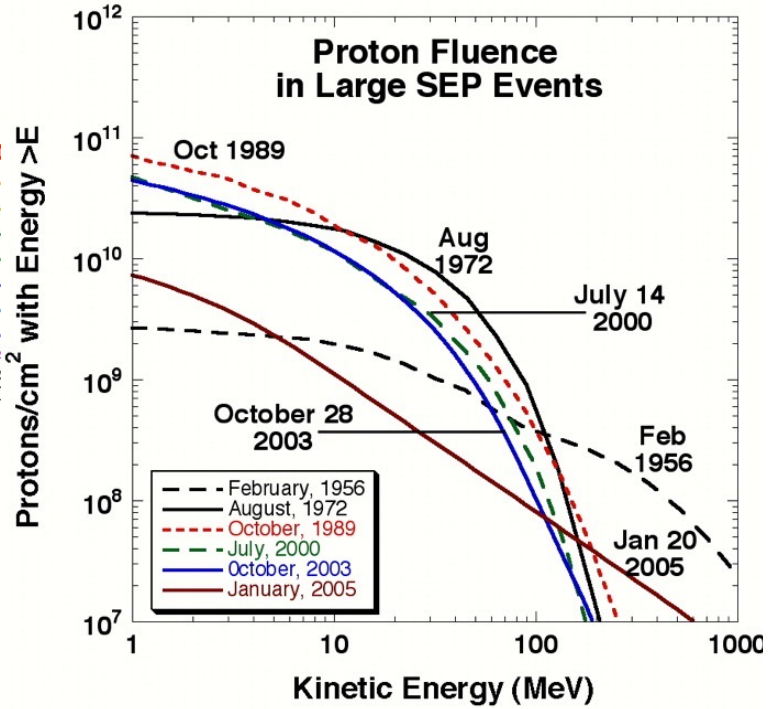


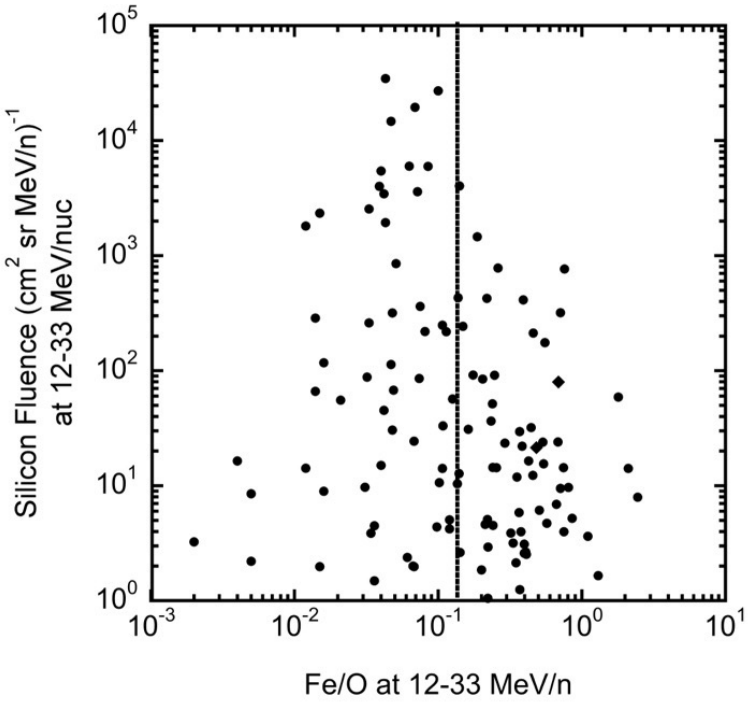


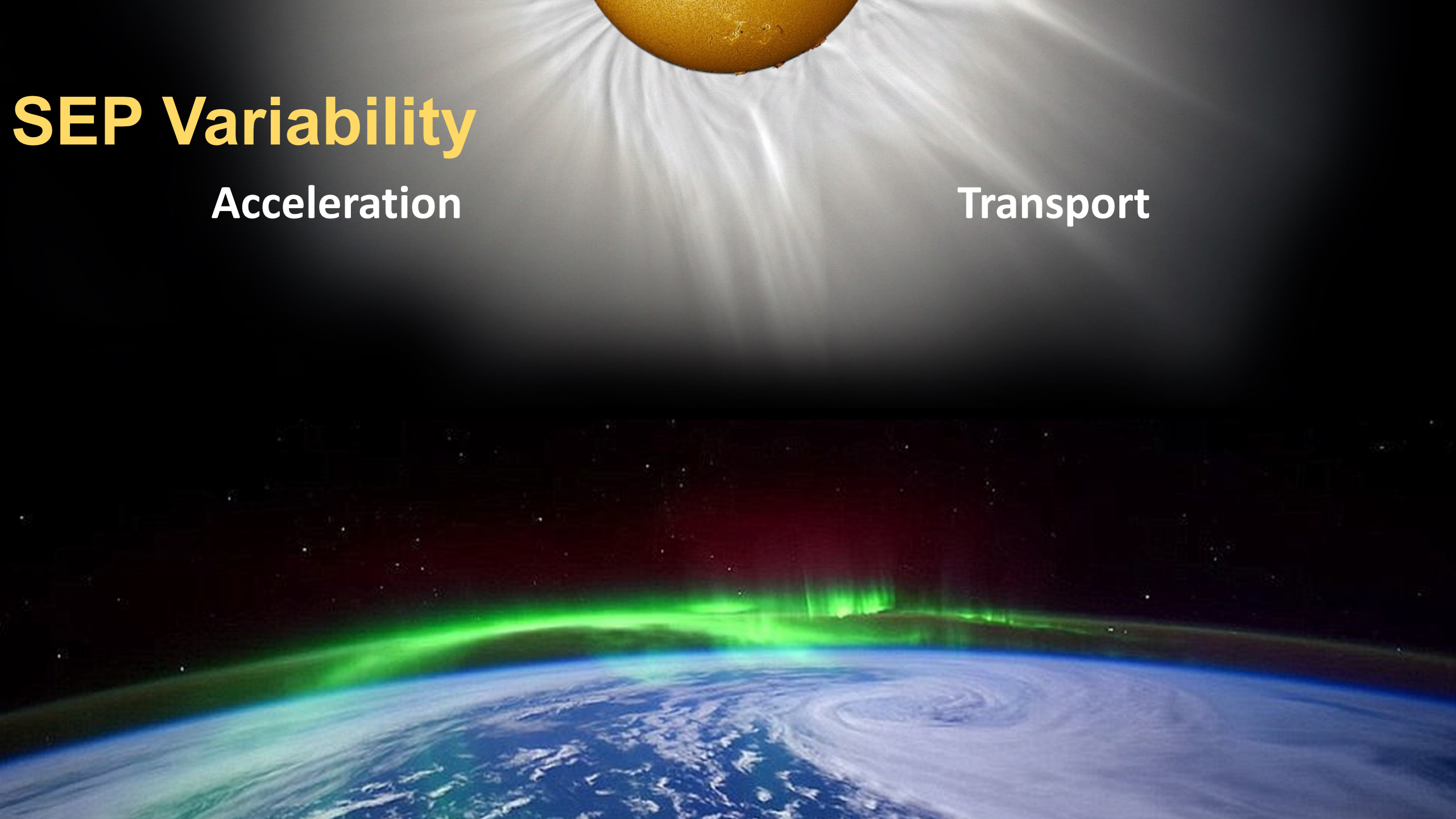
SEP Variability

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








SEP Variability
Acceleration
Transport

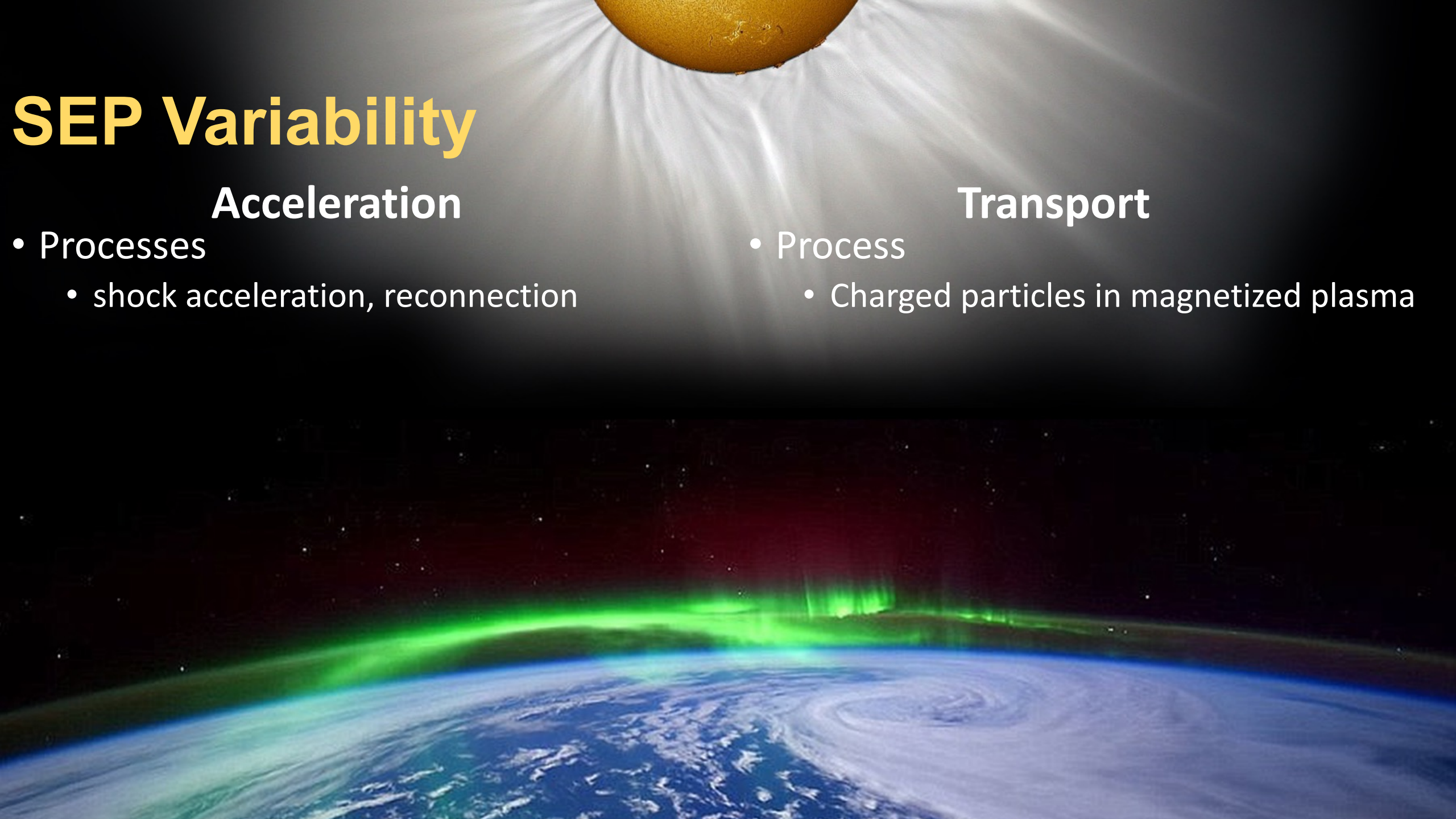
SEP Variability

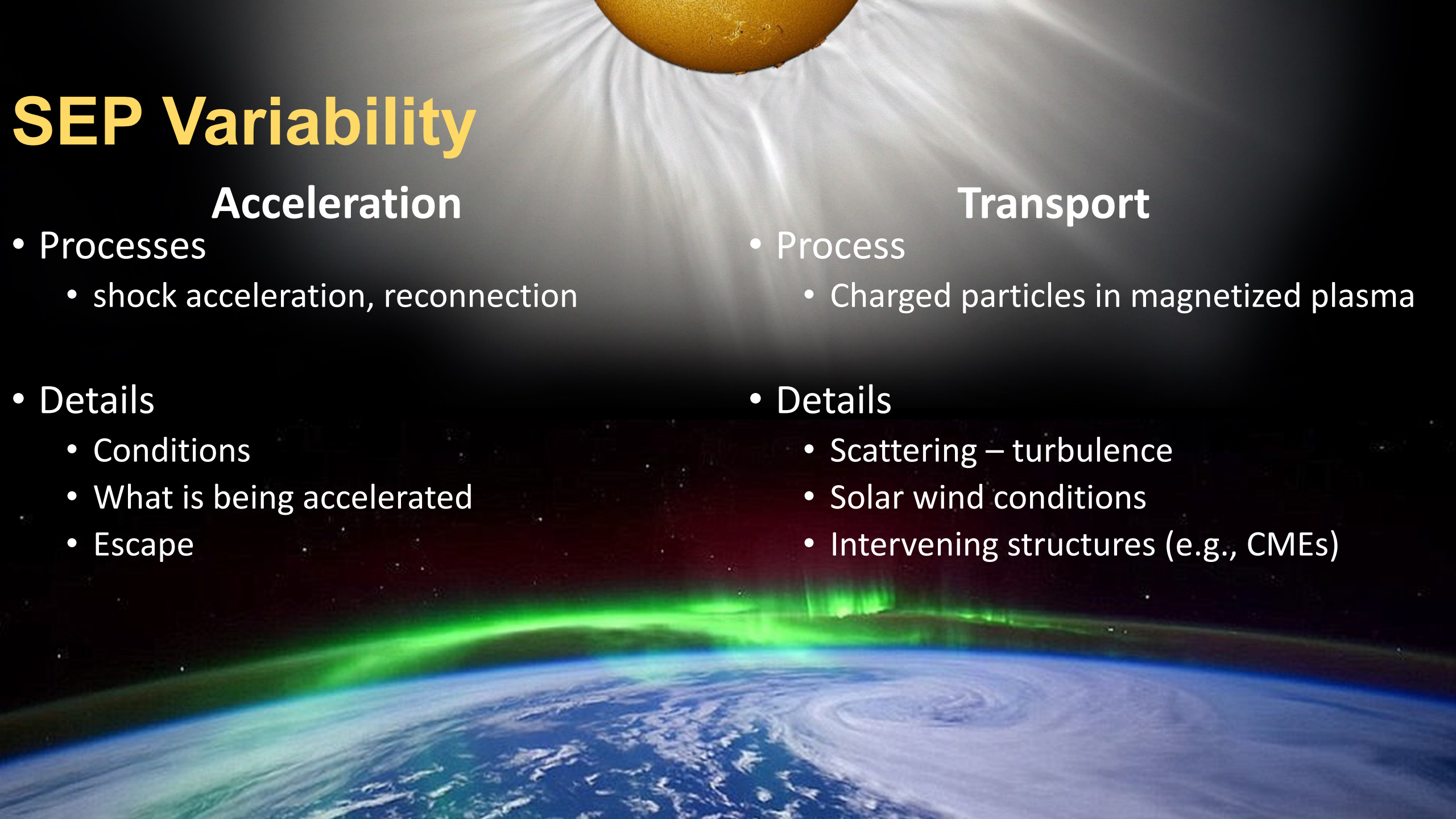
Acceleration

- 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)

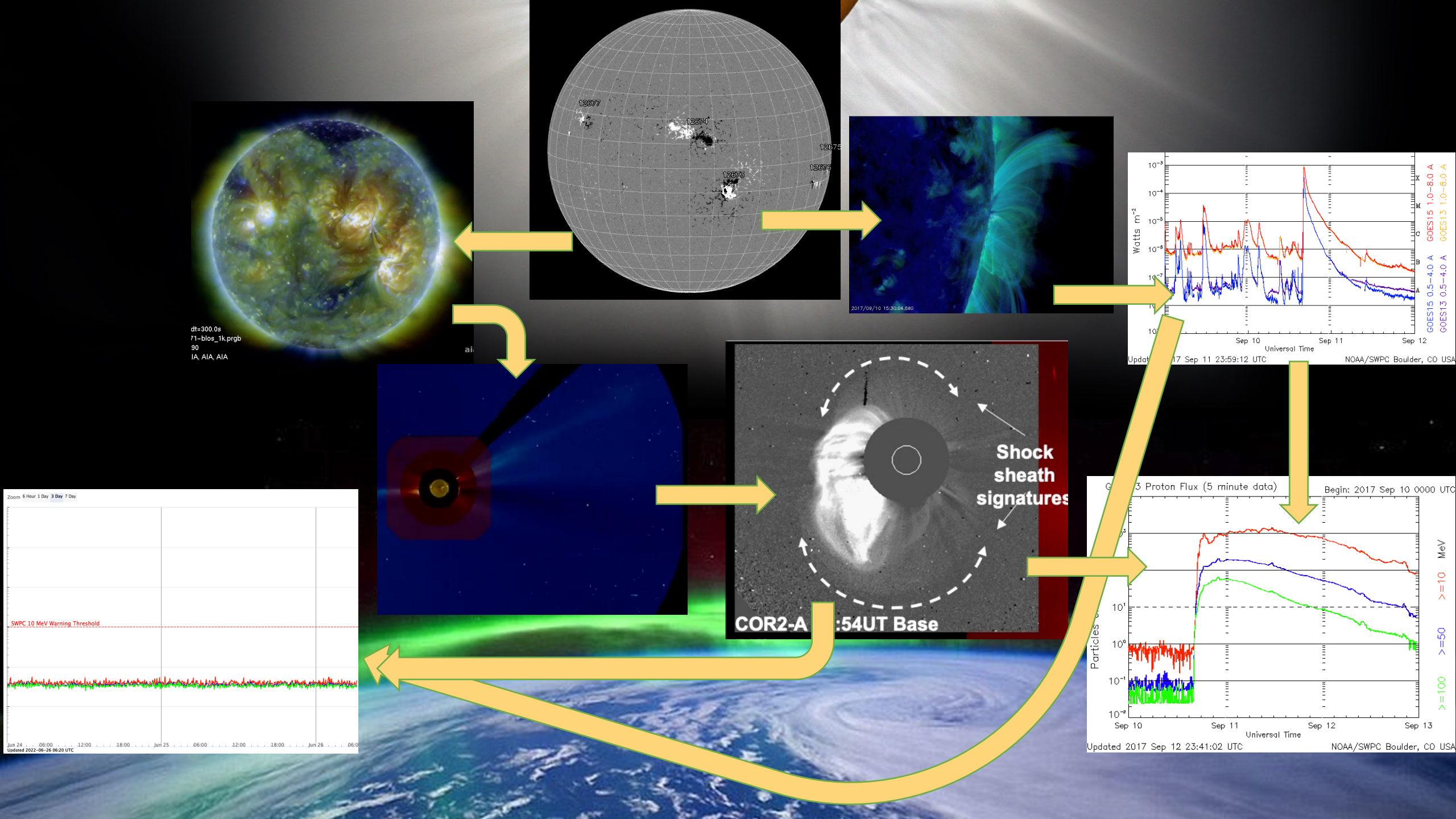
SEP Variability

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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12675
12676
12673
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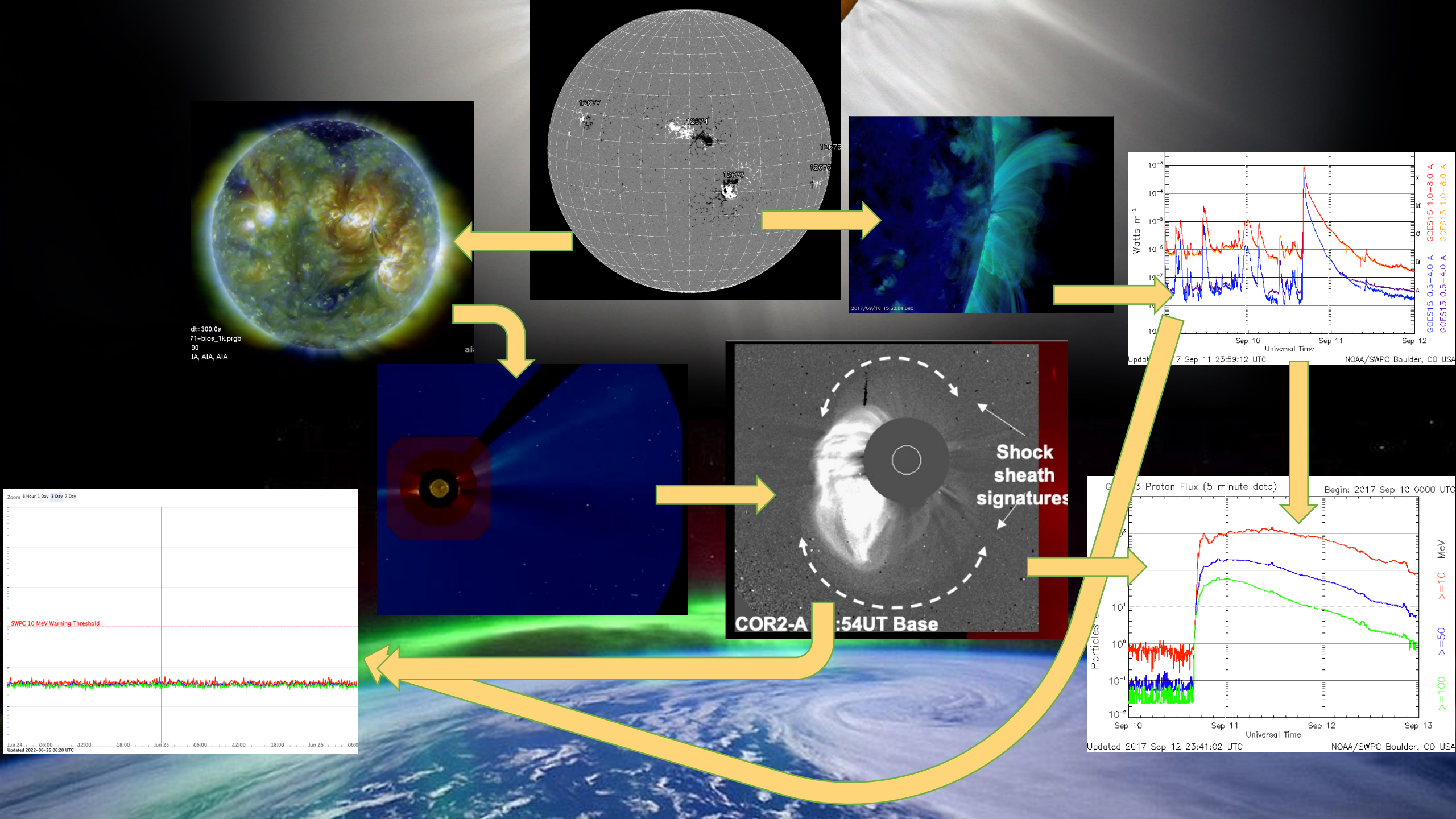
71-blos_1k.prgb
90
IA, AIA, AIA
2017/09/10 15:30:04.880
Watts m-2
GOES15 1.0-8.0 A
GOES13 1.0-8.0 A
GOES15 0.5-4.0 A
GOES13 0.5-4.0 A
Sep 10
Sep 11
Sep 12
Universal Time
NOAA/SWPC Boulder, CO USA
Shock
sheath
signatures
COR2-A
:54UT Base
Zoom 6 Hour 1 Day 3 Day 7 Day
SWPC 10 MeV Warning Threshold
Jun 24
06:00
12:00
18:00
Jun 25
06:00
12:00
18:00
Jun 26
Updated 2022-06-26 06:20 UTC
Begin: 2017 Sep 10 0000 UTC
Particles
MeV
>=10
>=50
>=100
Sep 10
Sep 11
Sep 12
Sep 13
Universal Time
Updated 2017 Sep 12 23:41:02 UTC
NOAA/SWPC Boulder, CO USA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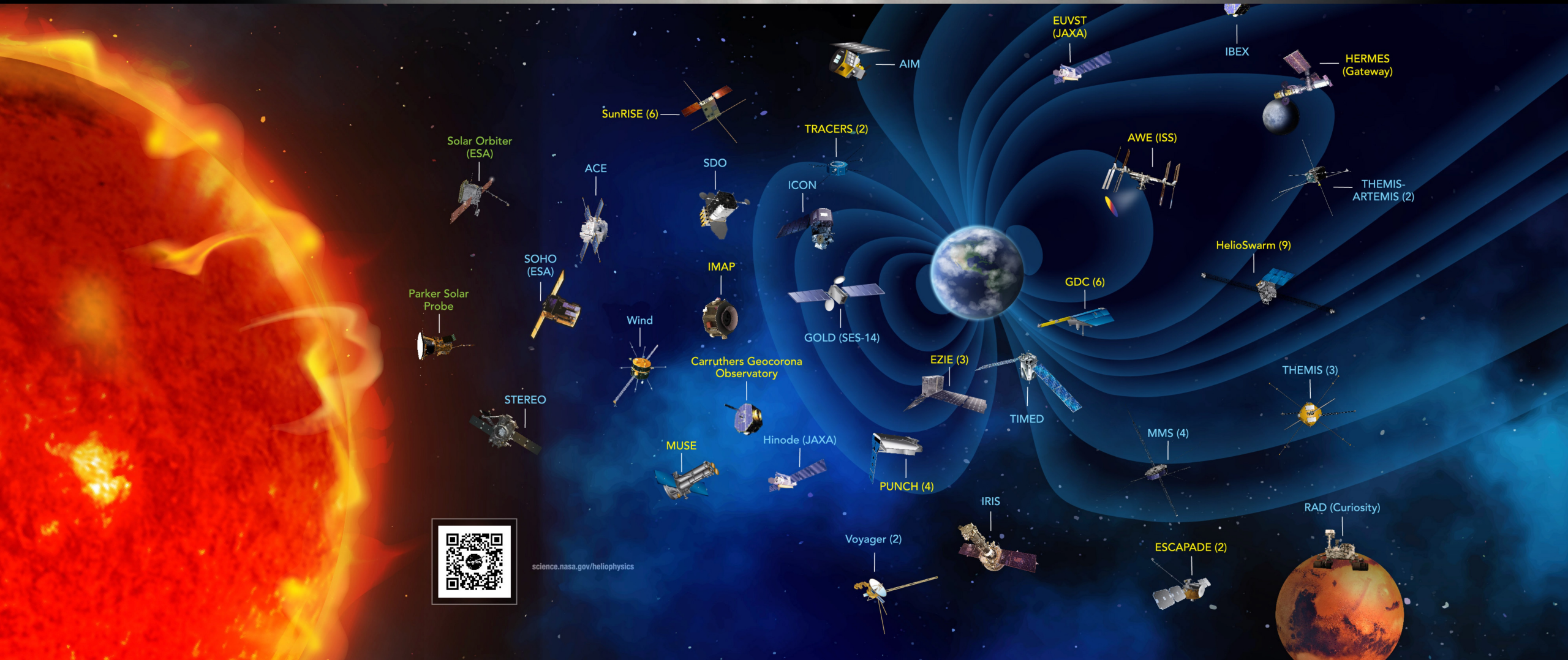
Observational Limitations



Los Ange

San Diego

North Pacific Ocean

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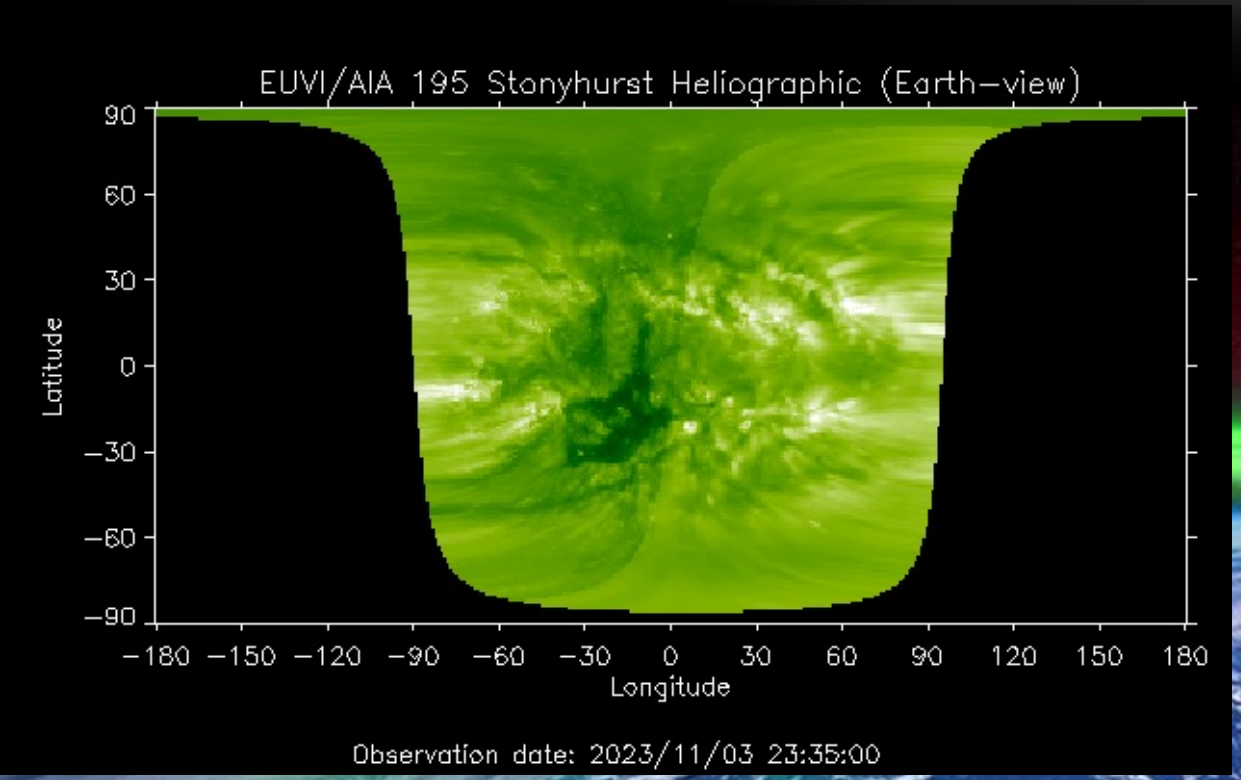
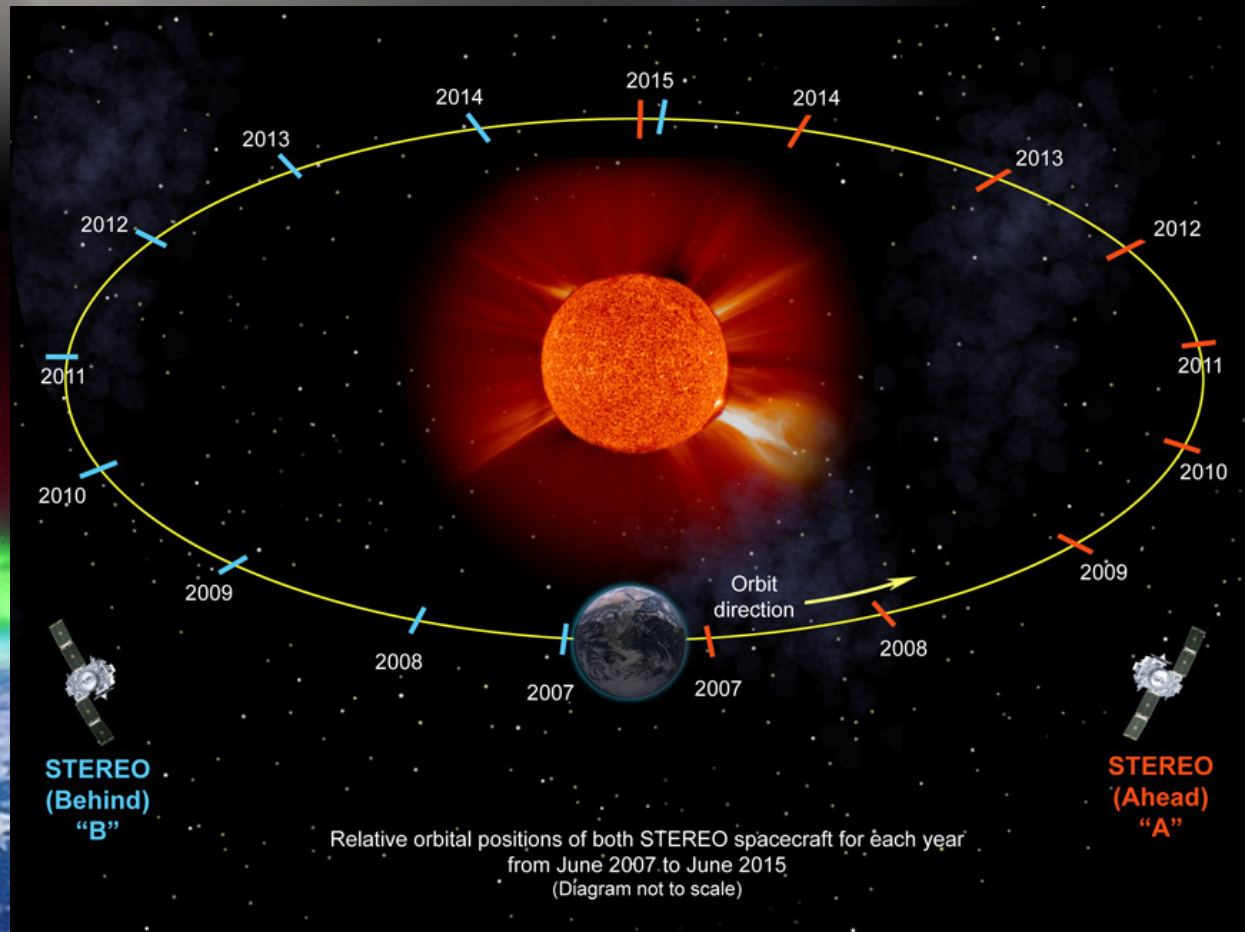
VAI'I


Vancouver
Chicago
Seoul
Tokyo
Shanghai
San Francisco
STEM OBSERVATORY
Dallas
Houston
Mexico City
Philippine Sea
North Pacific Ocean
Tropic of Cancer
Micronesia
Equator
Melanesia
Coral Sea
??

Observational Limitations

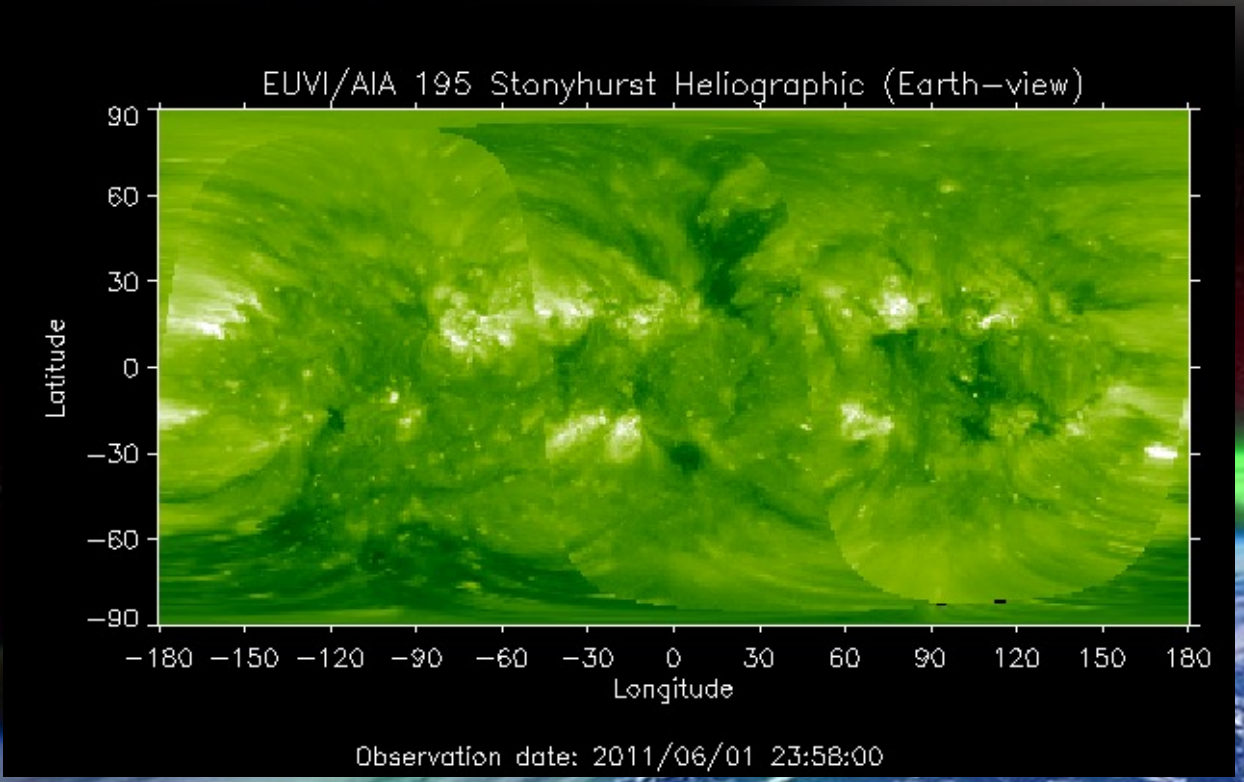
- You don’t know what you can’t see
  - Dark side of the Sun

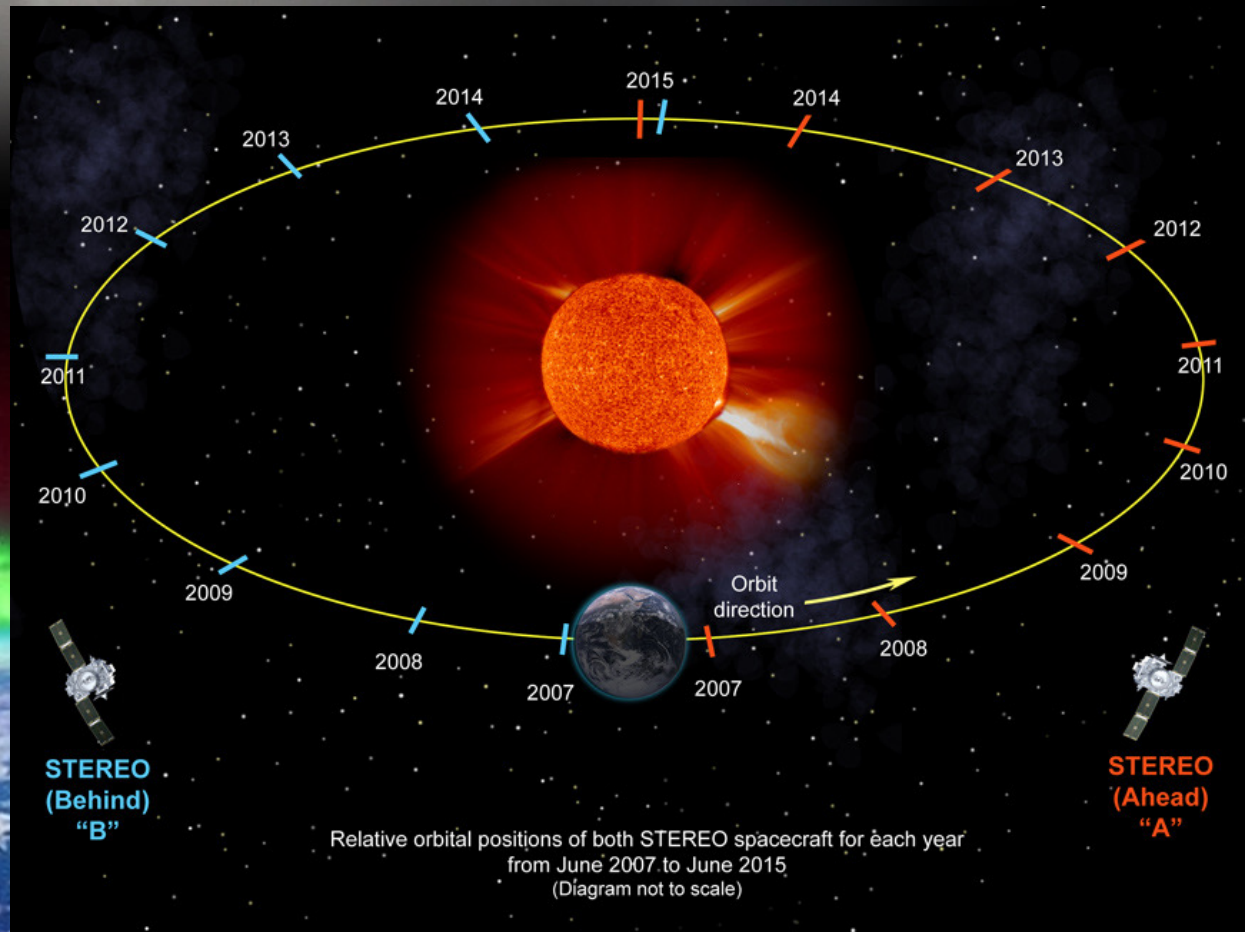




Observational Limitations

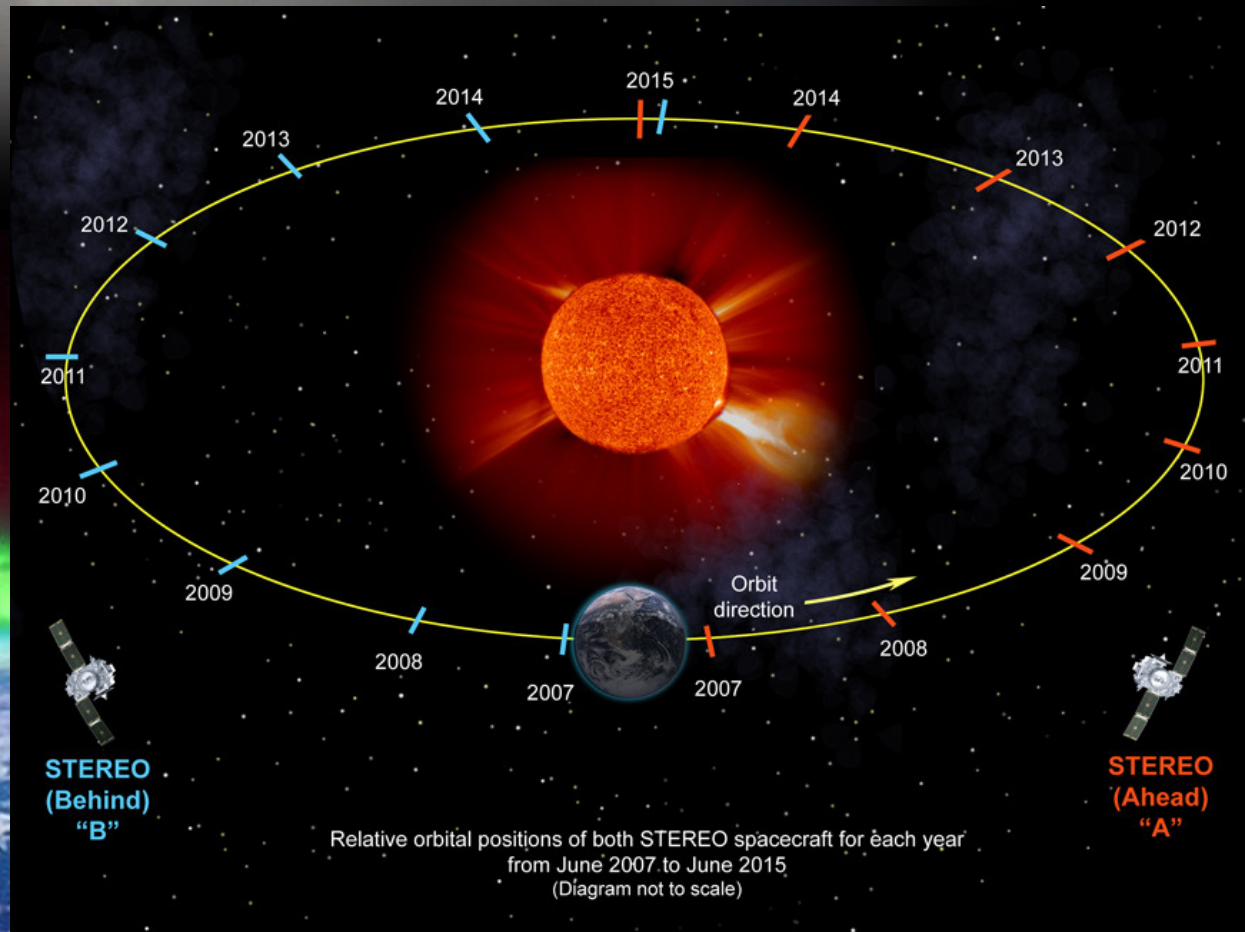
- You don’t know what you can’t see
  - Dark side of the Sun - illuminated





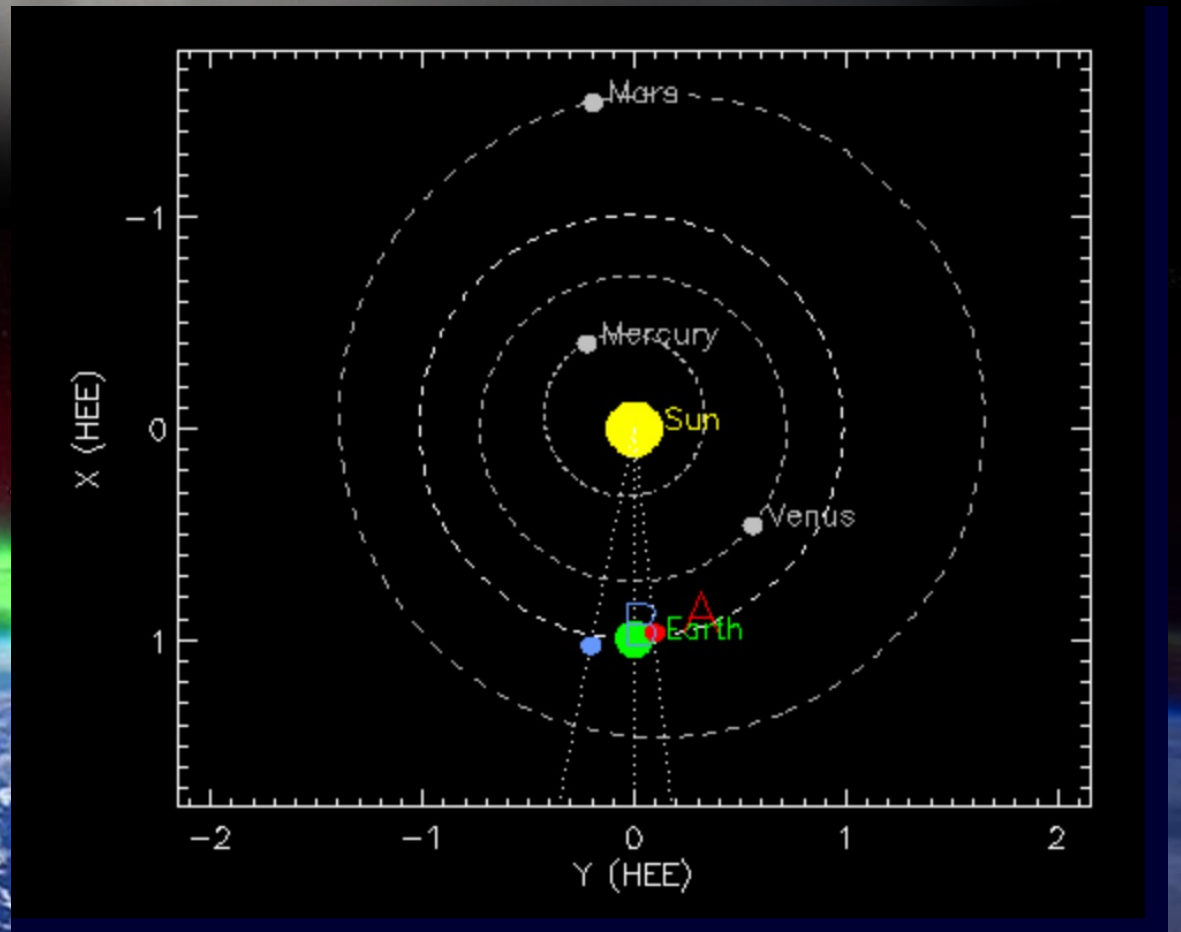
Observational Limitations

- 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



Los Ange

San Diego

North Pacific Ocean

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VAI'I

North Pacific Ocean

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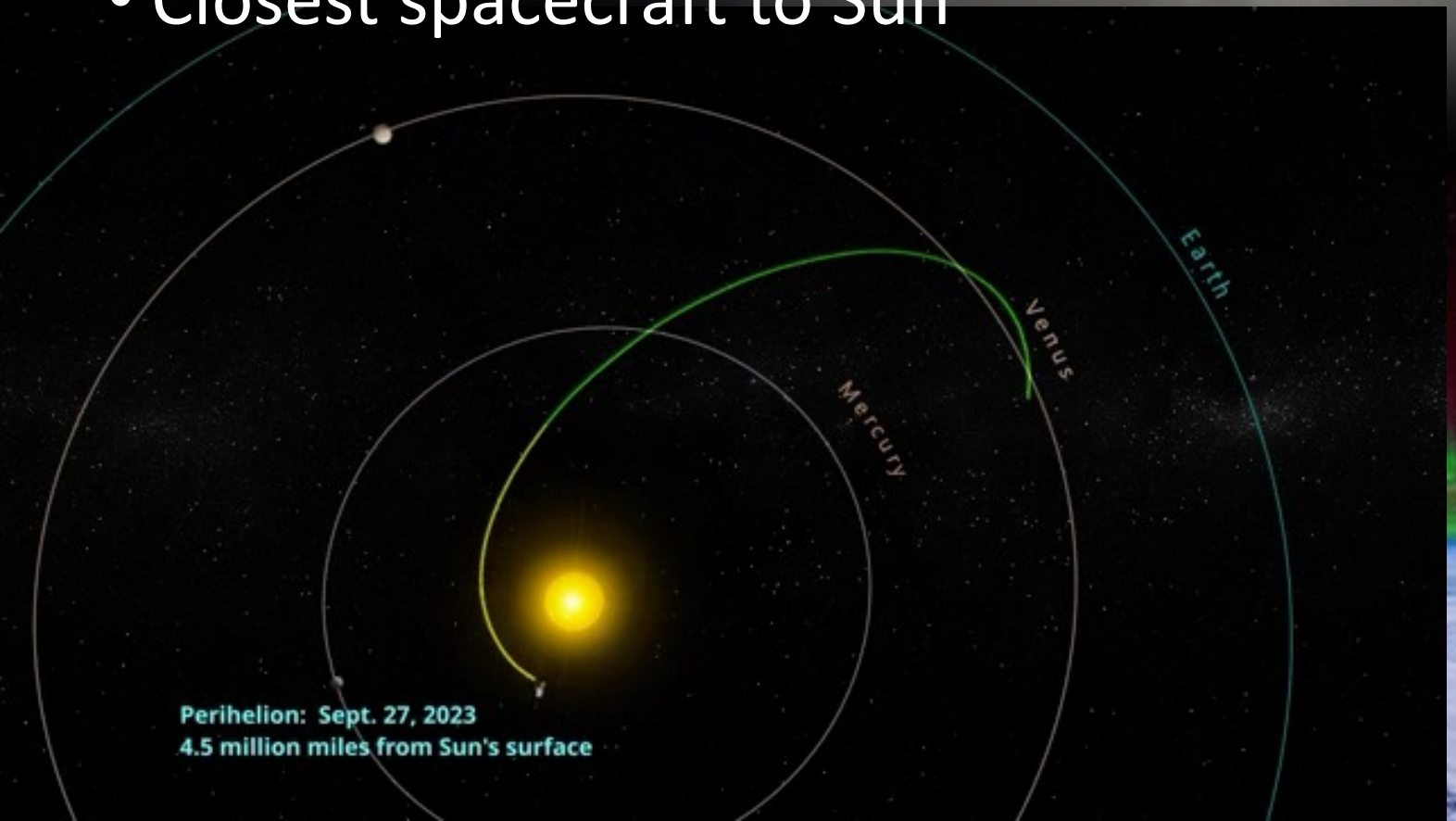
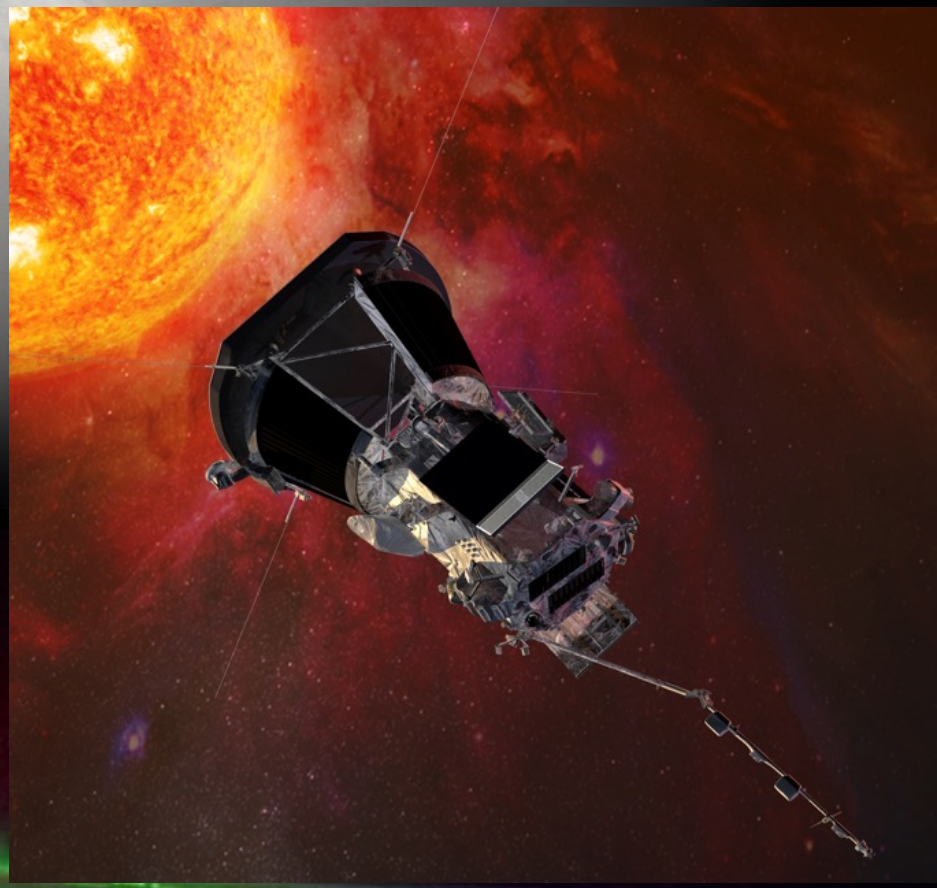
VAI'I

New Assets

- Parker Solar Probe
  - Closest spacecraft to Sun





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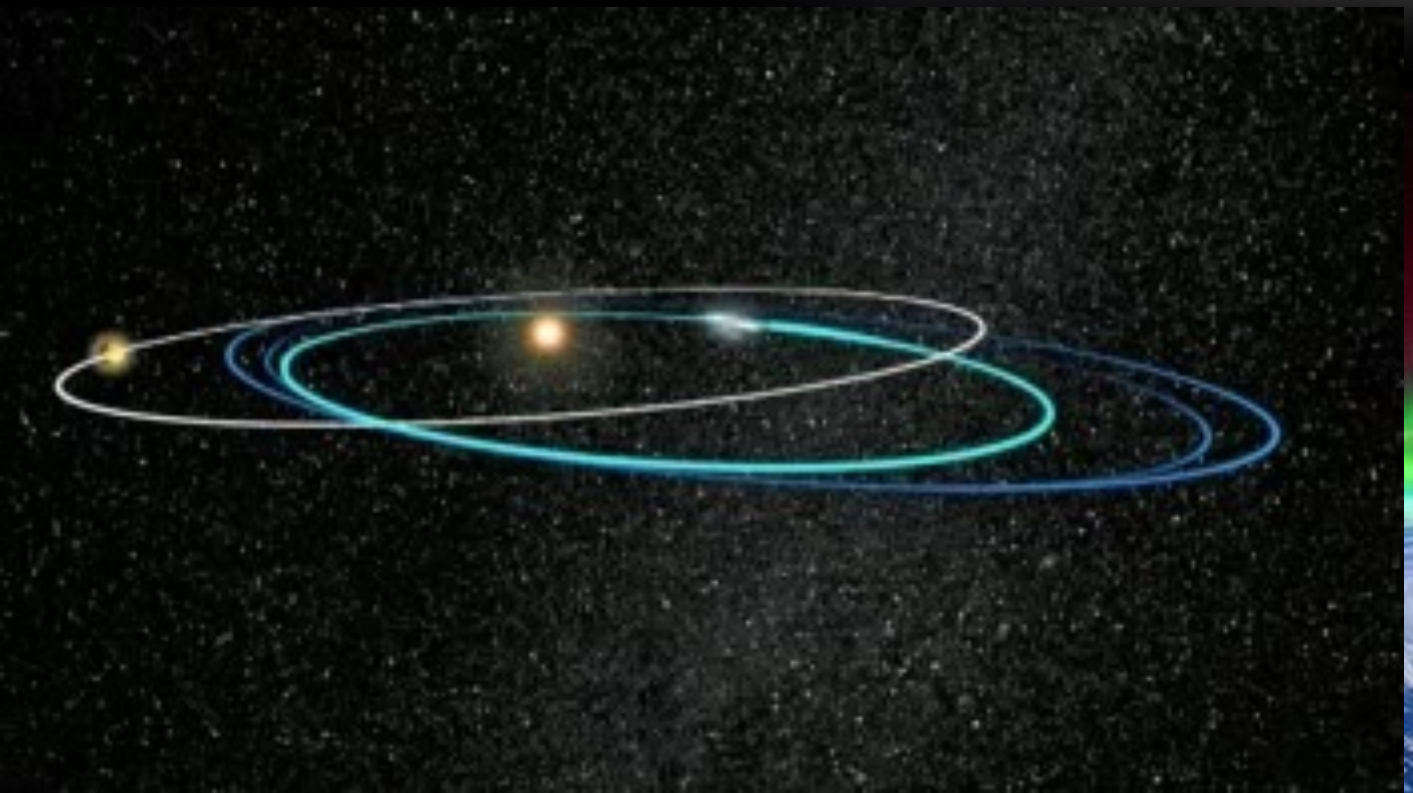
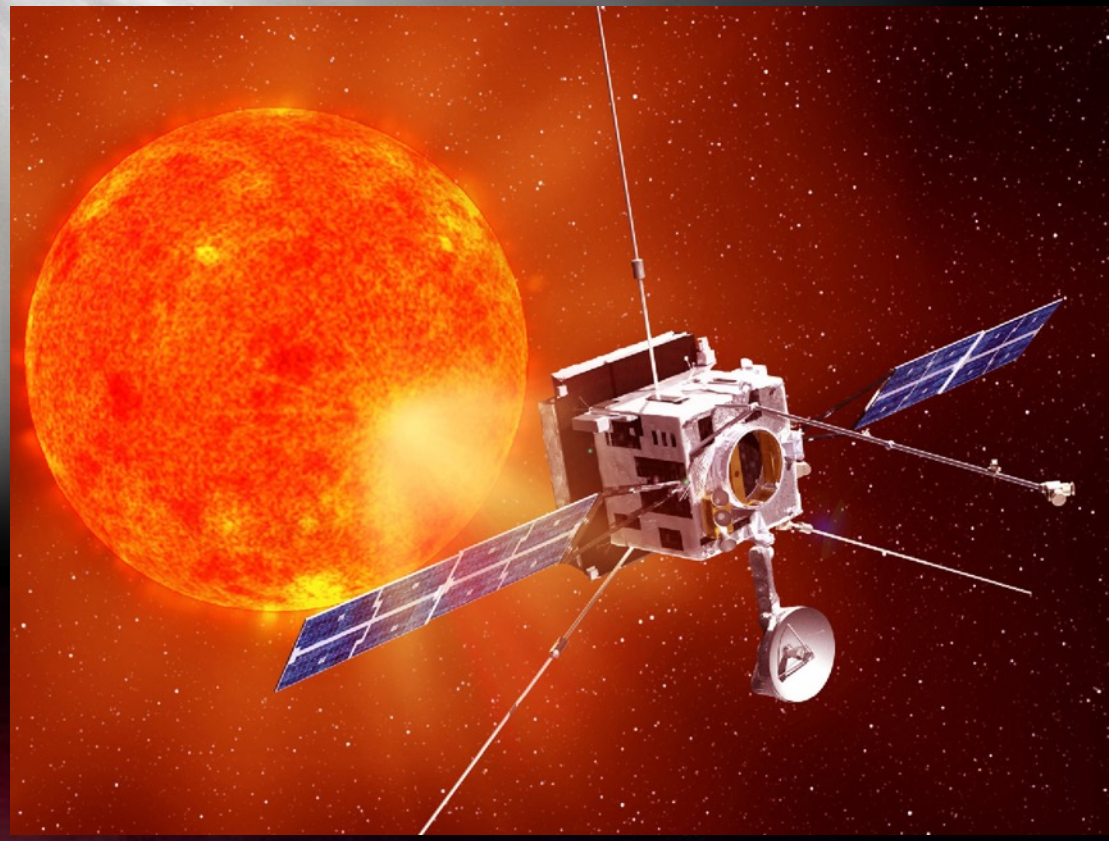
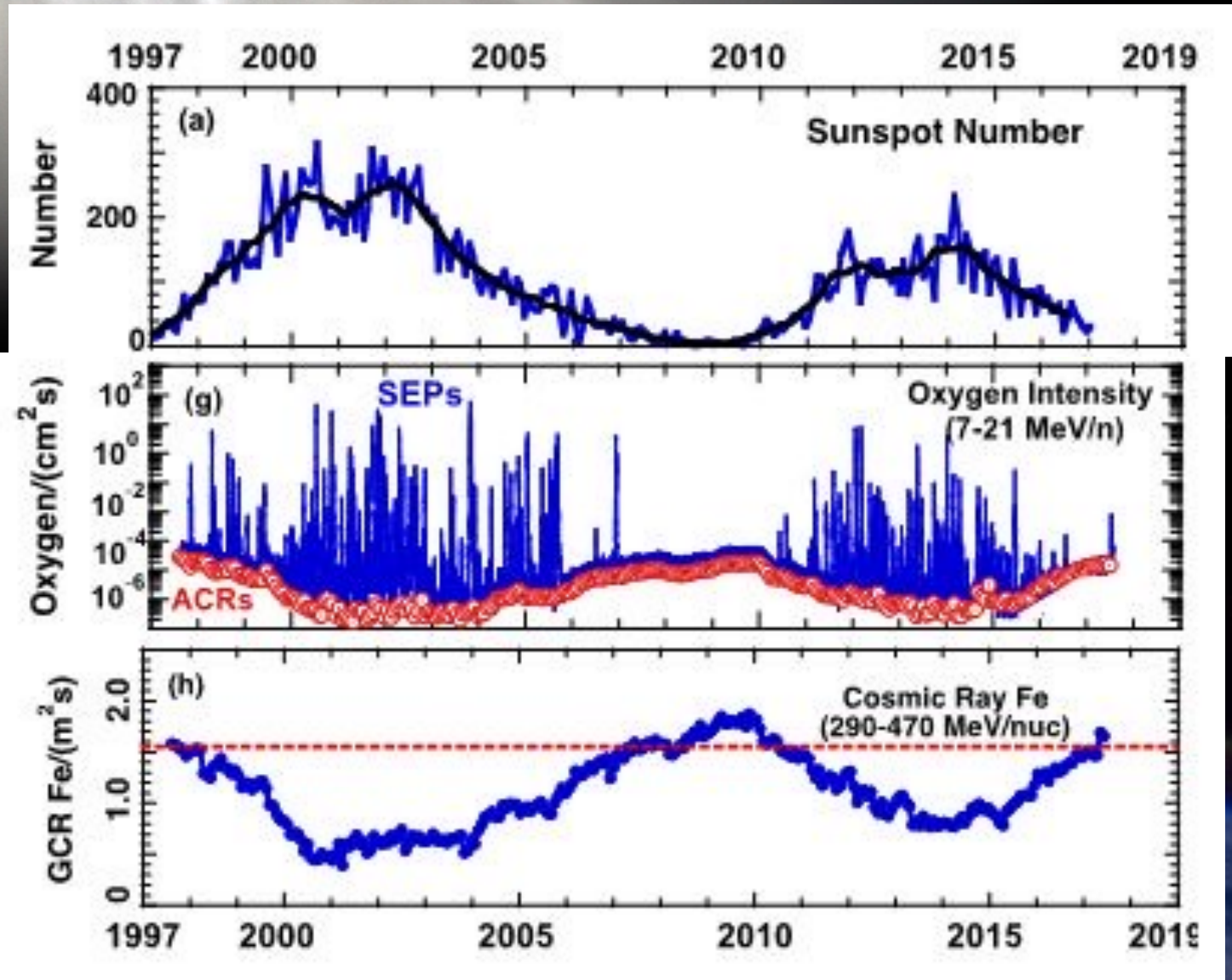




- Solar Orbiter
  - Close to Sun
  - Out of ecliptic

Solar Cycle and Pre-Space-Age

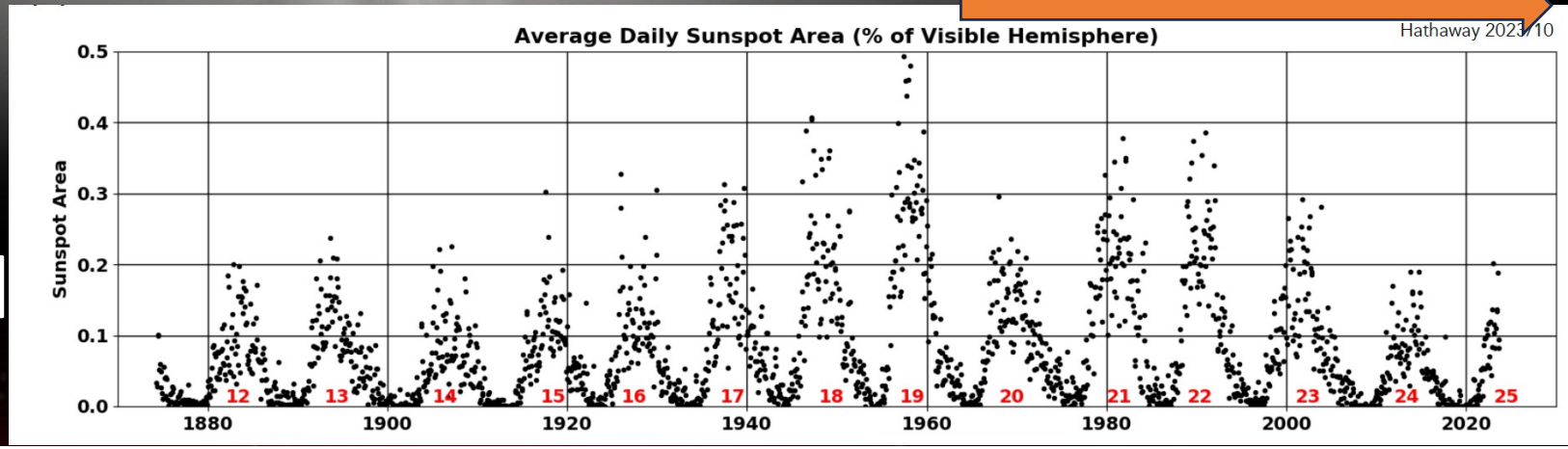
- SEP events vary over solar cycle

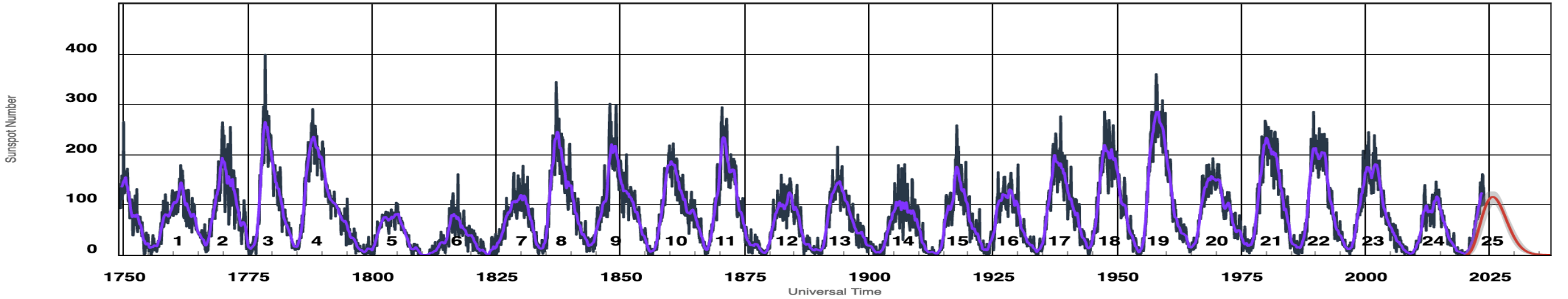


Solar Cycle and Pre-Space-Age

- SEP events vary over solar cycle
- In-situ measurements only over short period

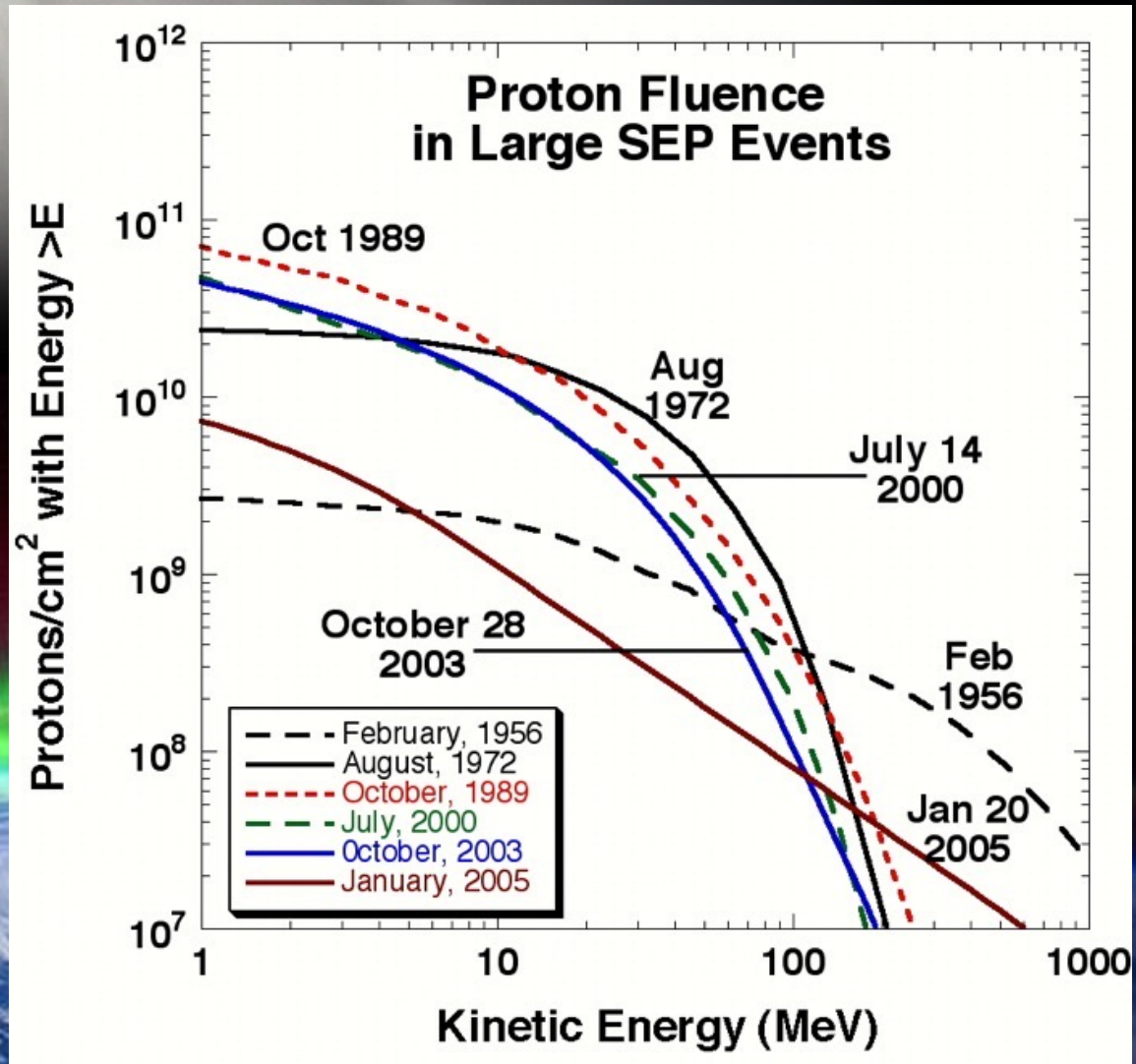
Space Age





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



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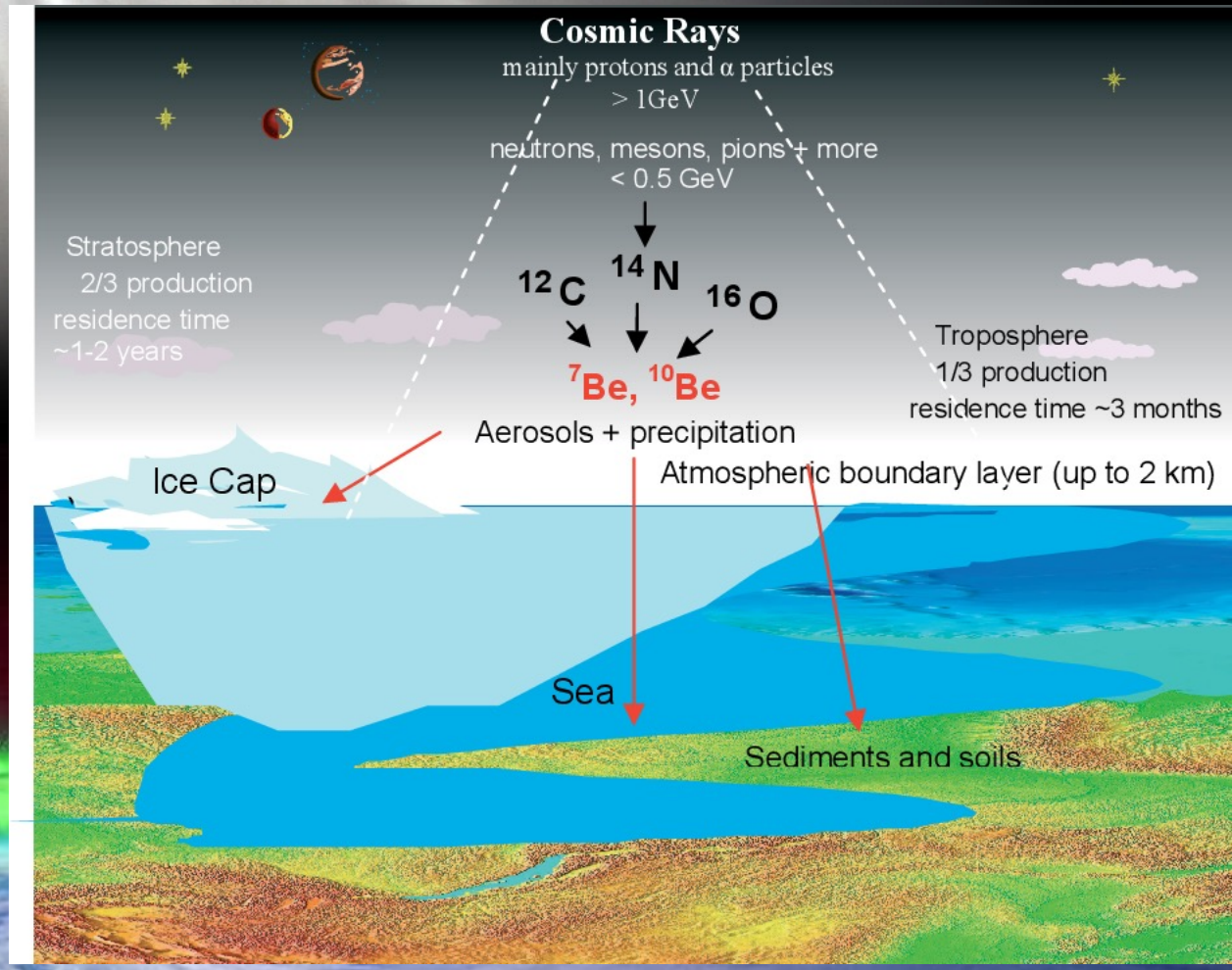
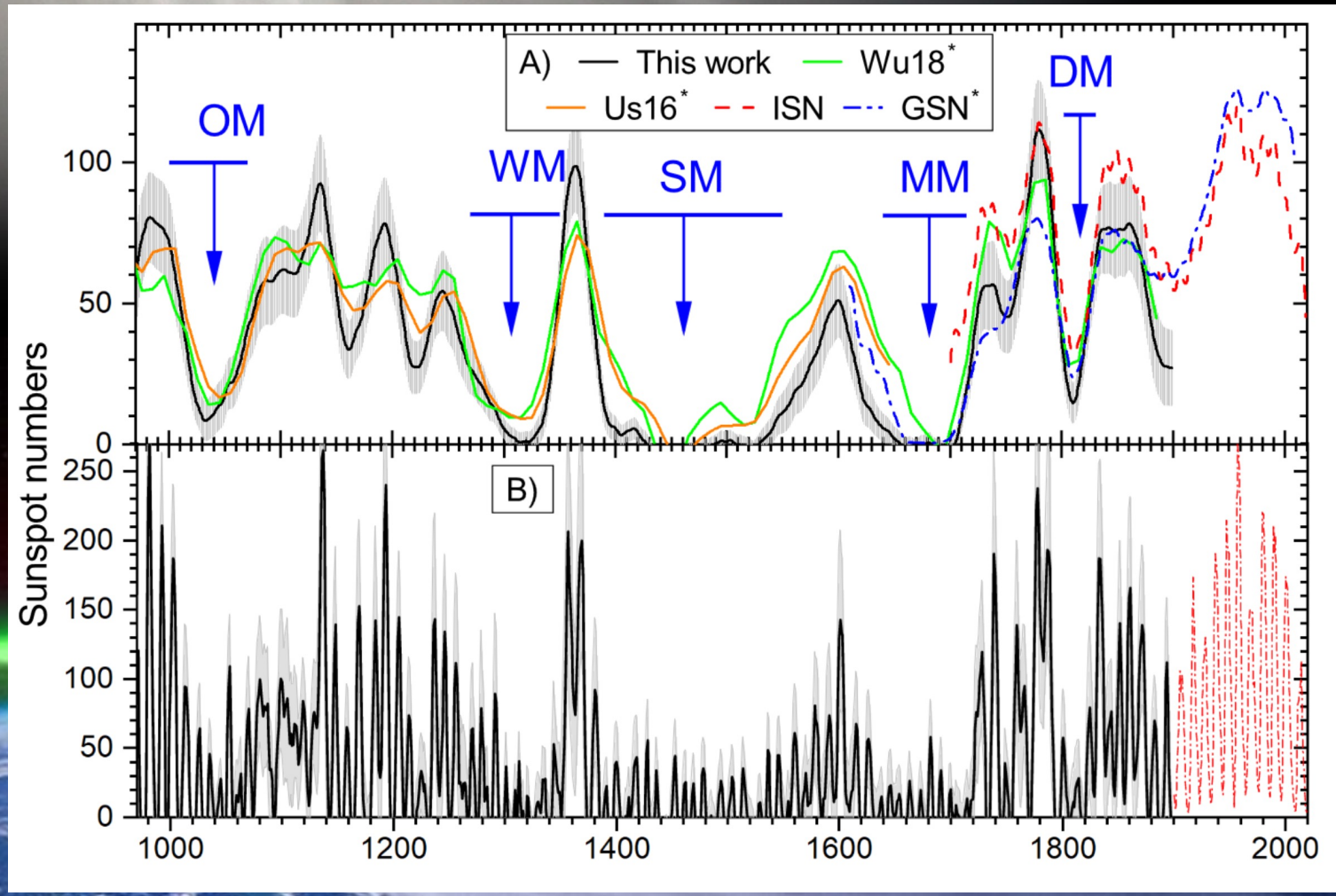


Tree rings & Ice Cores

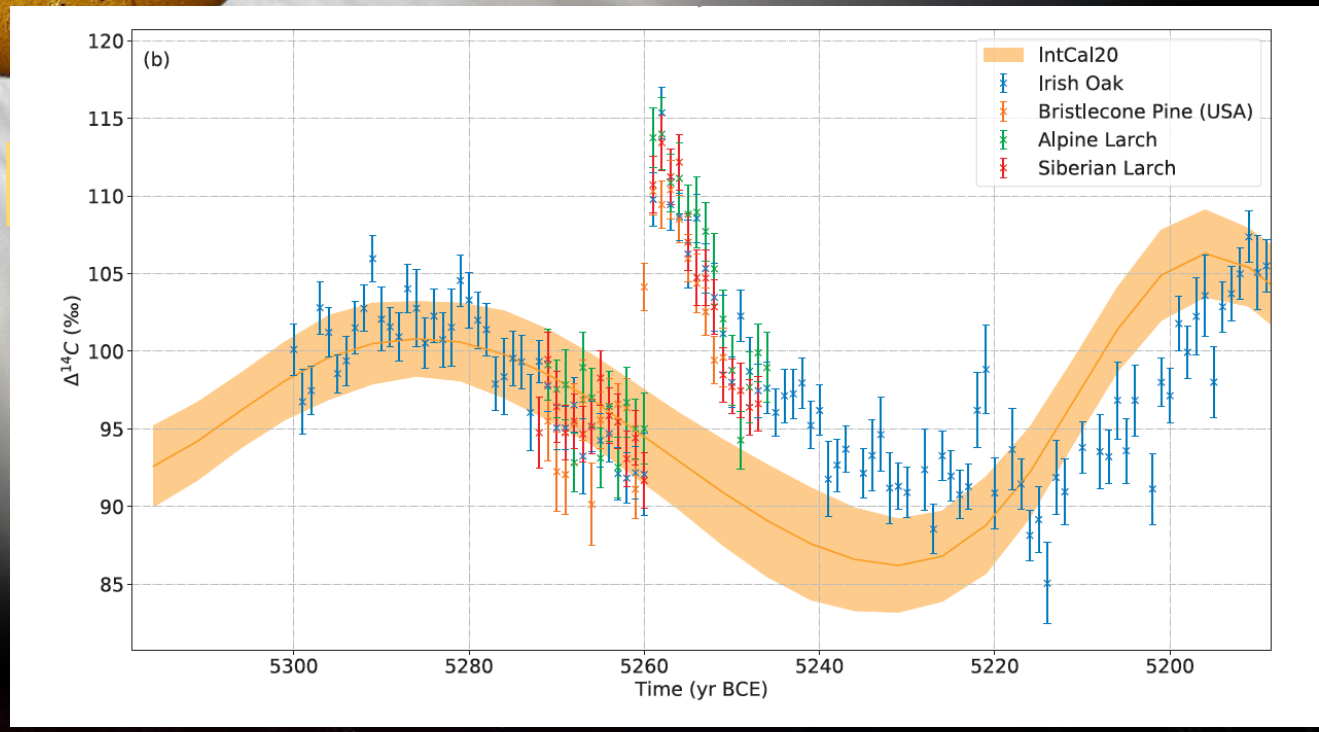
Solar Cycle and Pre-Space-Age

- ^{14}C from tree rings
  - Reconstruction of SSN

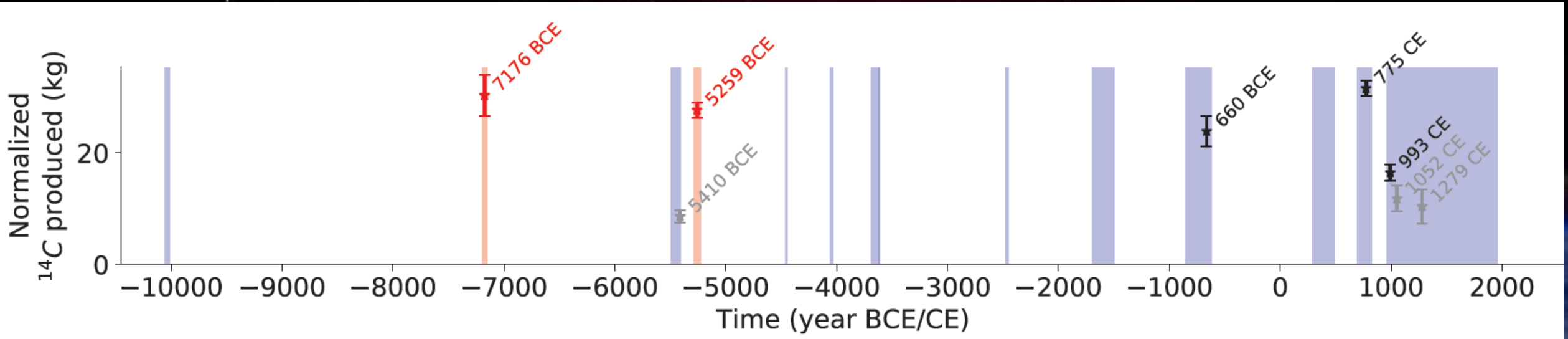


Solar Cycle and Pre-S

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

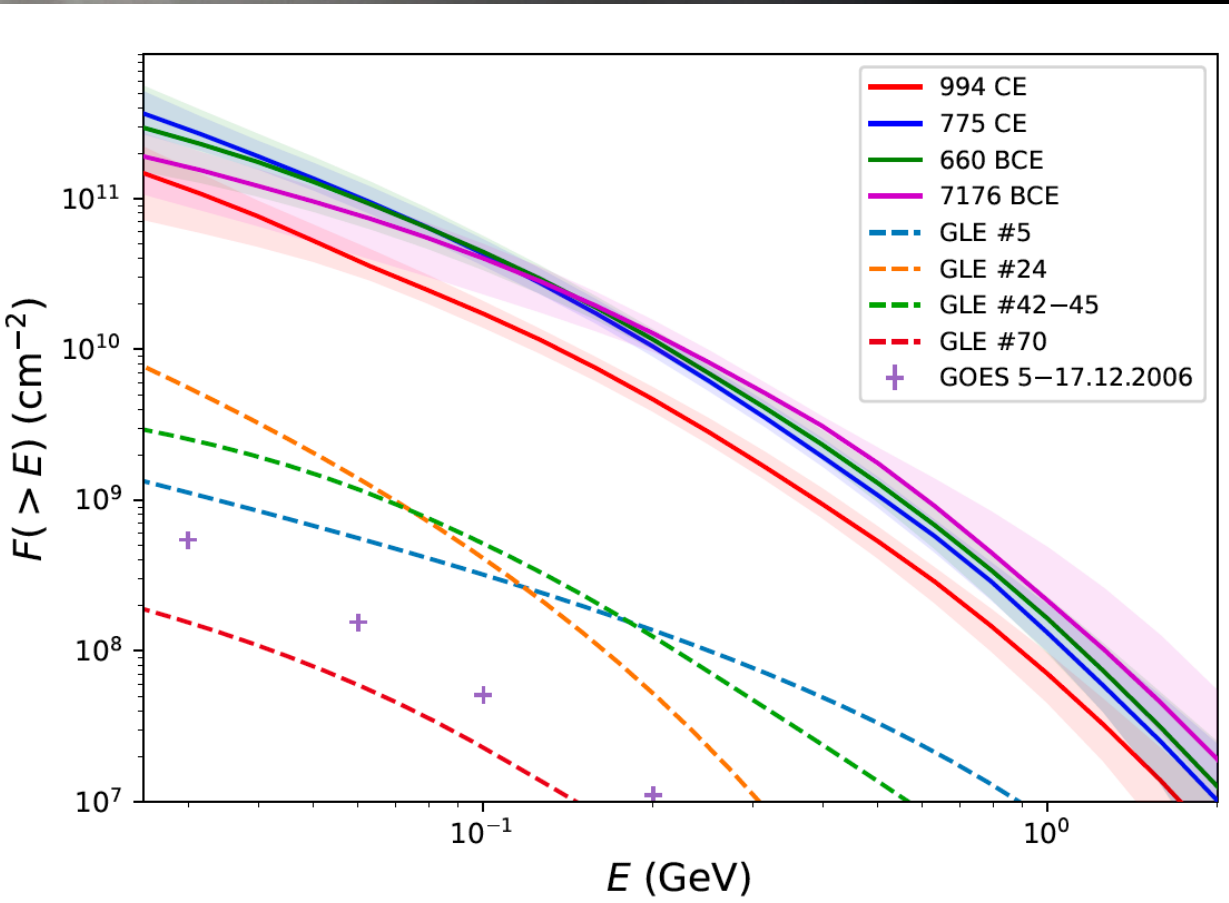


Only 16.5% examined



Solar Cycle and Pre-Space-Age

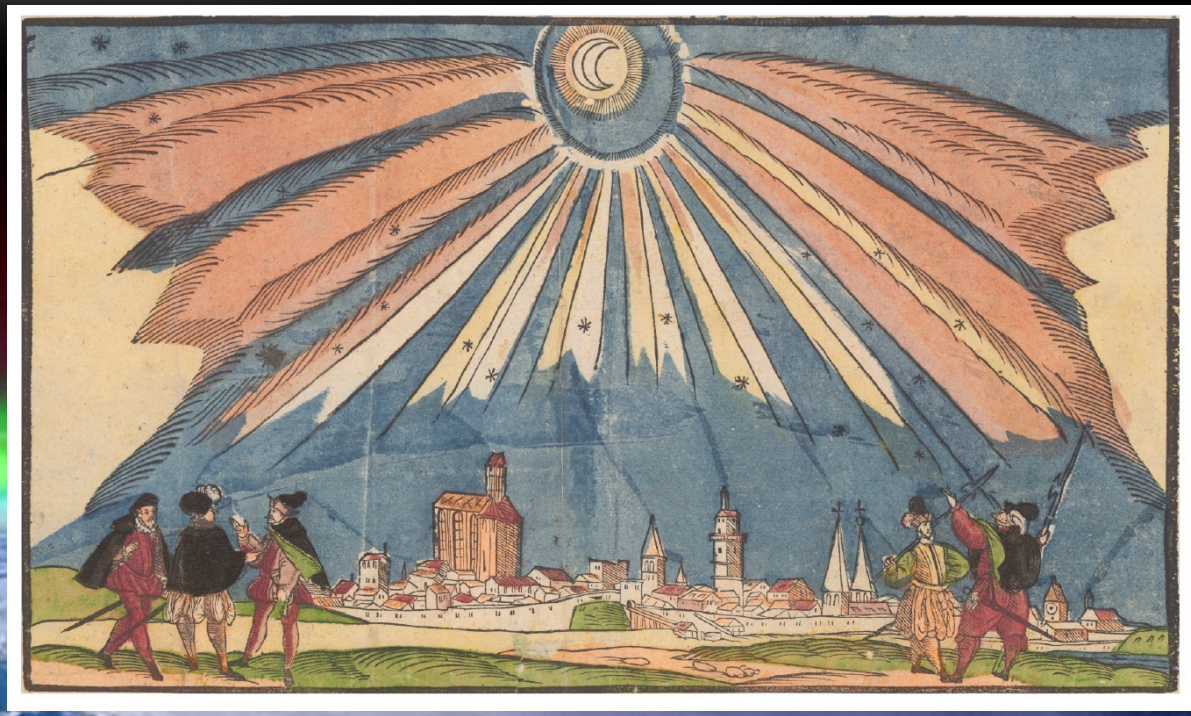
- ^{14}C from tree rings
  - Reconstruction of SSN
- & $^{10}Be/^{36}Cl$ ice cores
  - 5 extreme events + 3 possible
  - All much bigger than space-age
  - No current events have Cl sig.
  - Carrington event (1859) also no



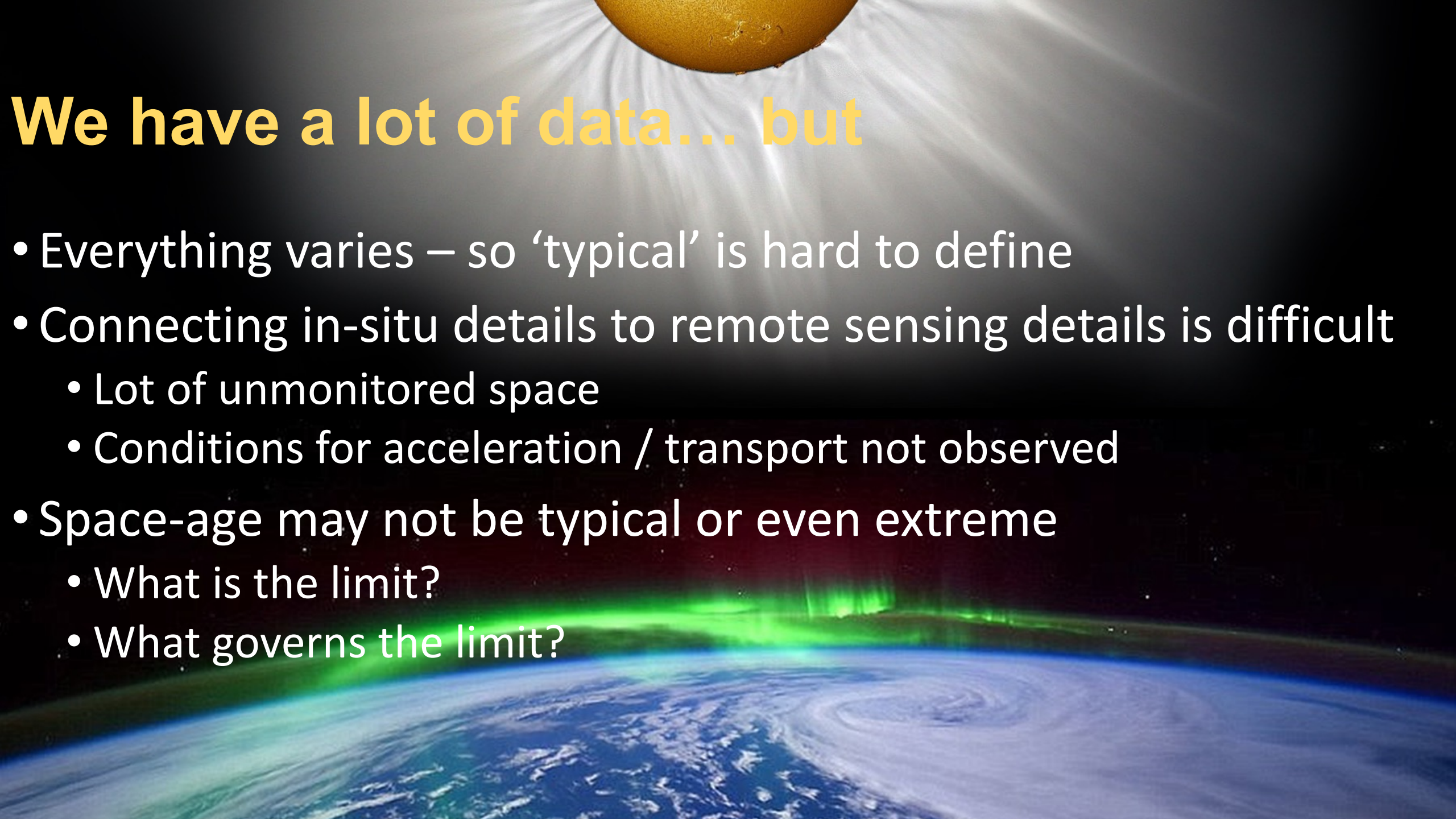
Solar Cycle and Pre-Space-Age

- ^{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?