SEPs and other energetic particles

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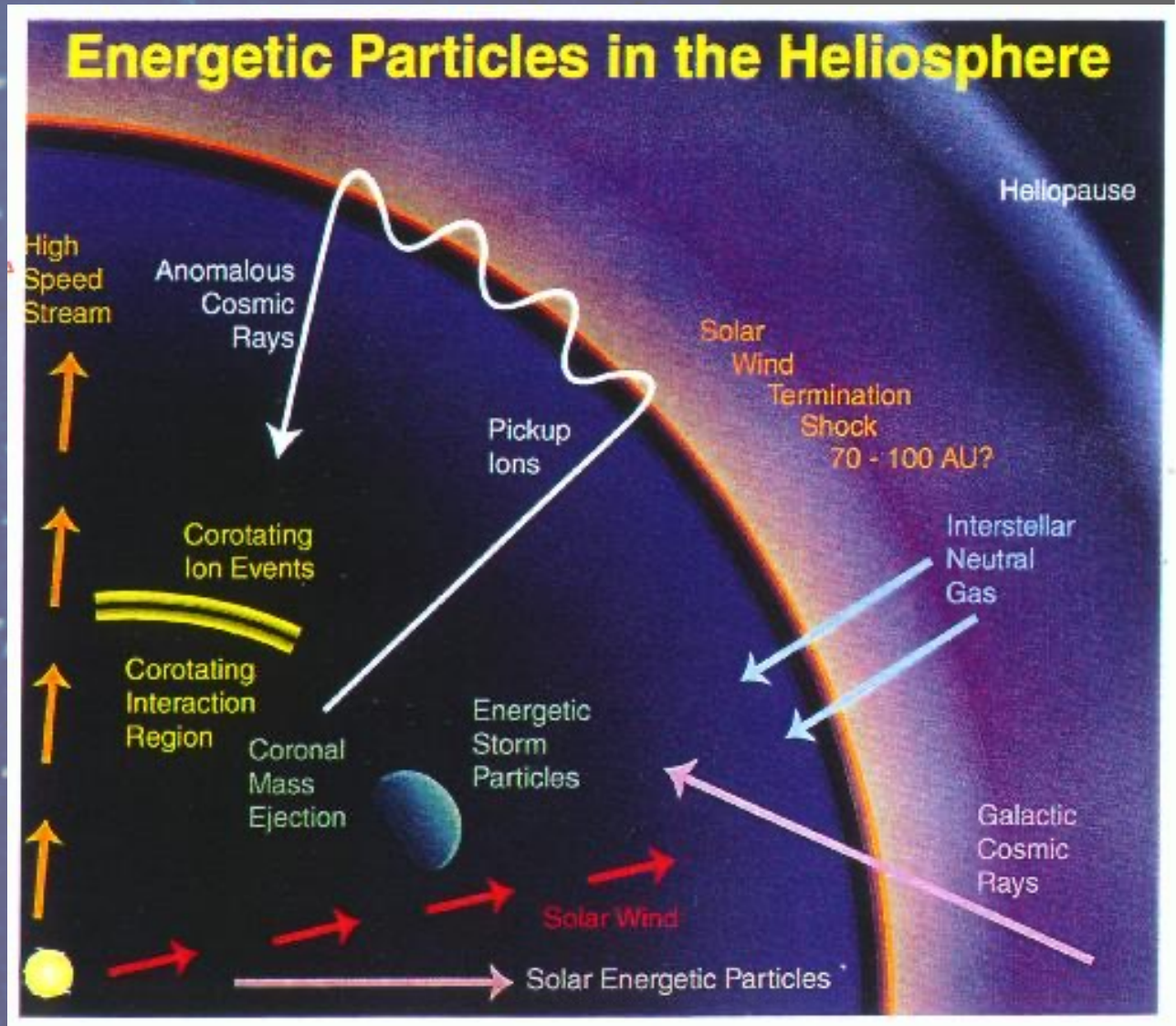
Caltech

Types of Energetic Particles

- Galactic Cosmic Rays (GCRs)
- Anomalous Cosmic Rays (ACRs)
- Radiation belt particles (planets, mostly Earth and Jupiter have been studied)
- Solar Energetic Particles (SEPs)



What are SEPs?

- Solar Energetic Particles
  - Solar = assumed to originate at the Sun
  - Energetic = historically above a few hundred keV/nuc
  - Particles = ions (mostly H, He like the Sun) + electrons
- Seen as increases in counting rates of ions (and/or electrons) of energies usually above 0.1 MeV/nucleon

What is the History of SEPs?

- First detection with connection to solar flare observation - Forbush 1946 in neutron monitor
- Timing related to gamma ray flare 1956 (most well studied)
- Better in space because can see them directly
  - intensity
  - energy spectra
  - composition

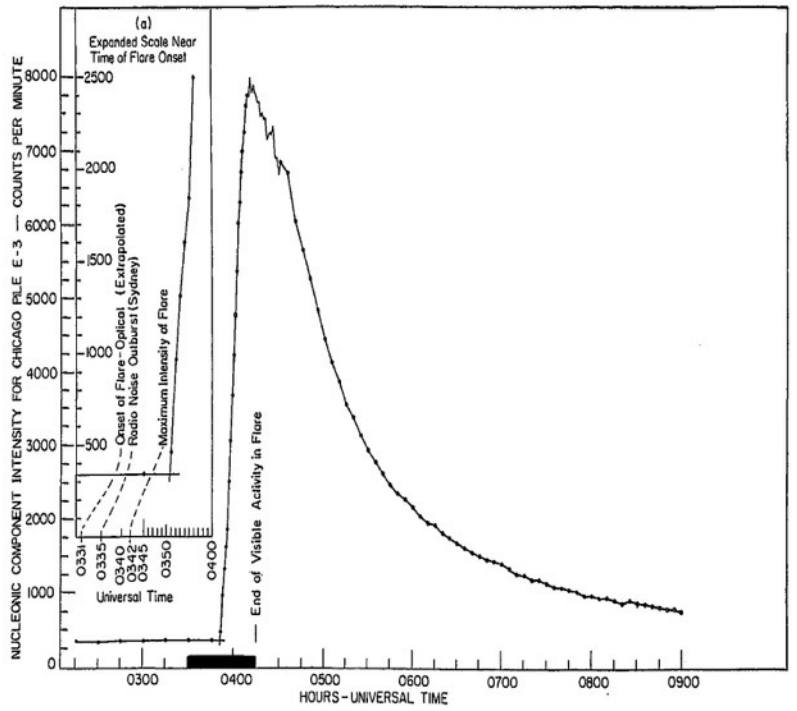


FIGURE 2. Chicago neutron monitor record of the ground level event of 23 February 1956 (adapted from 5).

What is the History of SEPs?

- At the same time…
  - flares are being categorized by size, duration, emission wavelength
  - radio emission is being categorized
  - flares and radio emission combined to create…
- Two classes of flares
  - Impulsive
  - Gradual

What is the History of SEPs?

- Correlations with SEP characteristics results in a 2 class SEP system:

	Impulsive	Gradual
Flare Characteristics	Short duration Compact/Point Source	Long duration Large Source
Radio Characteristics	Type III/V	Type II/IV
Particle Characteristics	^{3}He, e^{-}, heavy ion rich short duration, small, limited longitude	SW like composition long duration, large, wide longitude

What is the History of SEPs?

Gradual

Impulsive

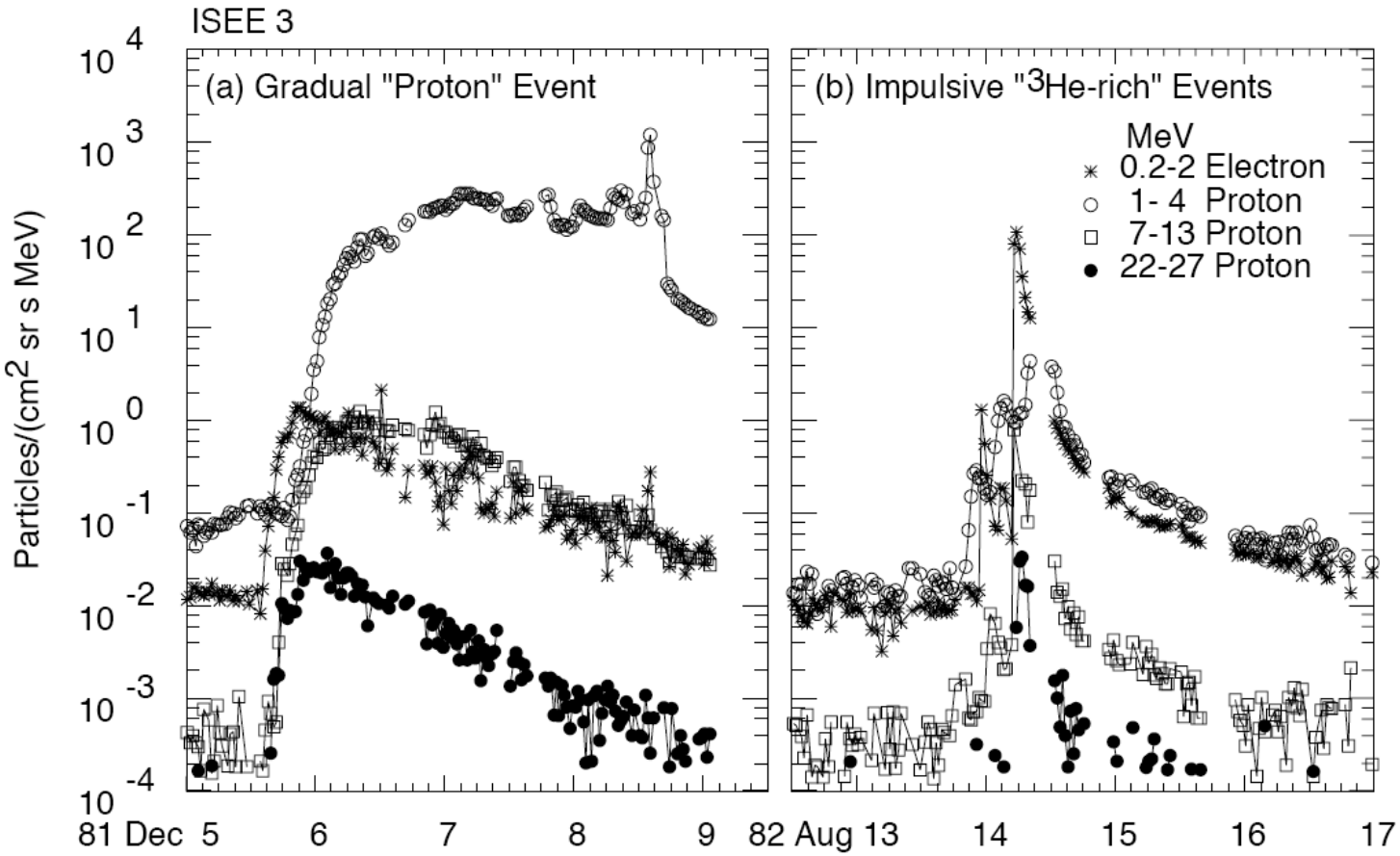


Figure 2.2. Intensity-time profiles of electrons and protons in 'pure' (a) gradual and (b) impulsive SEP events. The gradual event is a disappearing-filament event with a CME but no impulsive flare. The impulsive events come from a series of flares with no CMEs.

What is the History of SEPs?

- 'Paradigm Shift' (1980s)
  - Had 1 acceleration mechanism for all SEP events
  - Now have two independent acceleration mechanisms
    - CME-driven shock acceleration <=> Gradual SEP events
    - Impulsive flare acceleration <=> Impulsive SEP events
- ACE+ shake up
  - Not mutually exclusive
  - SEP properties not definitive

Reames 1999

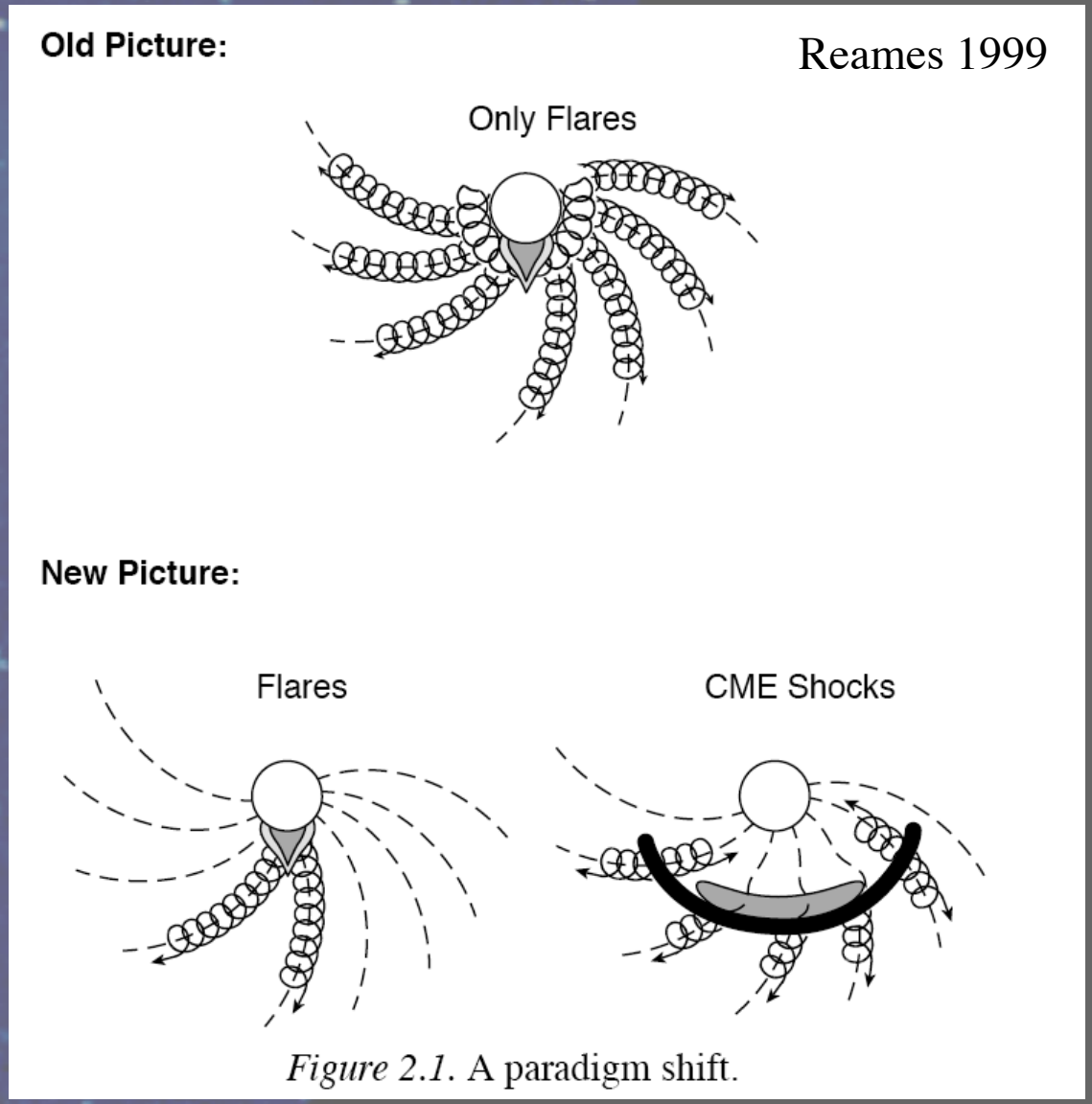
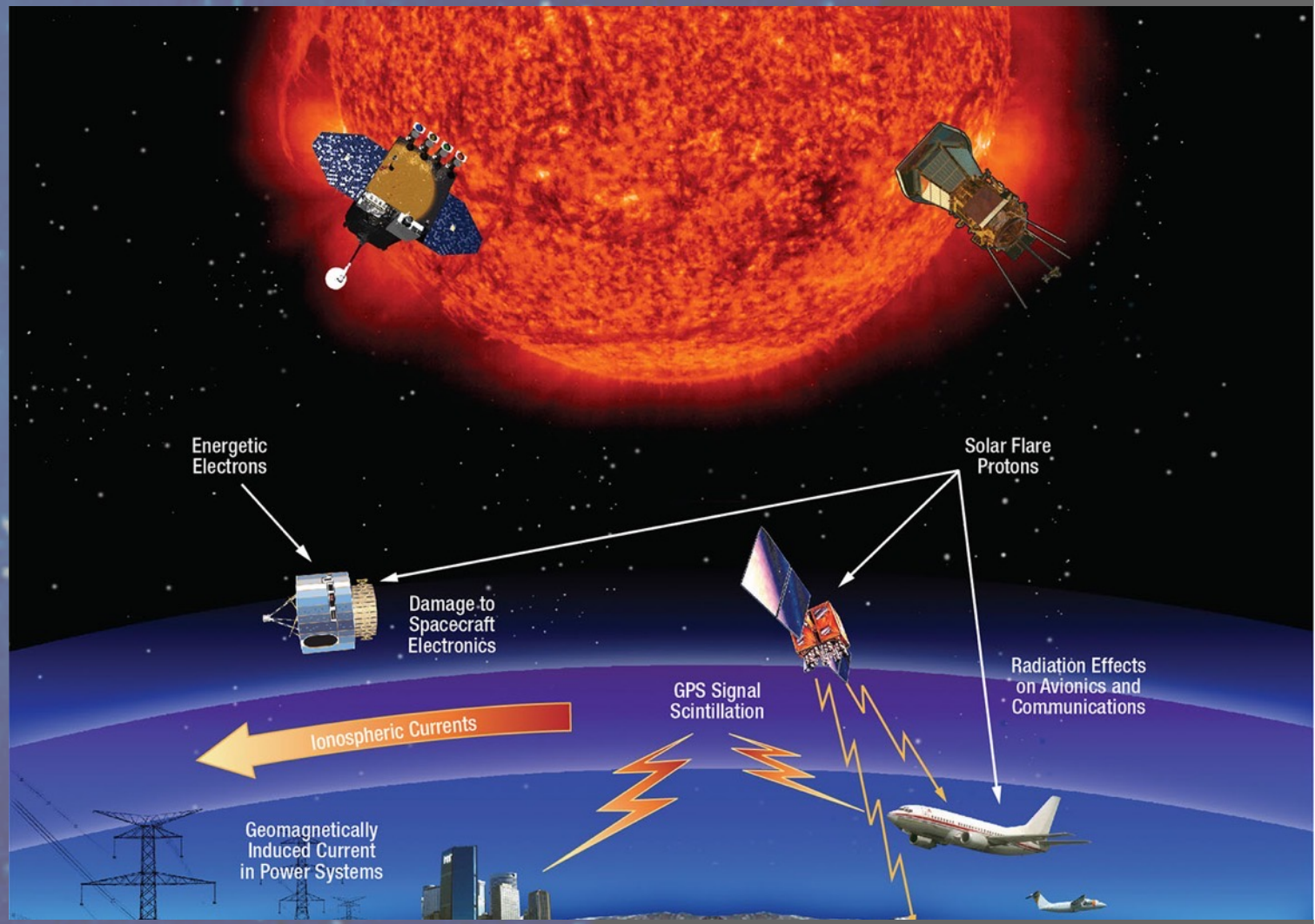


Figure 2.1. A paradigm shift.

Why Care About SEPs?

- Space weather concerns
  - Near Earth



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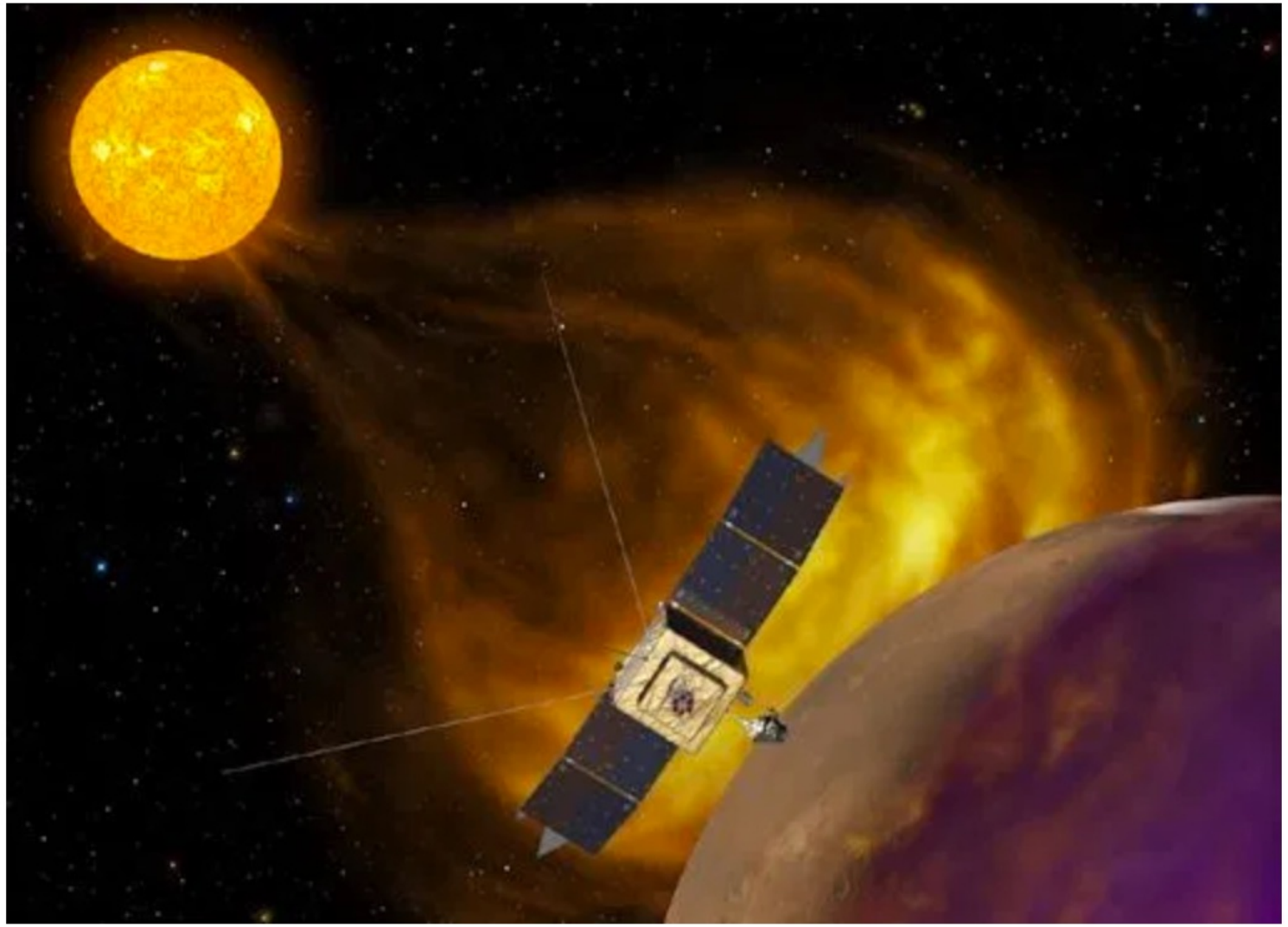

Why Care About SEPs?

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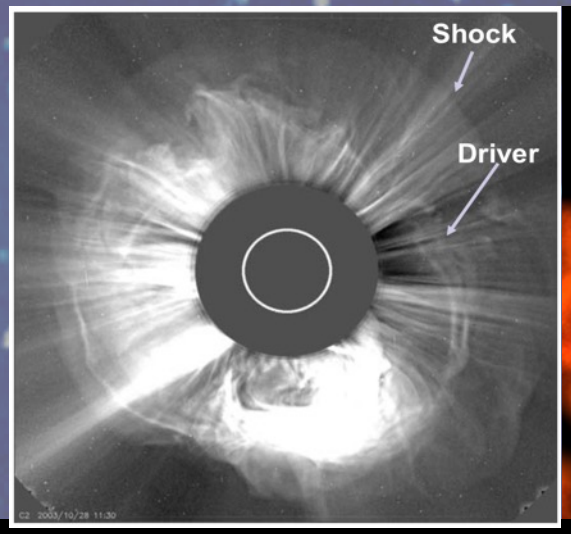
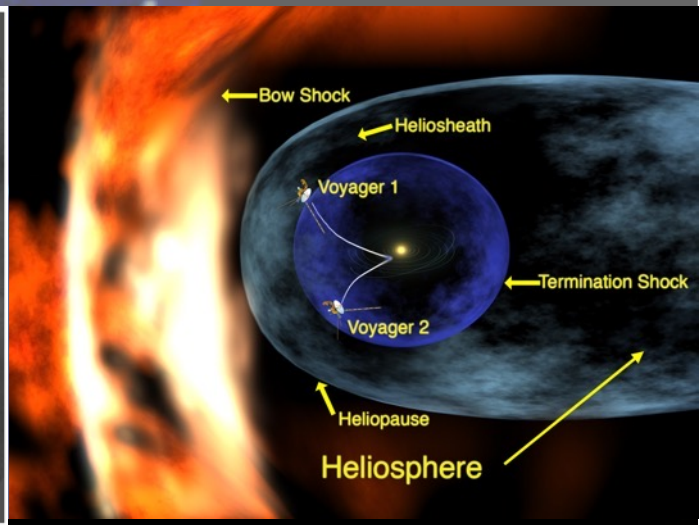
- Science of particle acceleration
  - Shocks
    - CMEs, termination shock, supernovae, Earth's bow shock…





Why Care About SEPs?

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  - Near Earth
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- Science of particle acceleration
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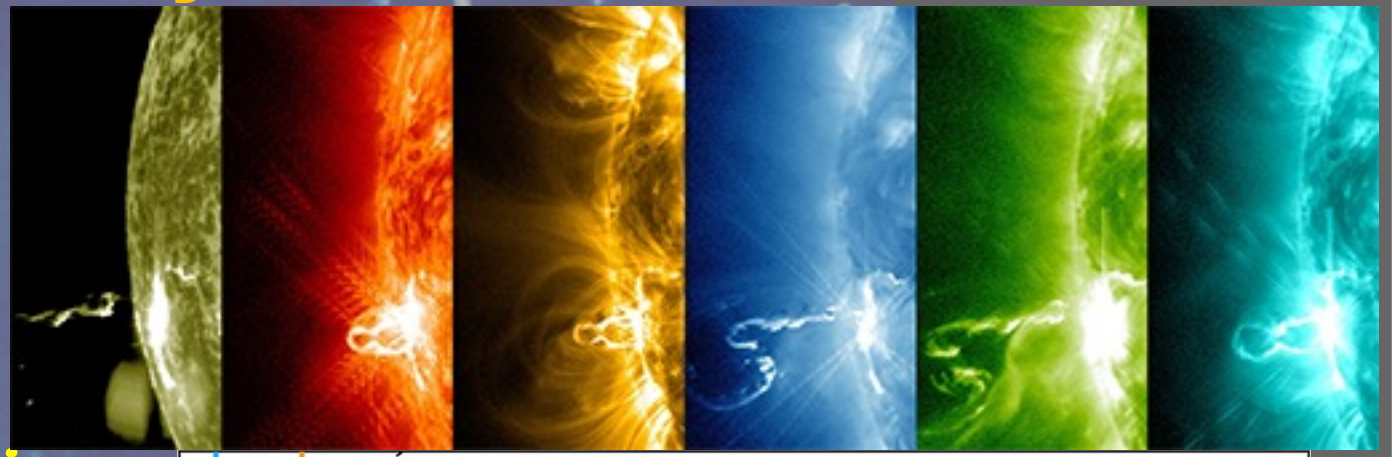
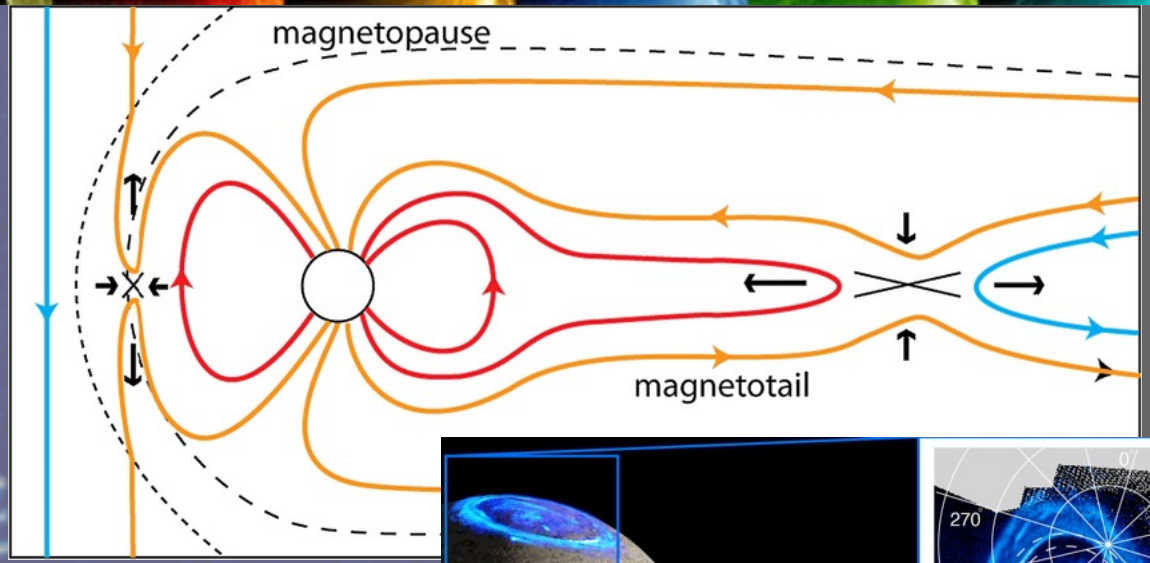
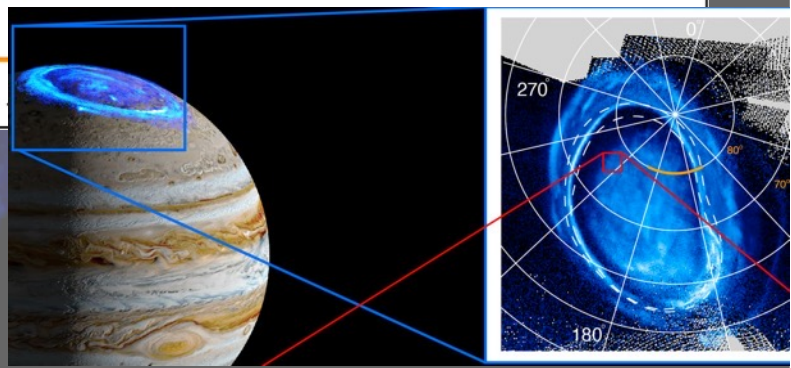
  - Reconnection
    - Sun, magnetosphere, Jupiter…

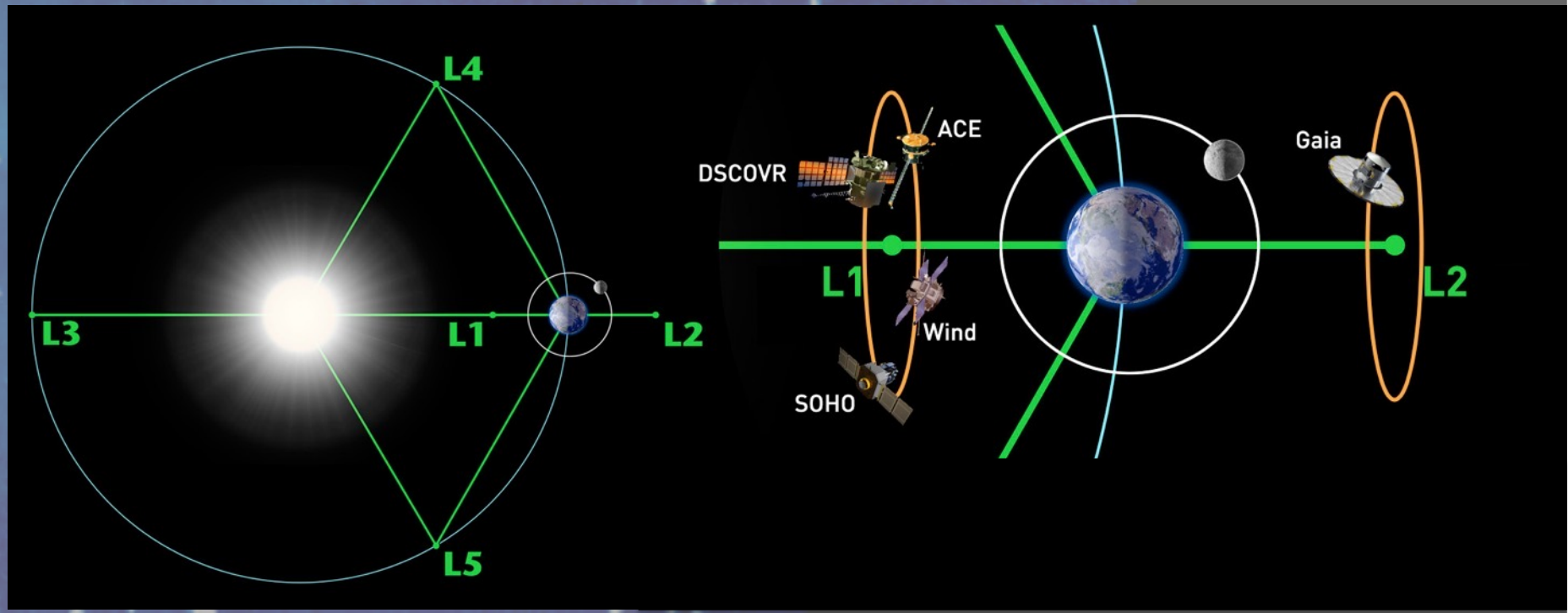






How Do We Study Them?

- See next lecture for instrumentation
- Locations
  - L1 is very common



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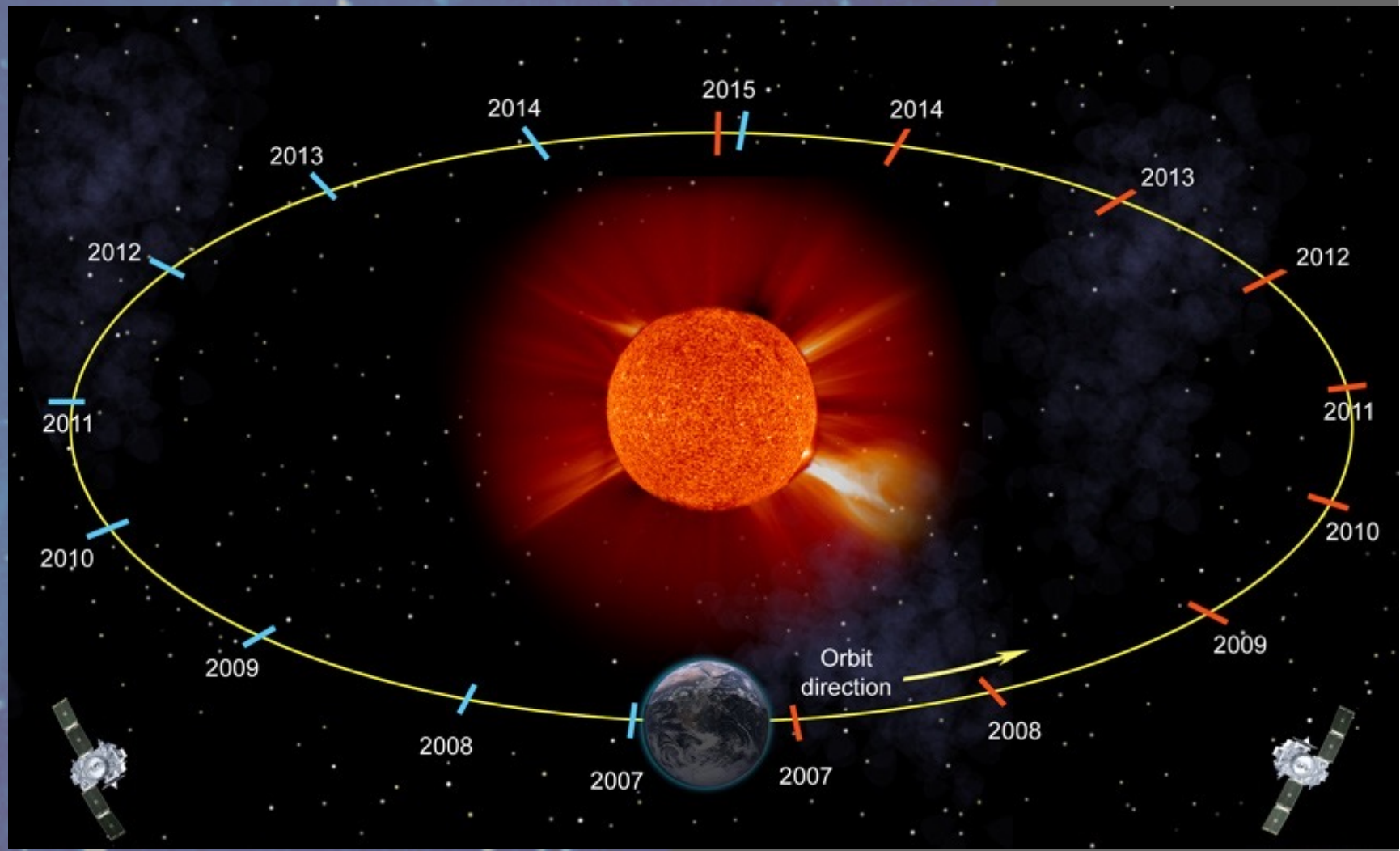

How Do We Study Them?

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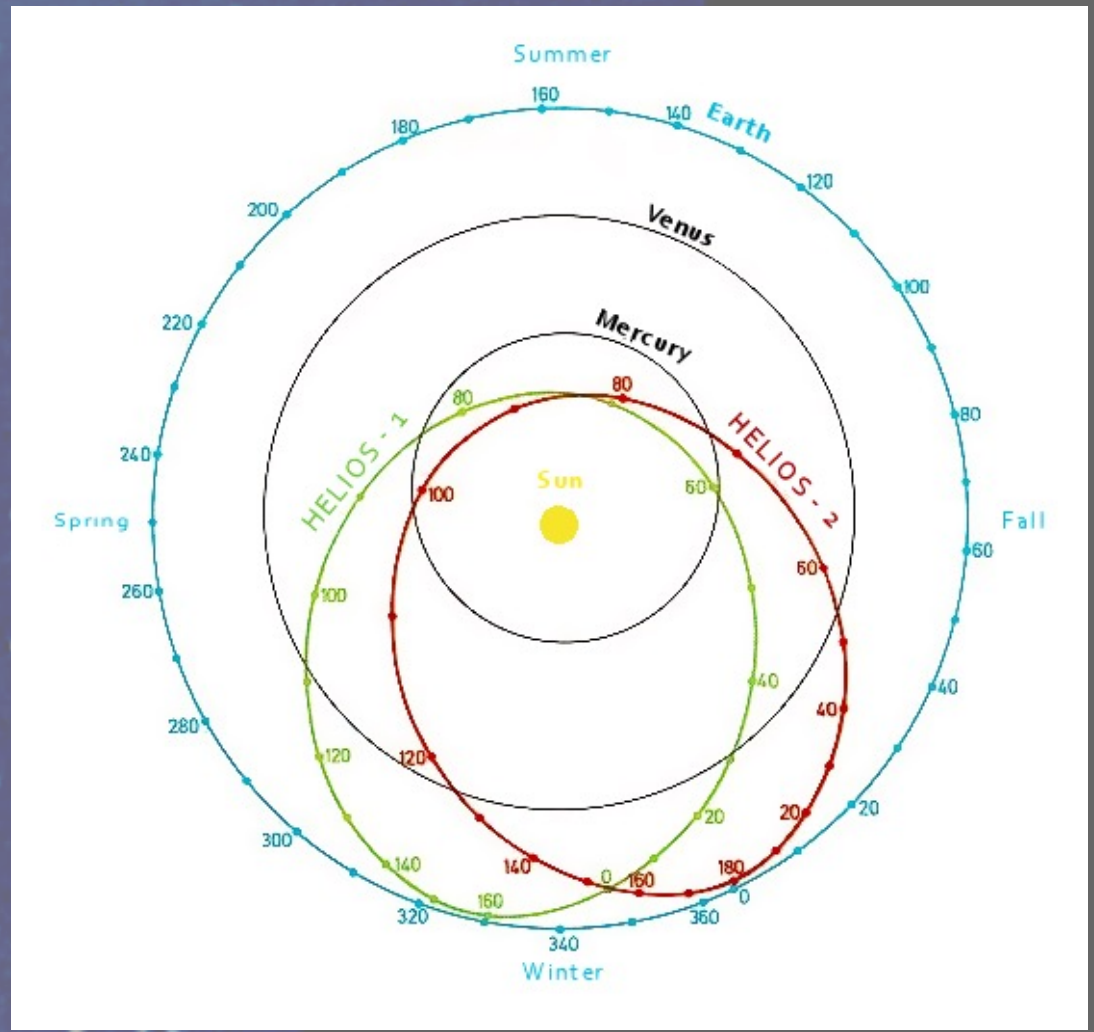
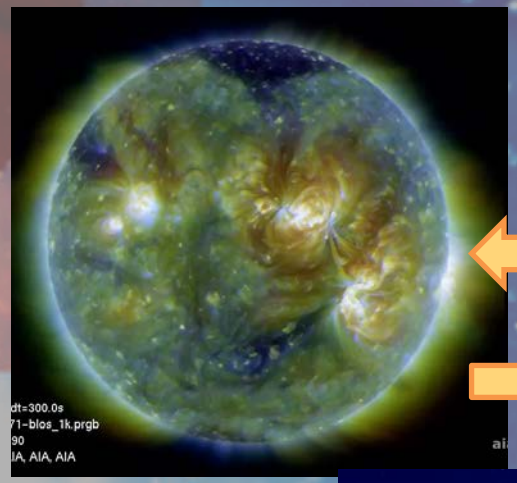
  - STEREO drifts wrt Earth
  - Once had Helios



Why is it Hard?

How it Goes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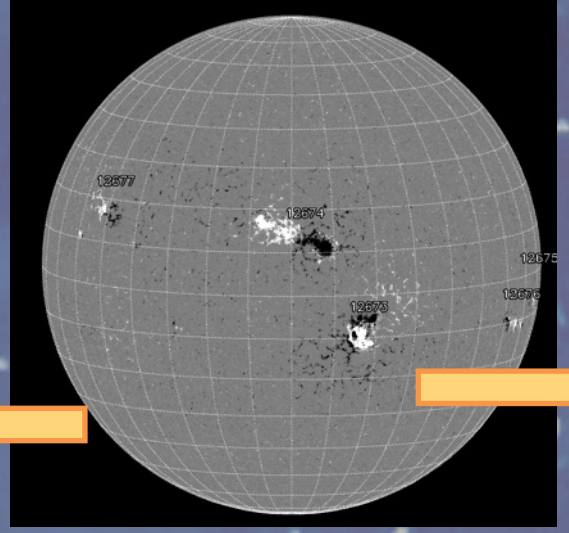
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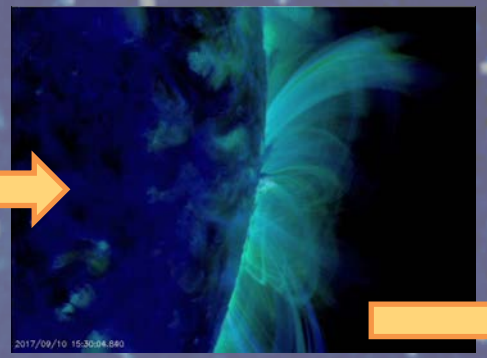

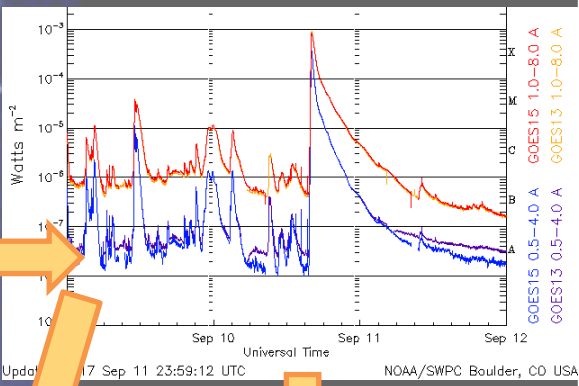
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GOES13 0.5–4.0 A
Sep 10
Sep 11
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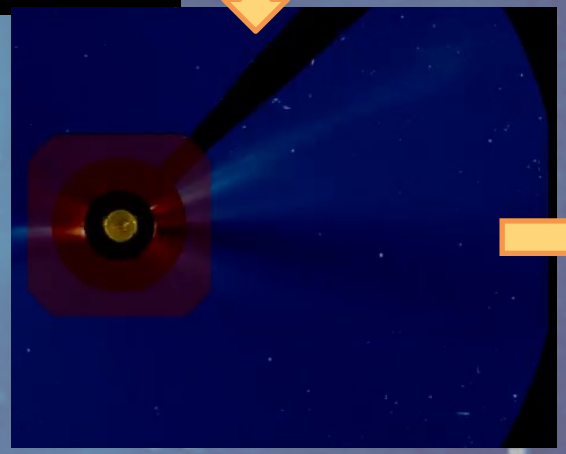
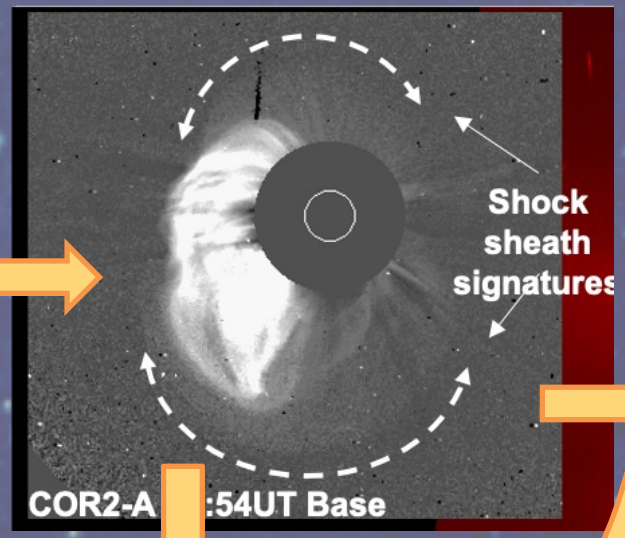
Universal Time
NOAA/SWPC Boulder, CO USA




Shock
sheath
signatures
COR2-A
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Zoom 6 Hour 1 Day 3 Day 7 Day
SWPC 10 MeV Warning Threshold
Jun 24
06:00
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06:00
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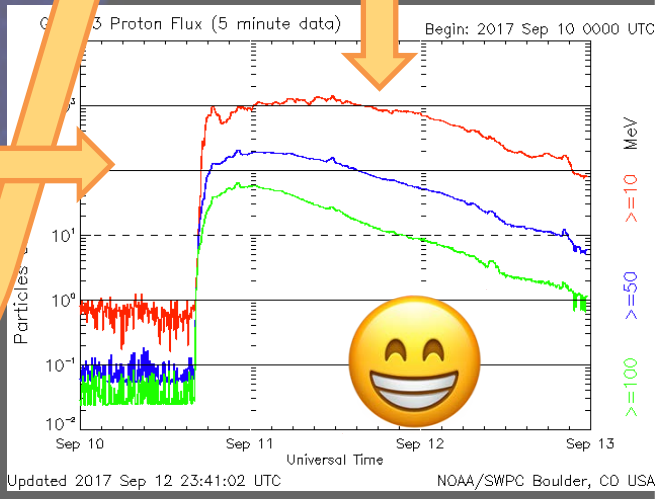
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Begin: 2017 Sep 10 0000 UTC
Particles
MeV
>=10
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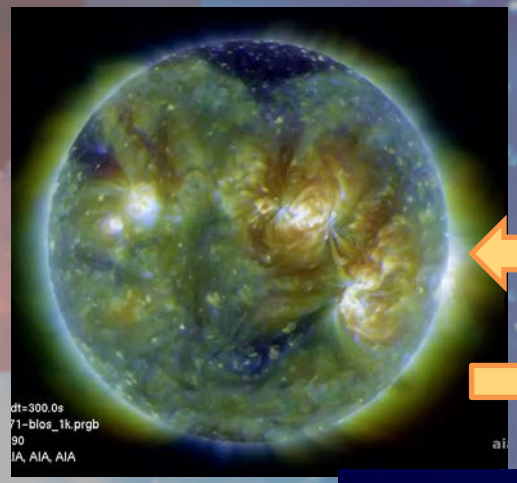
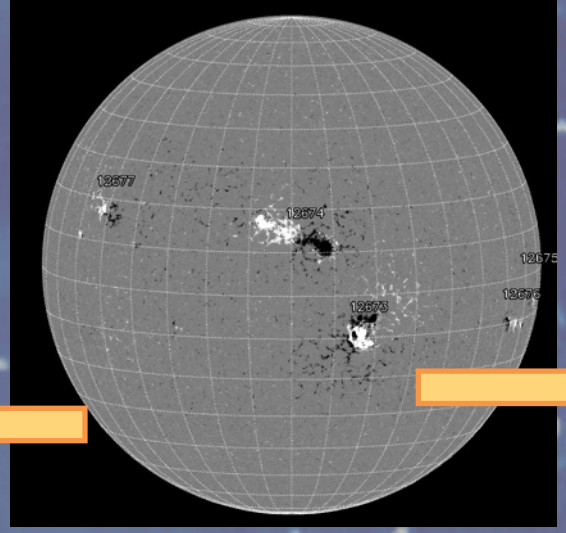
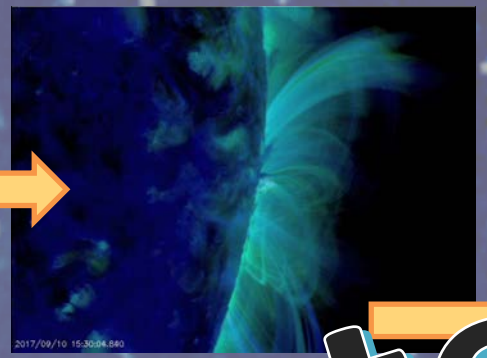
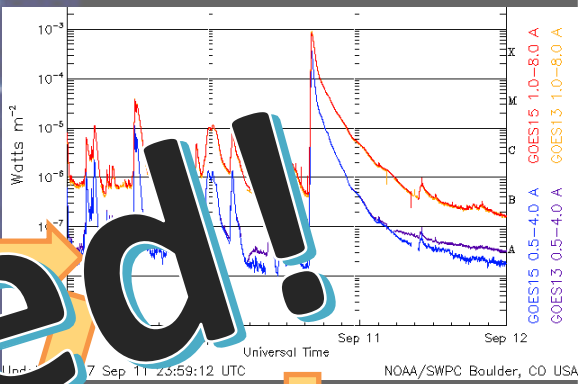
NOAA/SWPC Boulder, CO USA

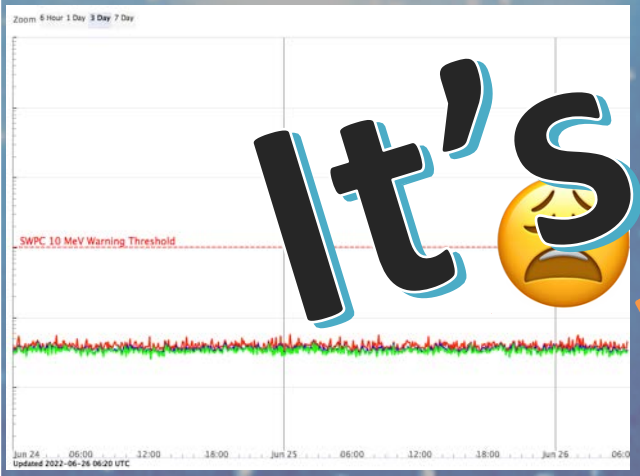
How it Goes

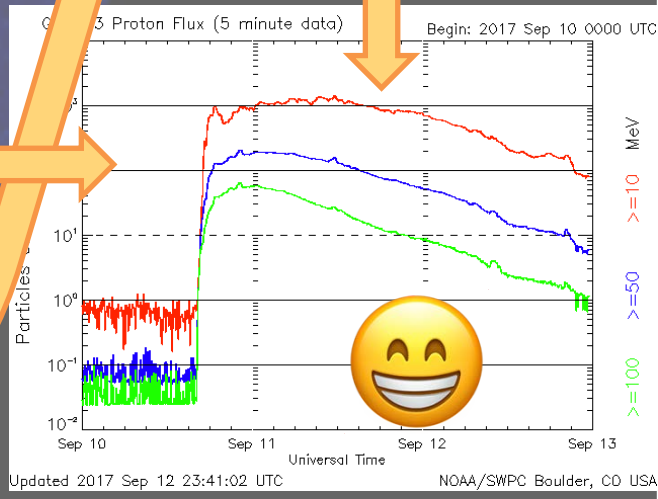








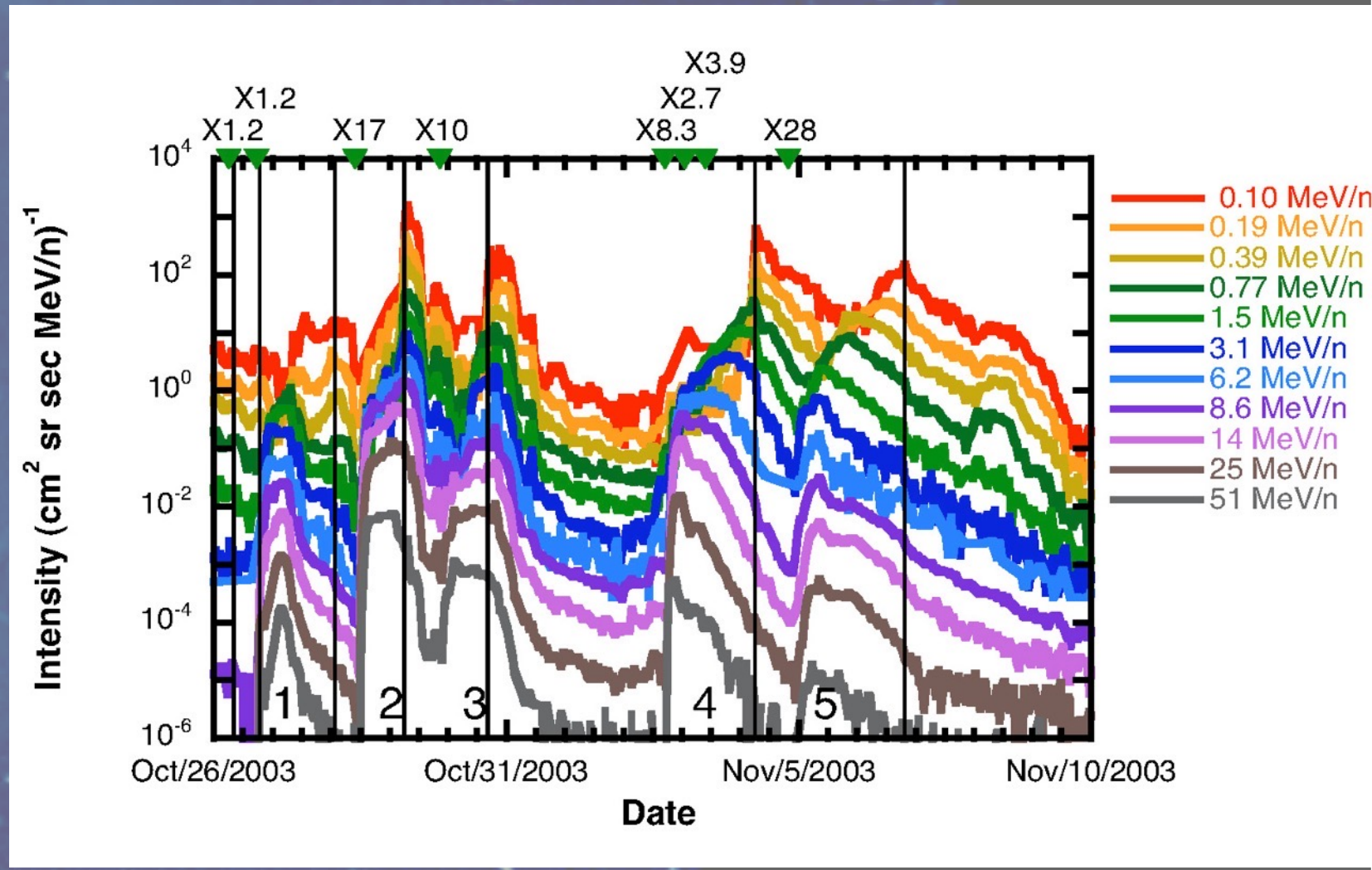




It's Complicated!

Everything varies

- With time
  - Peak
  - Duration -> fluence



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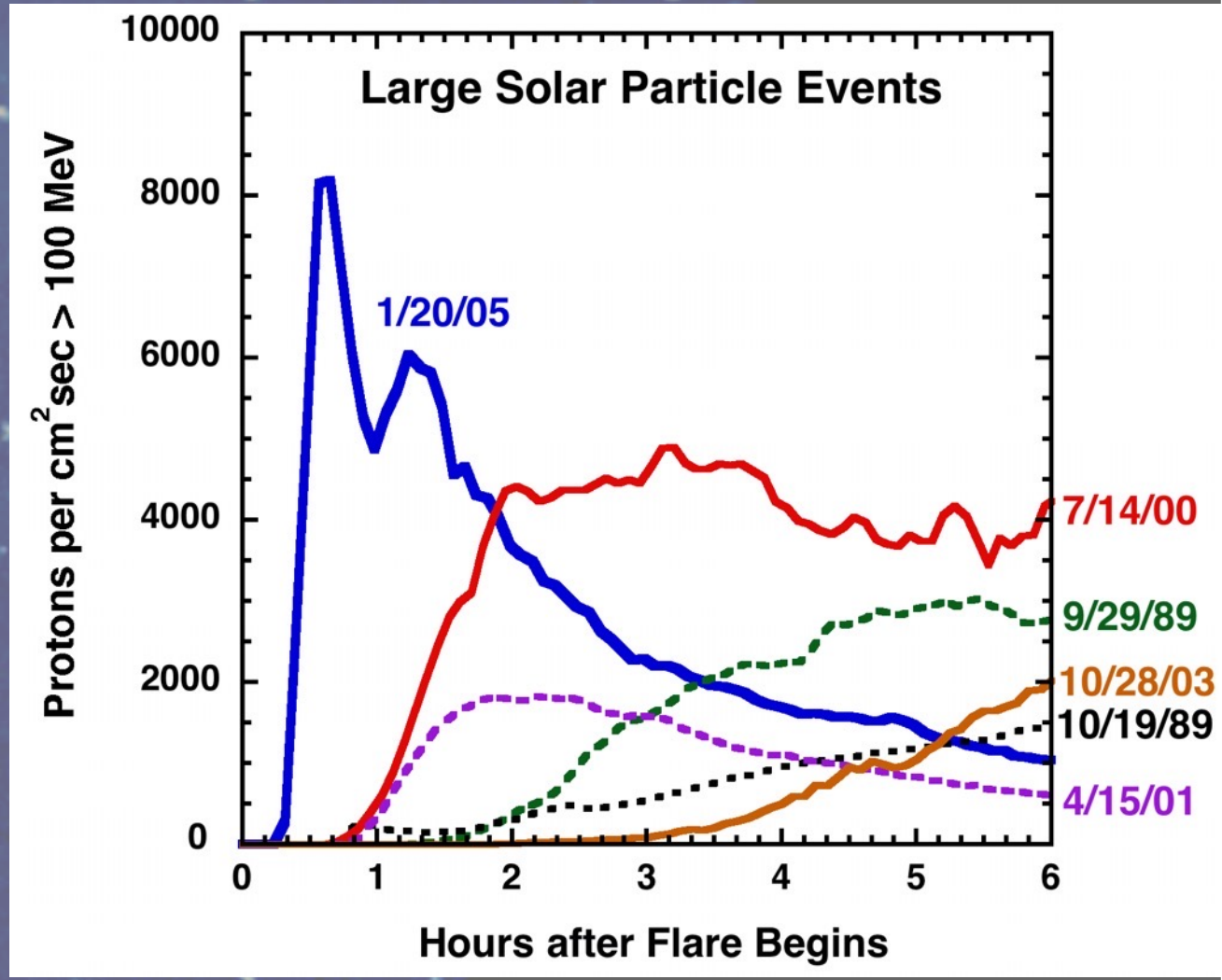

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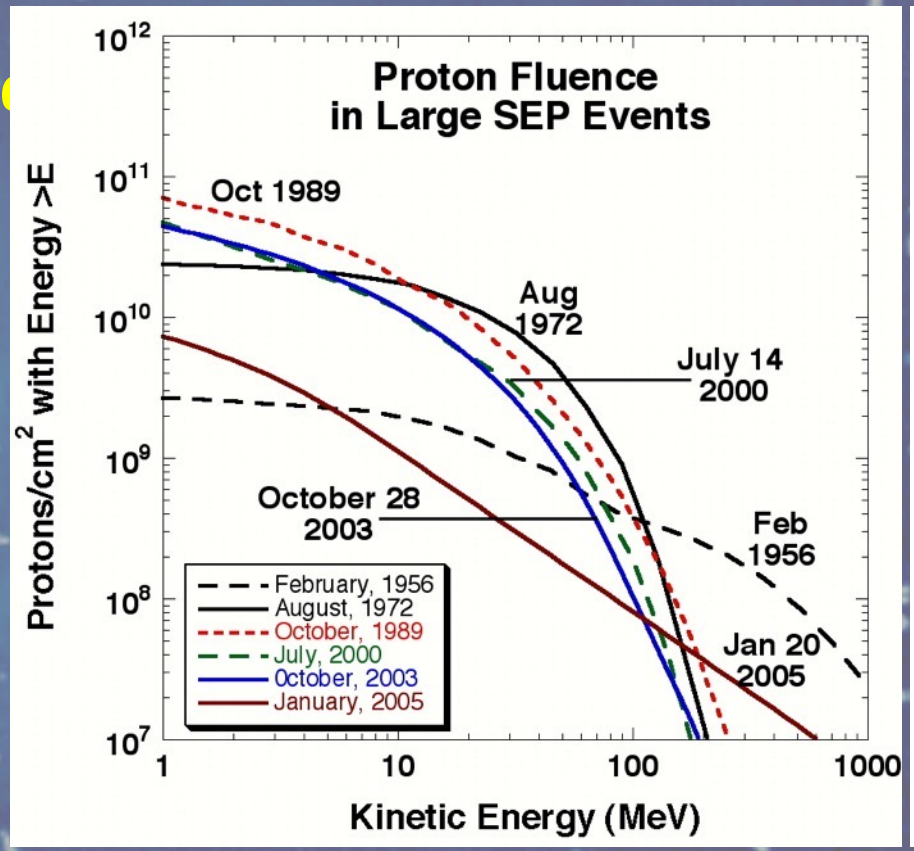
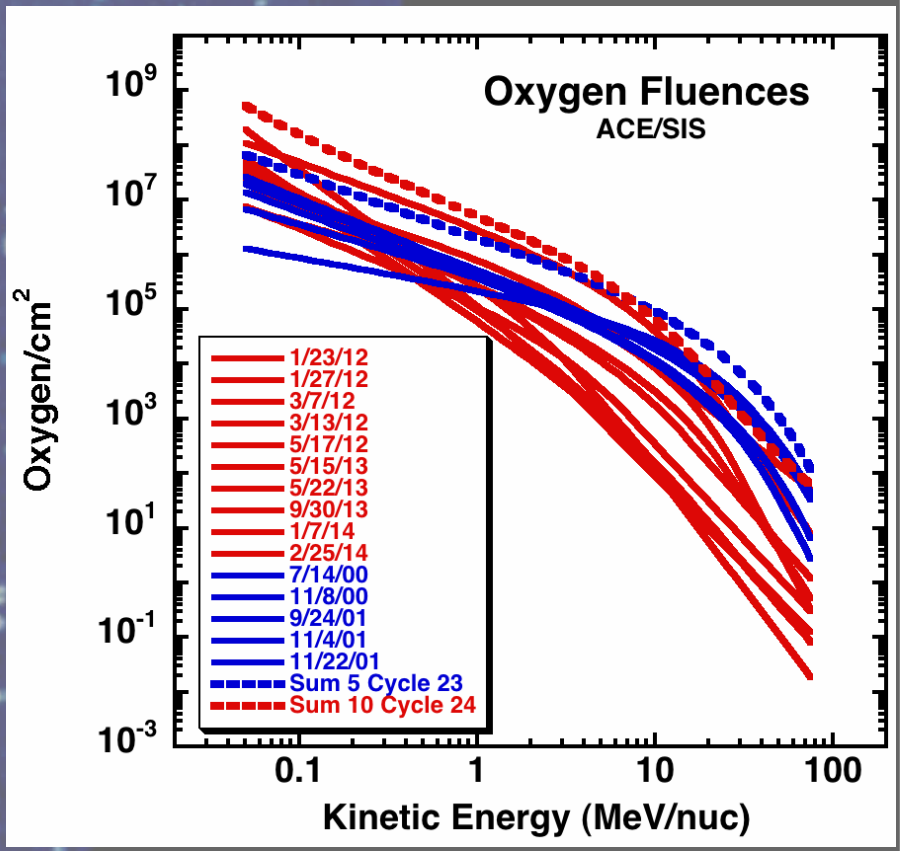
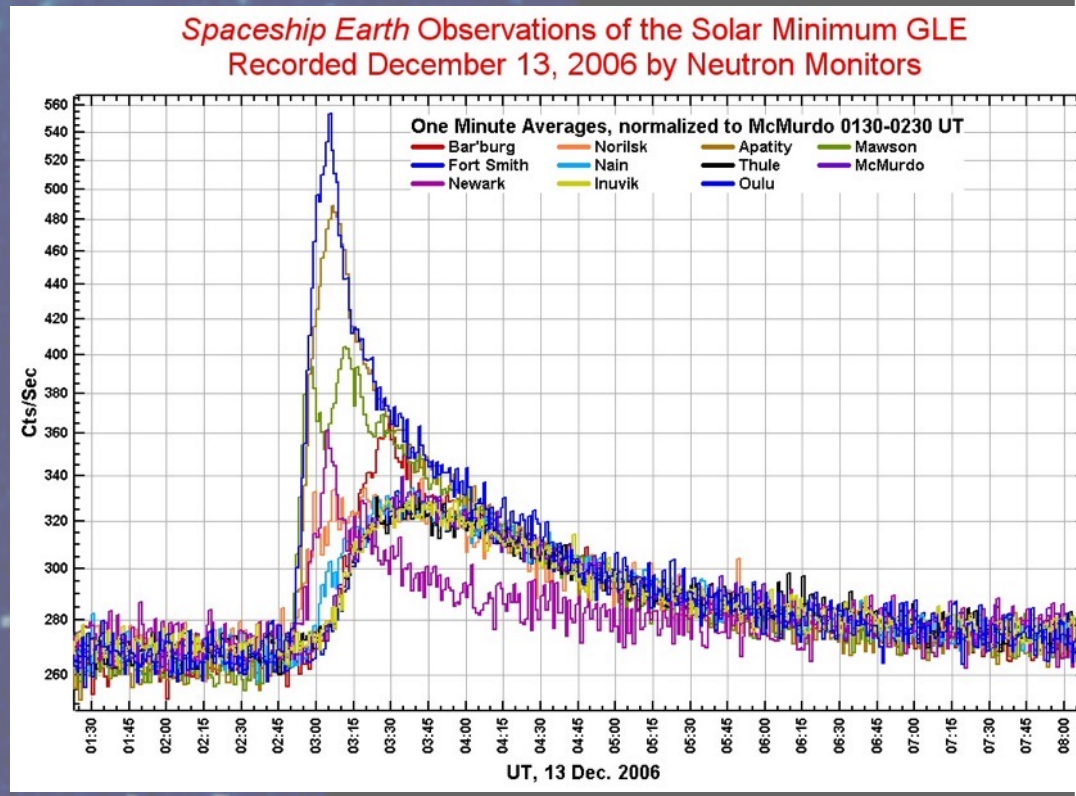
- With energy





Everything varies

- With time
  - Peak
  - Duration -> fluence
  - Onset
- With energy
  - Ground level enhancement (GLE Event)



Everything varies

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  - Peak
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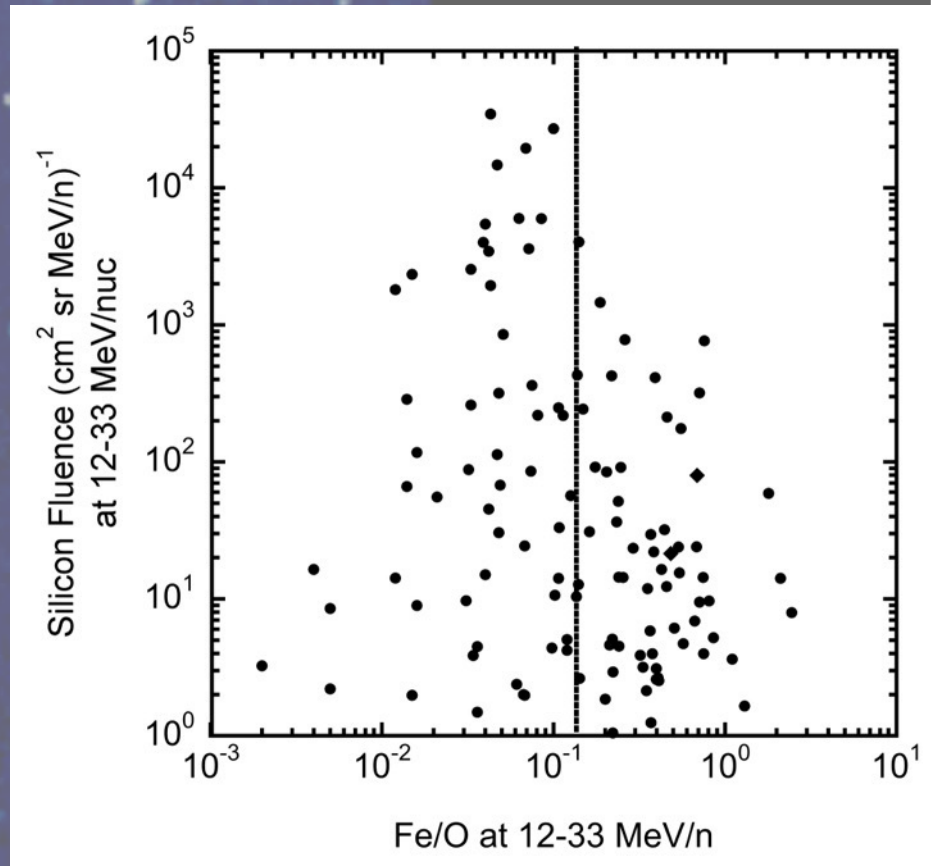
  - Onset
- With energy
  - Ground level enhancement (GLE Event)
- Composition
  - Big events



Ev

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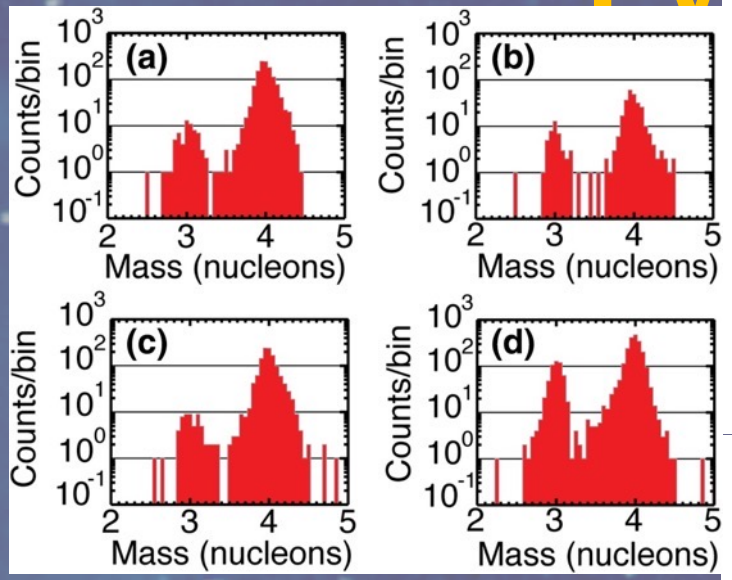
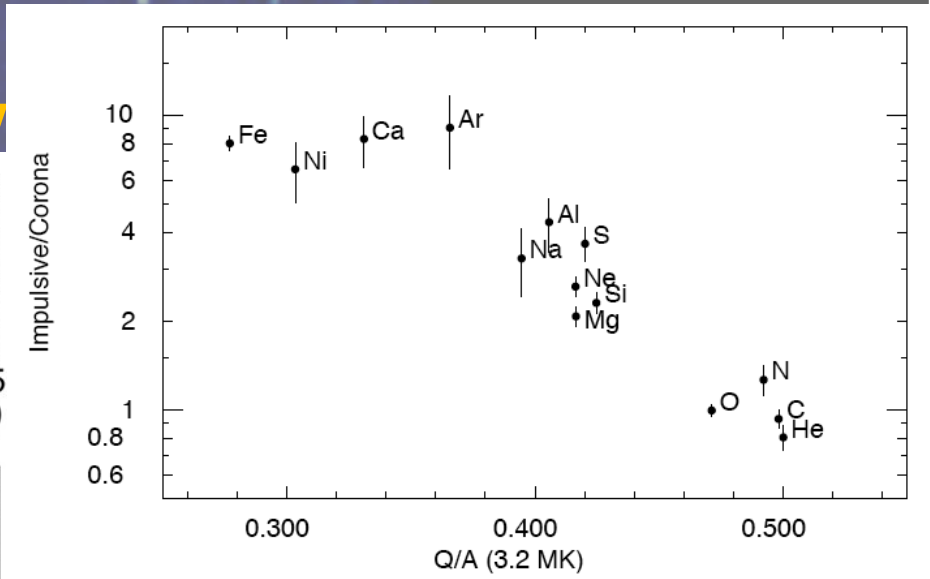
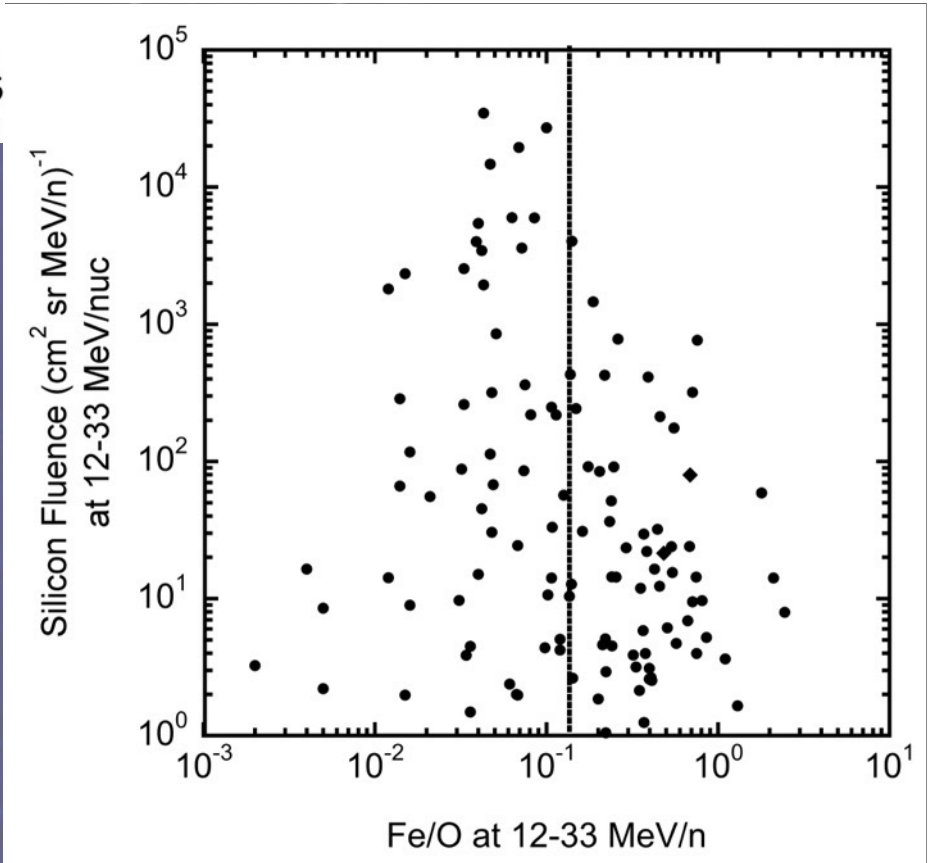
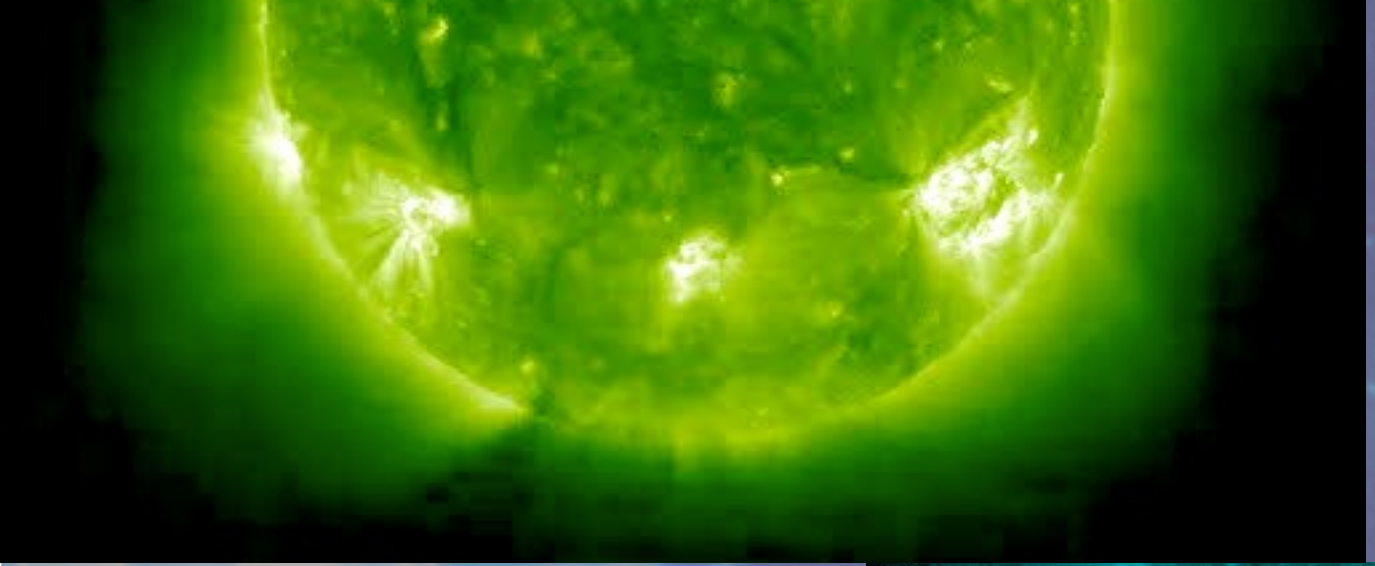
  - ^{3}He-rich events

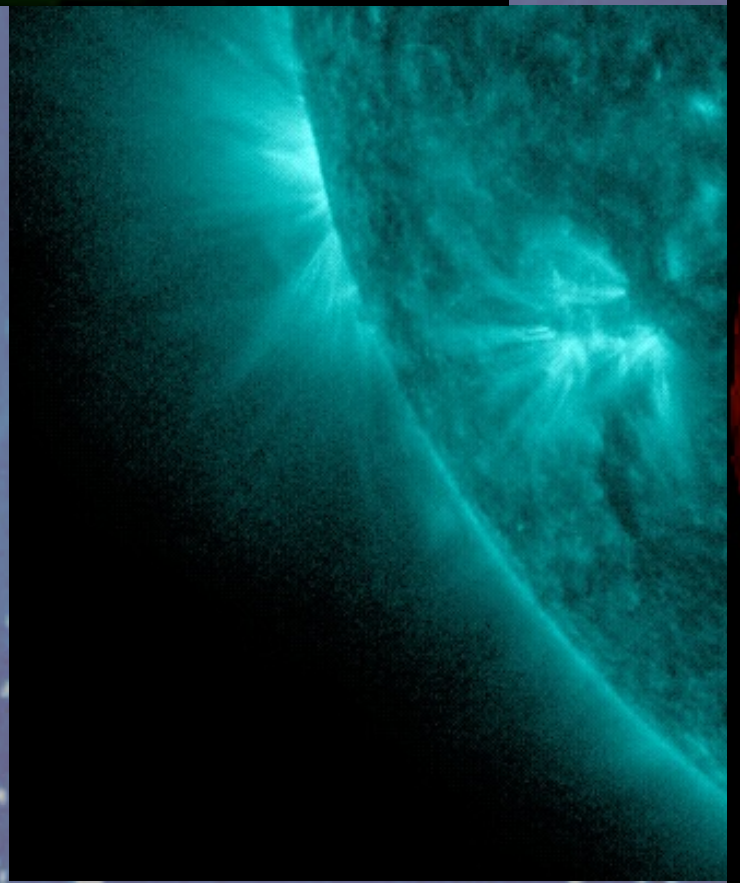


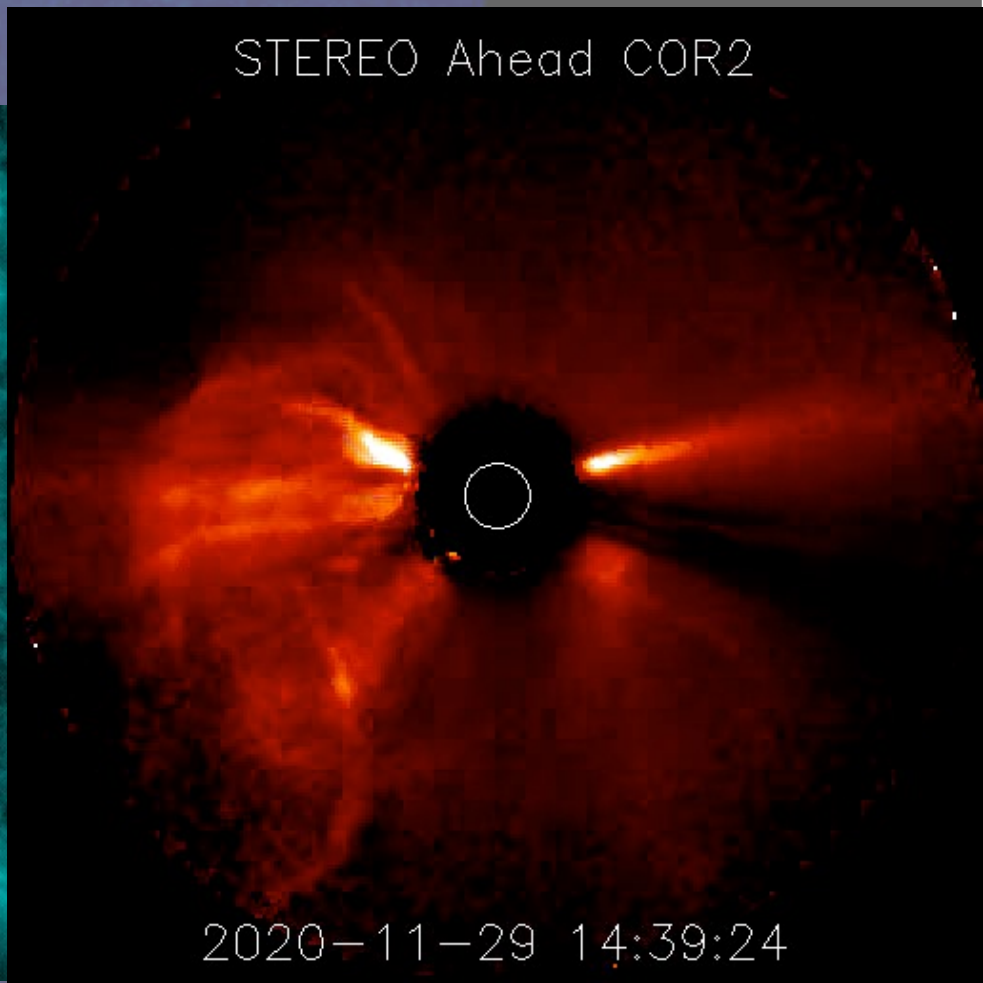


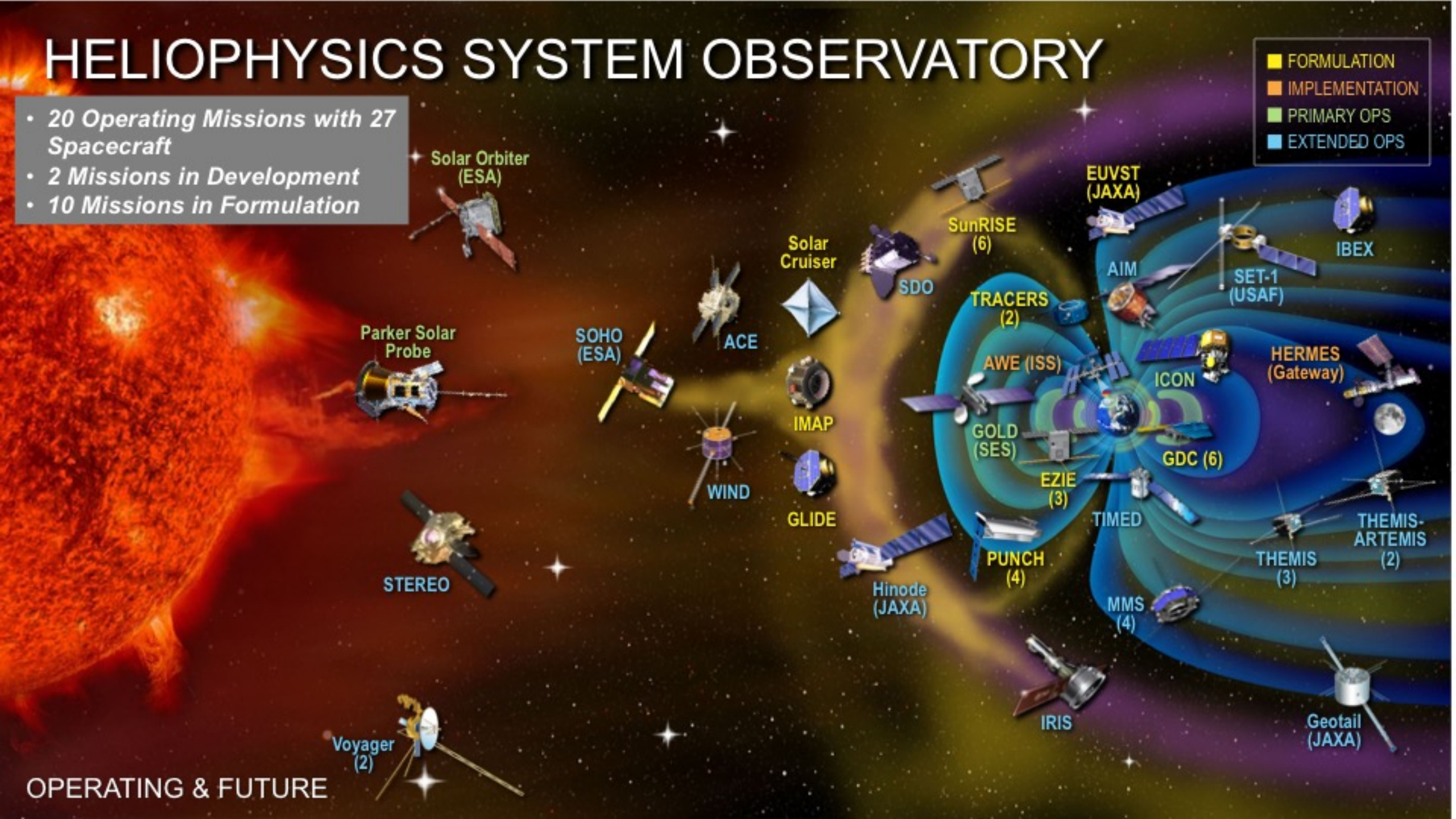


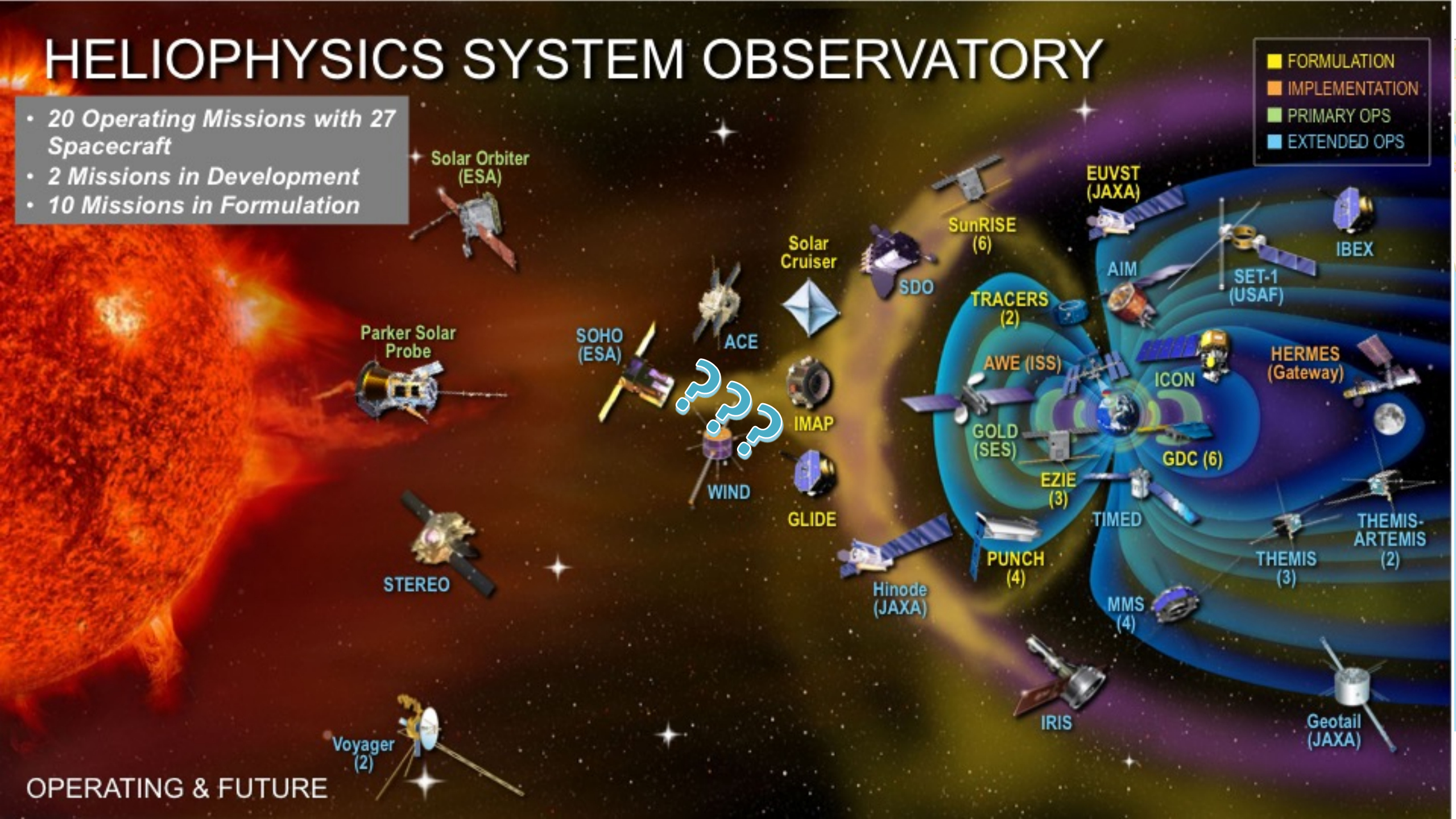
Lots of assets








HELIOPHYSICS SYSTEM OBSERVATORY
• 20 Operating Missions with 27 Spacecraft
• 2 Missions in Development
• 10 Missions in Formulation
FORMULATION
IMPLEMENTATION
PRIMARY OPS
EXTENDED OPS
Solar Orbiter (ESA)
Parker Solar Probe
SOHO (ESA)
ACE
Solar Cruiser
IMAP
WIND
GLIDE
STEREO
SDO
SunRISE (6)
EUVST (JAXA)
AIM
SET-1 (USAF)
IBEX
TRACERS (2)
AWE (ISS)
ICON
HERMES (Gateway)
GOLD (SES)
GDC (6)
EZIE (3)
TIMED
THEMIS-ARTEMIS (2)
THEMIS (3)
PUNCH (4)
Hinode (JAXA)
MMS (4)
IRIS
Geotail (JAXA)
Voyager (2)
OPERATING & FUTURE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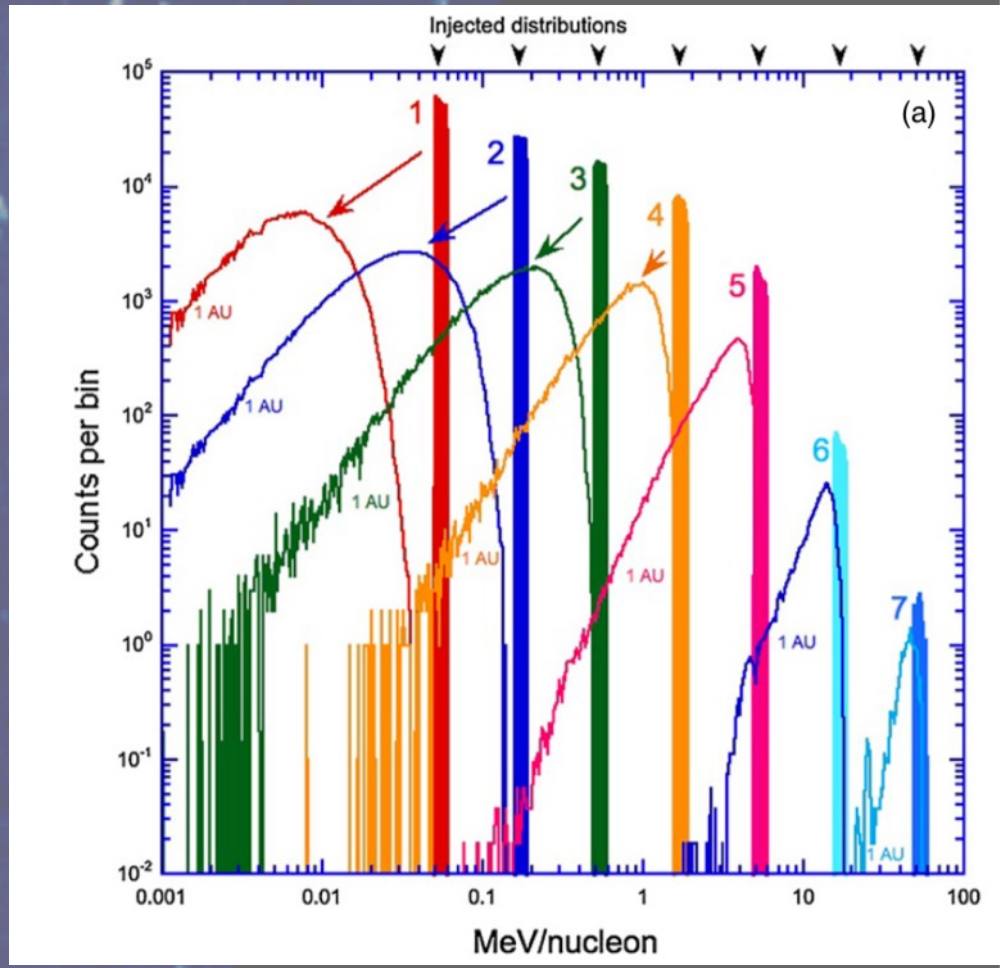
OPERATING & FUTURE

What Happens in the Gap?

- Transport effects
  - Lose energy
  - Scattering



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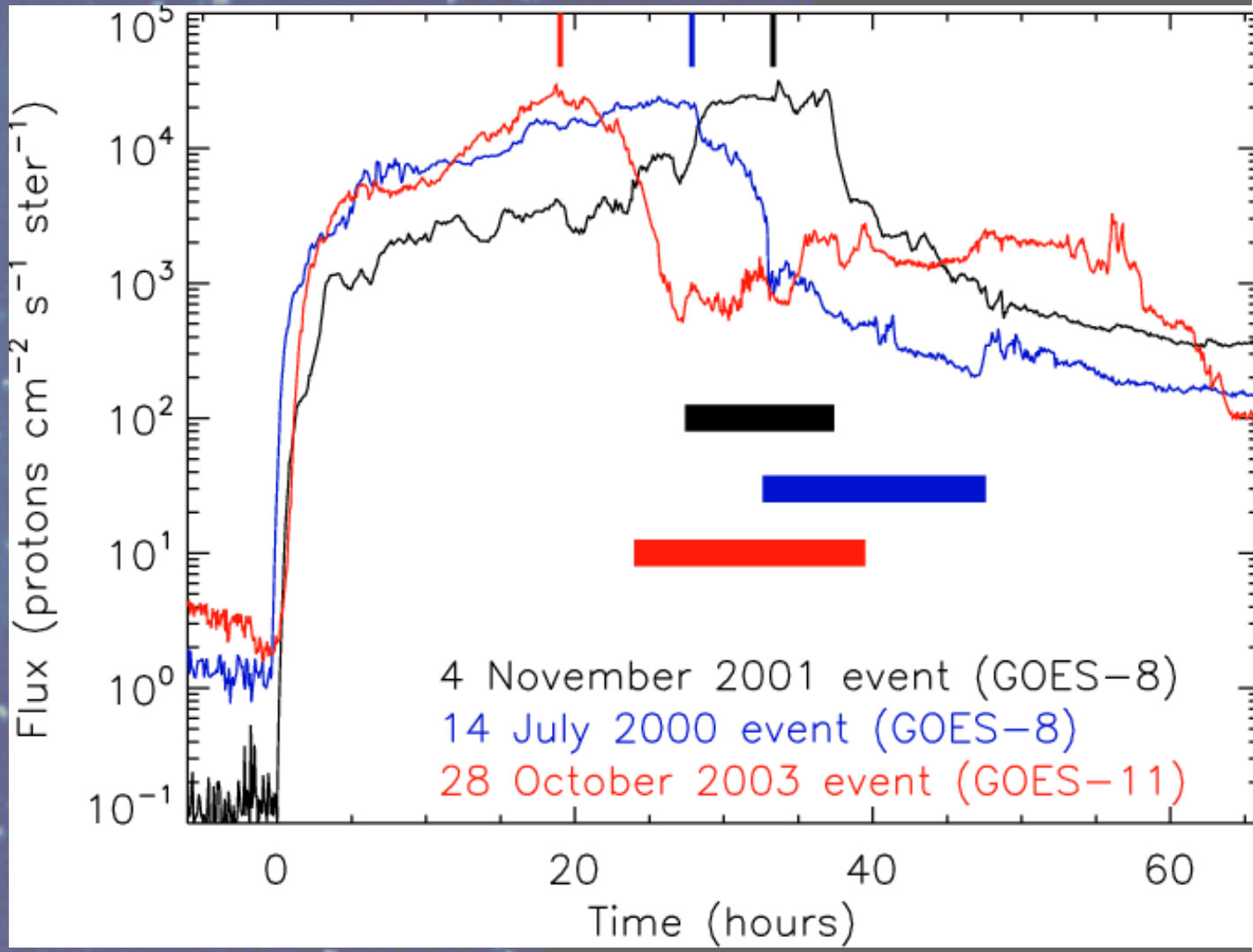

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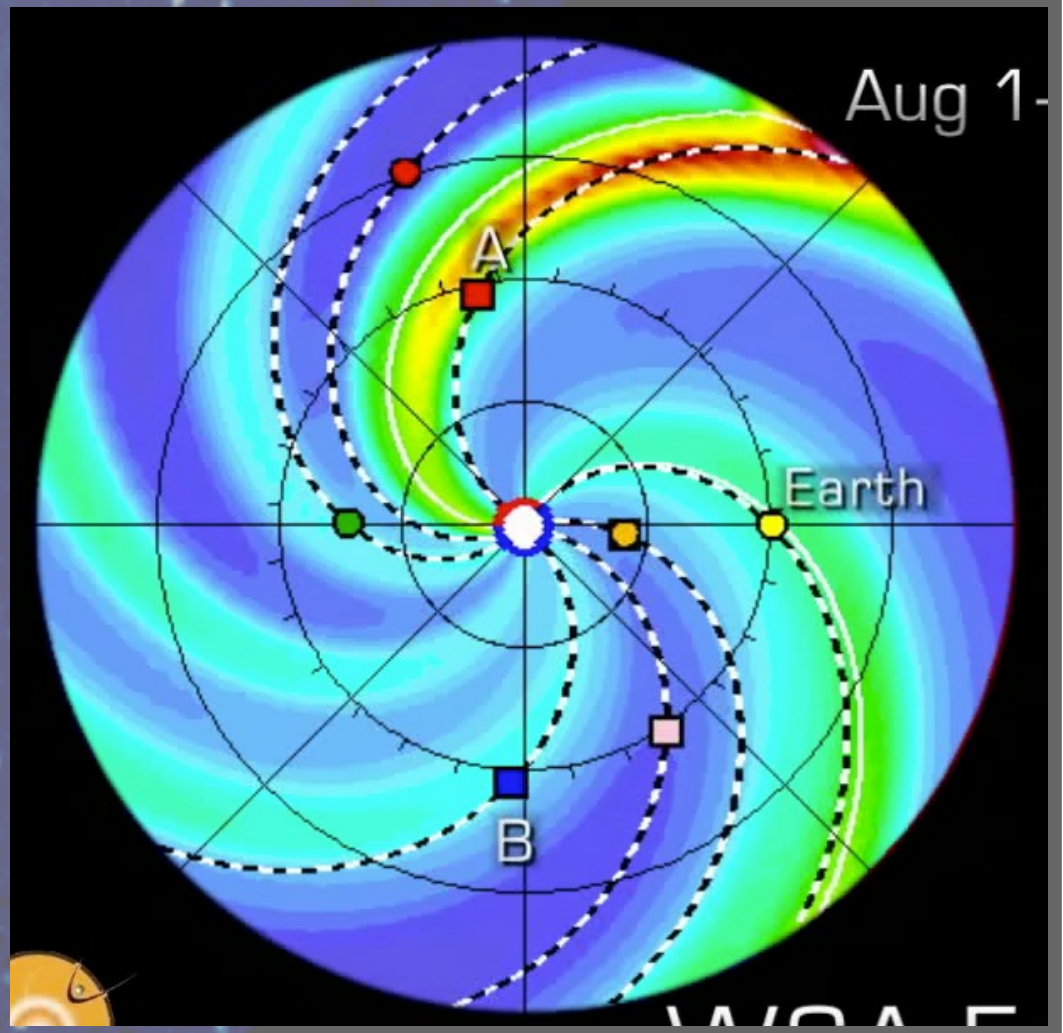
  - Interplanetary structures
- Evolution of conditions
  - Shock parameters
  - Background solar wind



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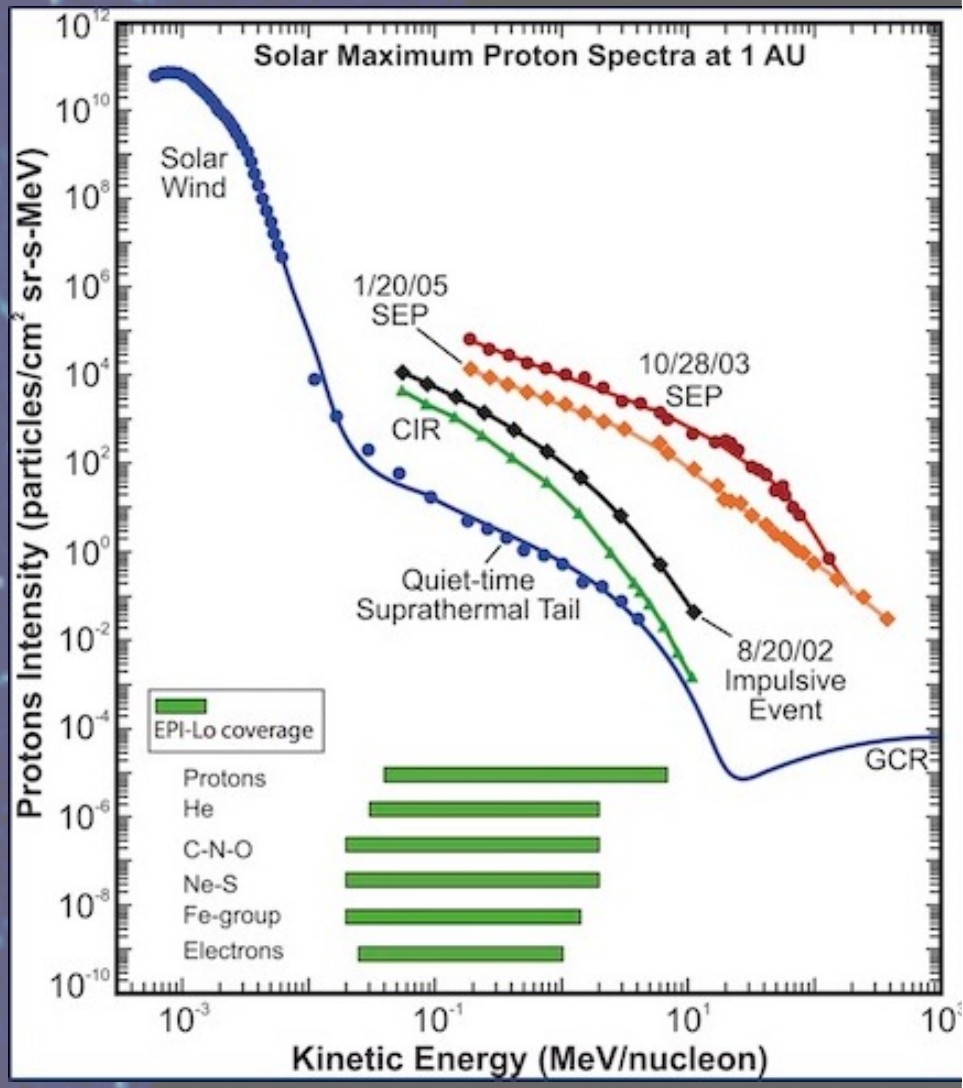

What Happens in the Gap?

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  - Interplanetary structur
- Evolution of condition
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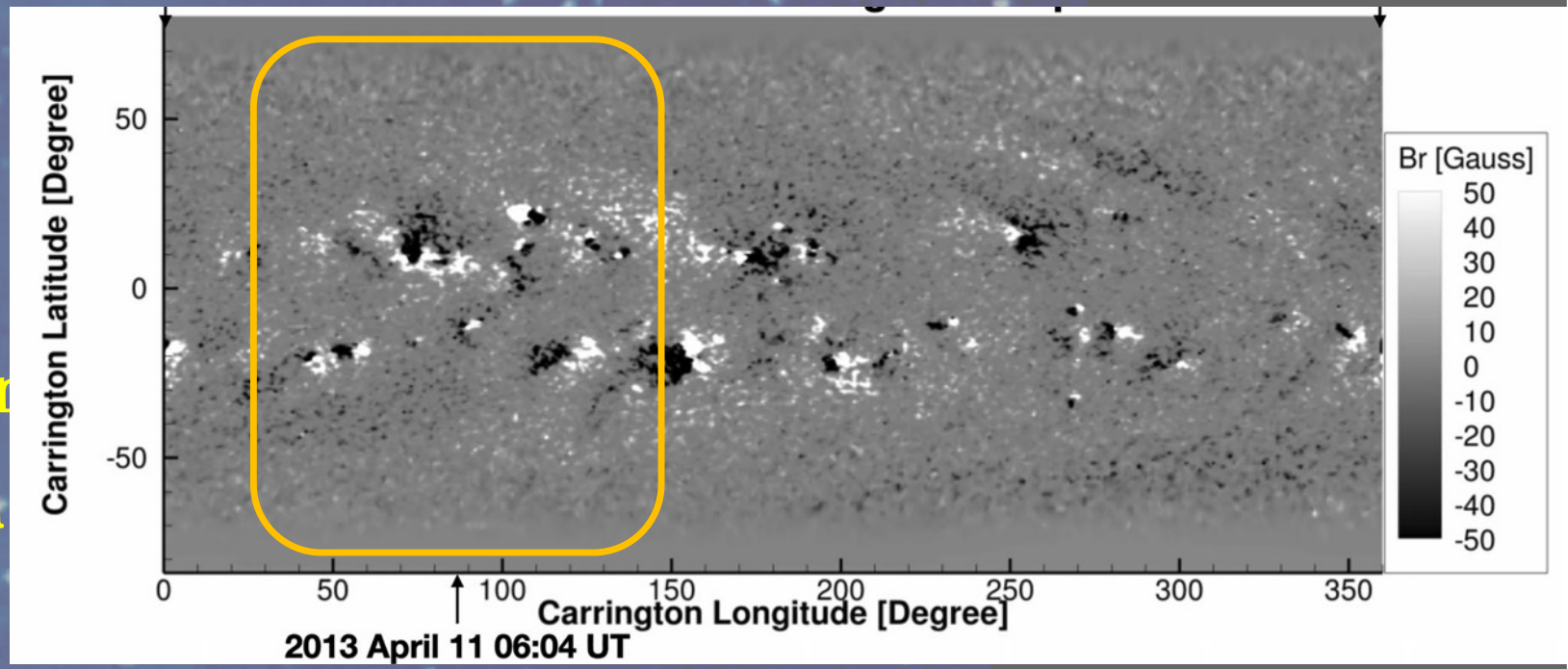
  - Background solar wind
  - Seed population
- Lack of Measurements



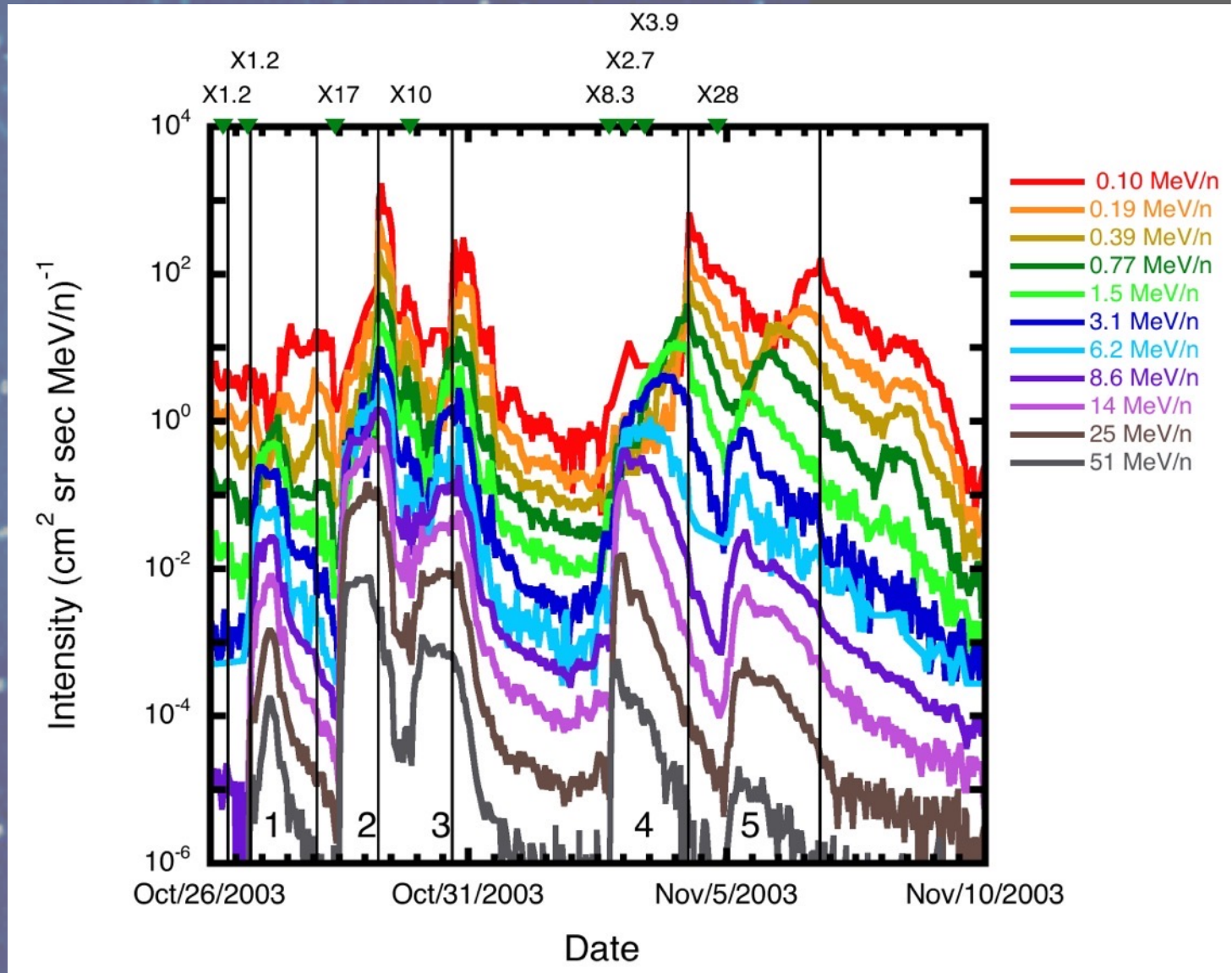
Knowns & Unknowns

Category	Process	What we know	What we don't
Energization	Shock acceleration	Observations Correlations Verified Theory/Models	Missing Observations Observations not Understood Unverified Theory/Models
	Reconnection acceleration		
Transport	Field aligned		
	Cross field		
Conditions	Plasma + Structures		
	Seed population		

Energization: Shock Acceleration

Know

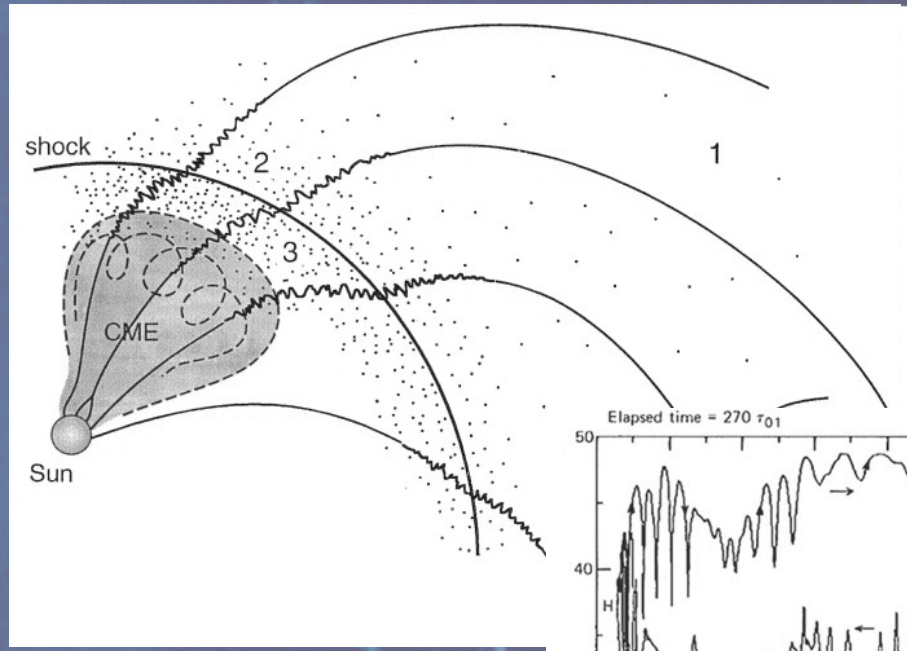
- See it in action

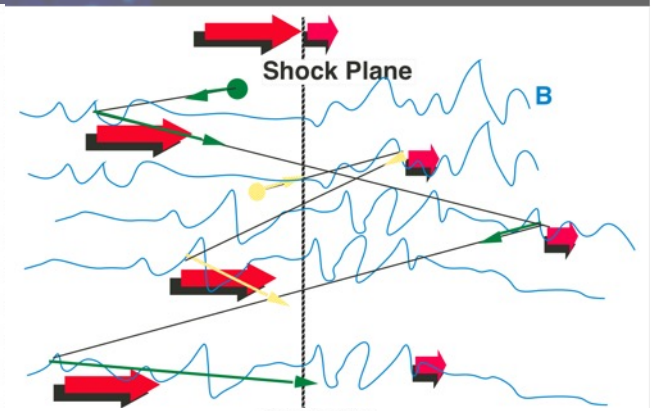


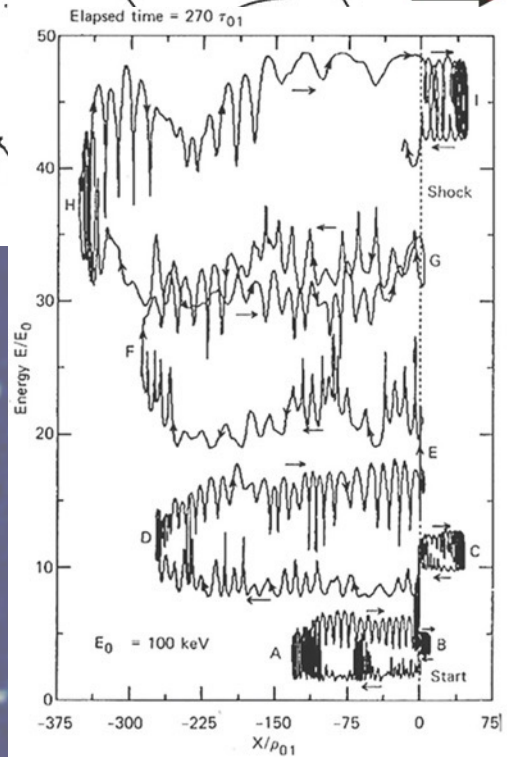
Energization: Shock Acceleration

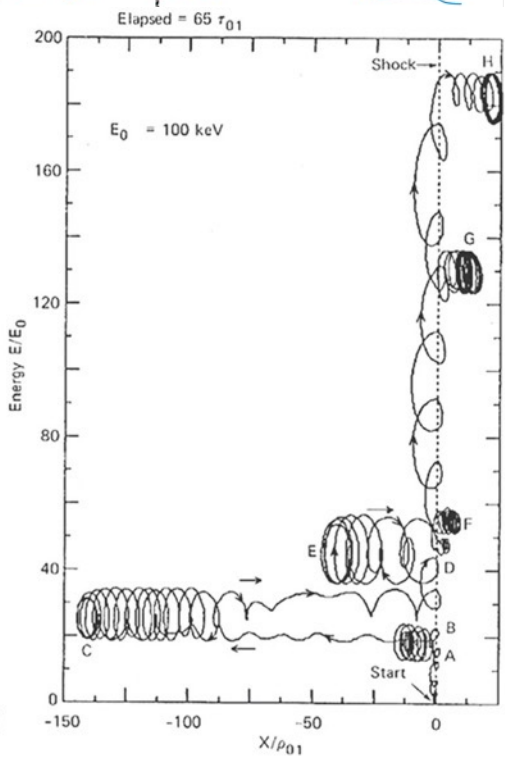
Know

- See it in action
- Basic concepts
  - Diffusive shock acceleration
  - Shock drift acceleration





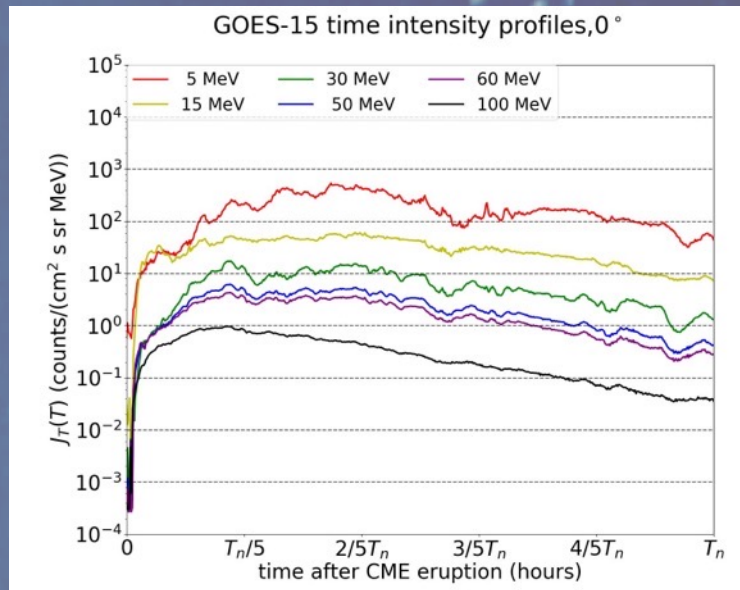


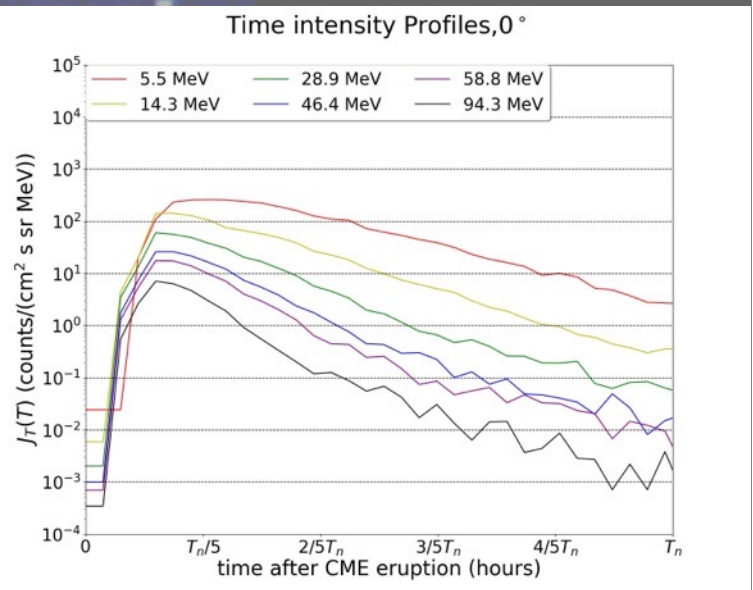


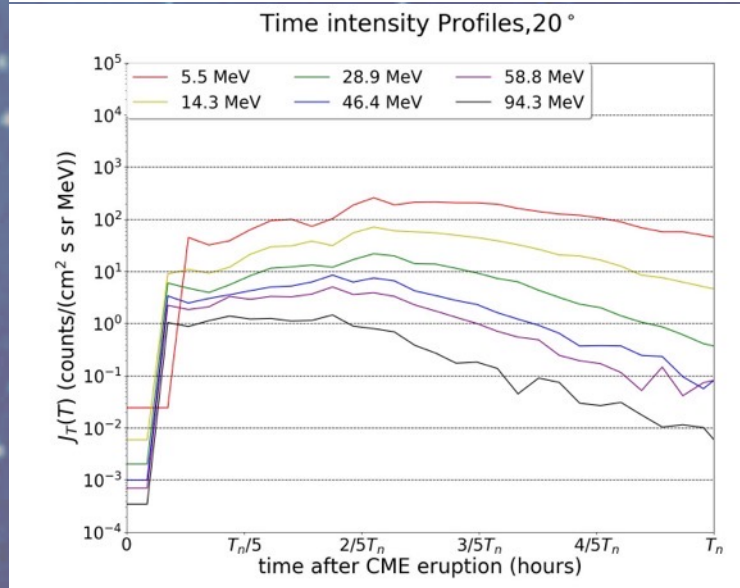
Energization: Shock Acceleration

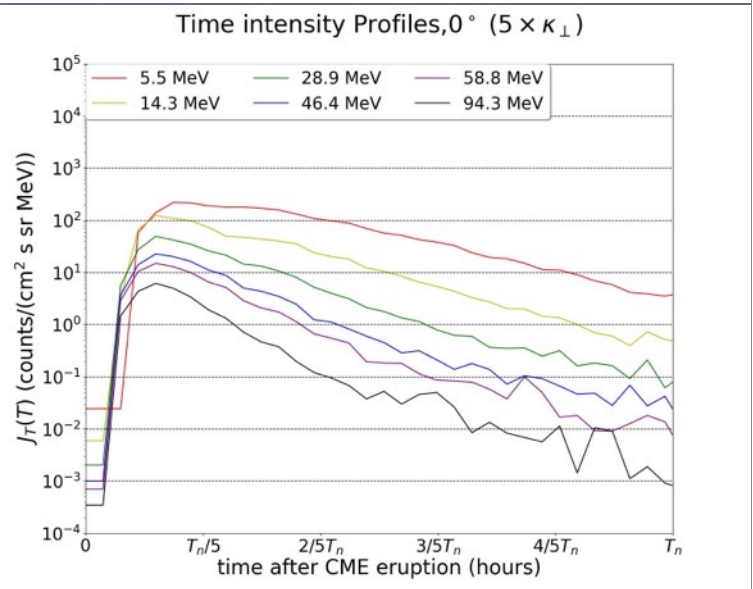
Know

- See it in action
- Basic concepts
  - Diffusive shock acceleration
  - Shock drift acceleration
- Role of certain parameters
  - Strength, orientation
  - Turbulence





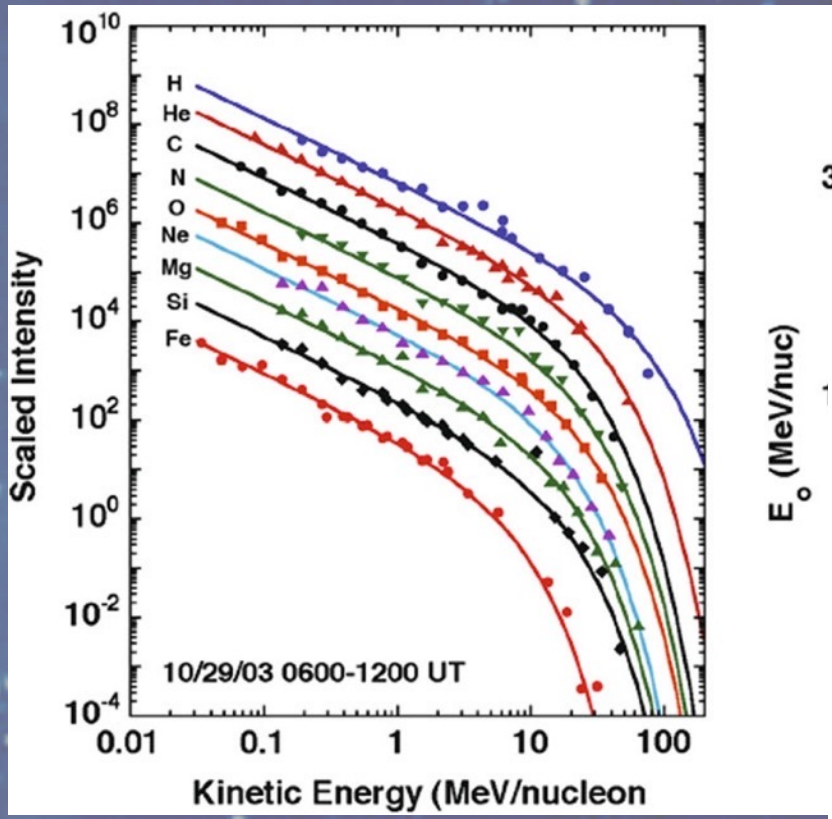


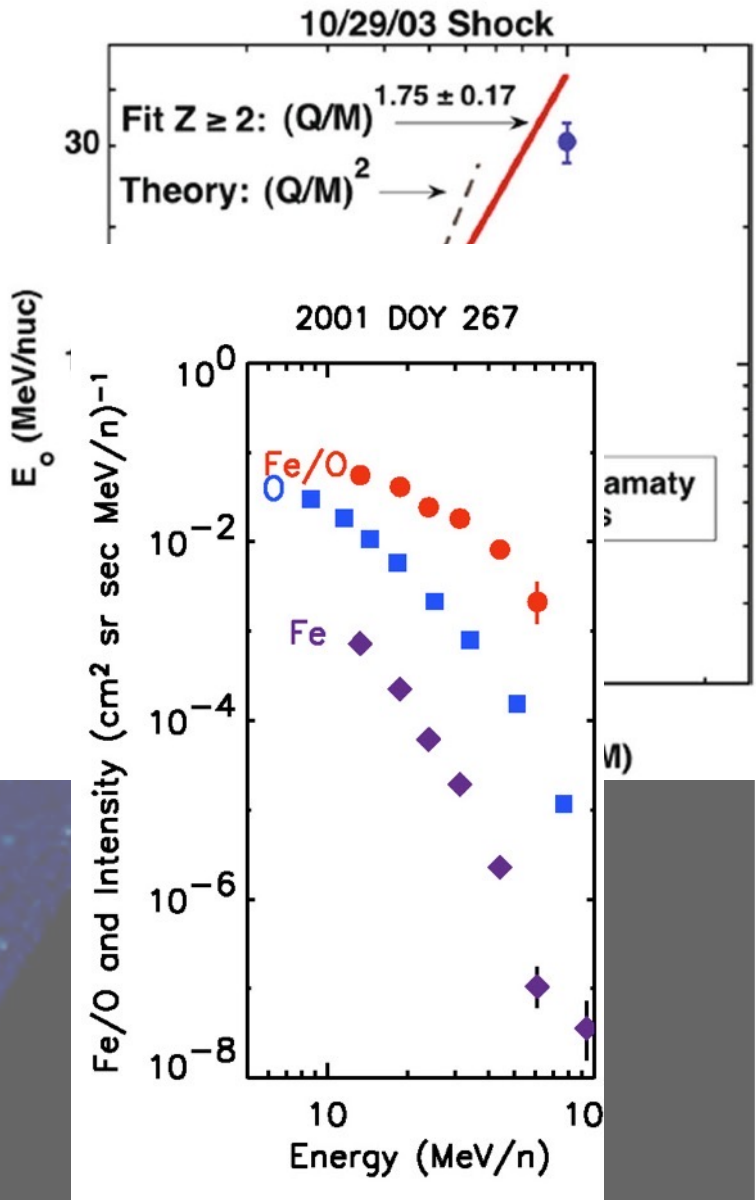


Energization: Shock Acceleration

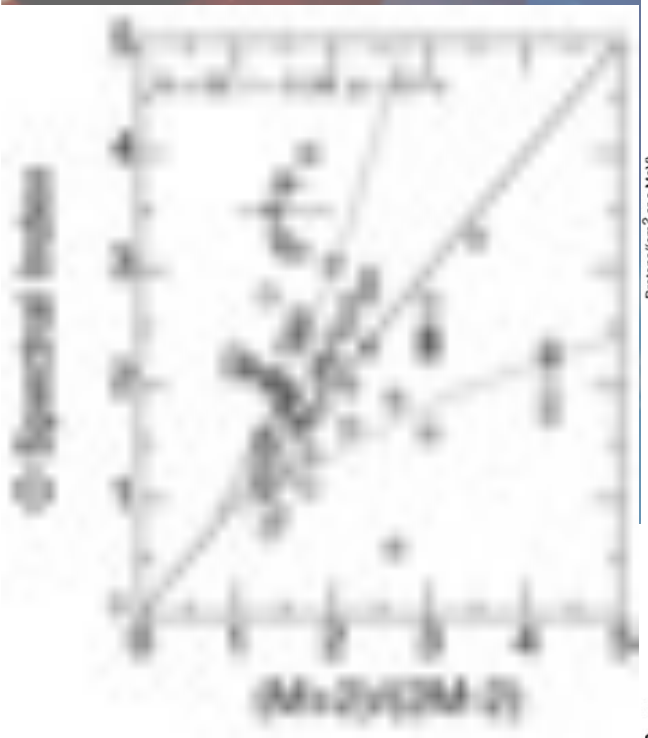
Know

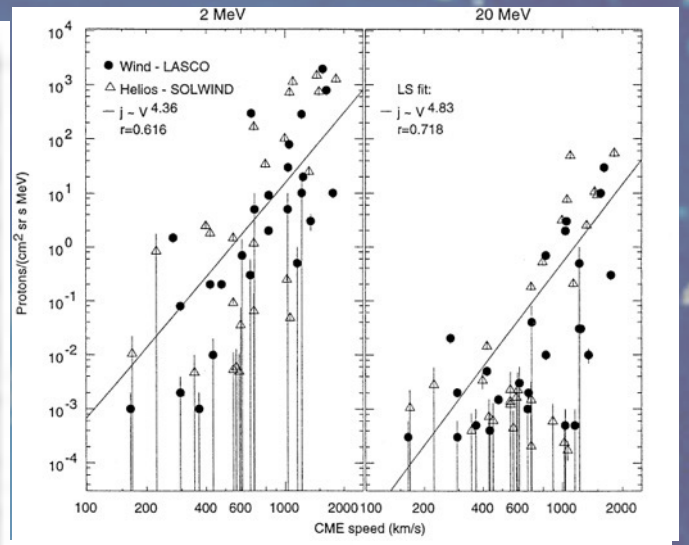
- See it in action
- Basic concepts
  - Diffusive shock acceleration
  - Shock drift acceleration
- Role of certain parameters
  - Strength, orientation
  - Turbulence
- Properties
  - Spectral features
  - Composition

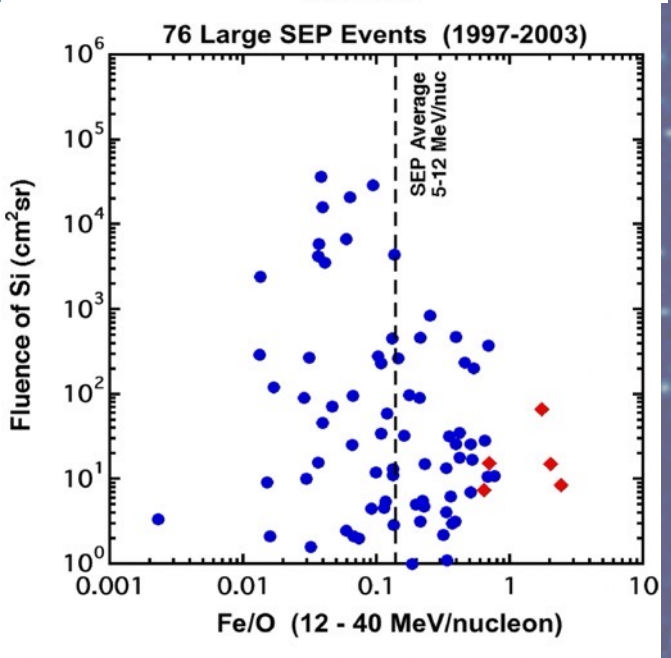




Energization: Shock Acceleration



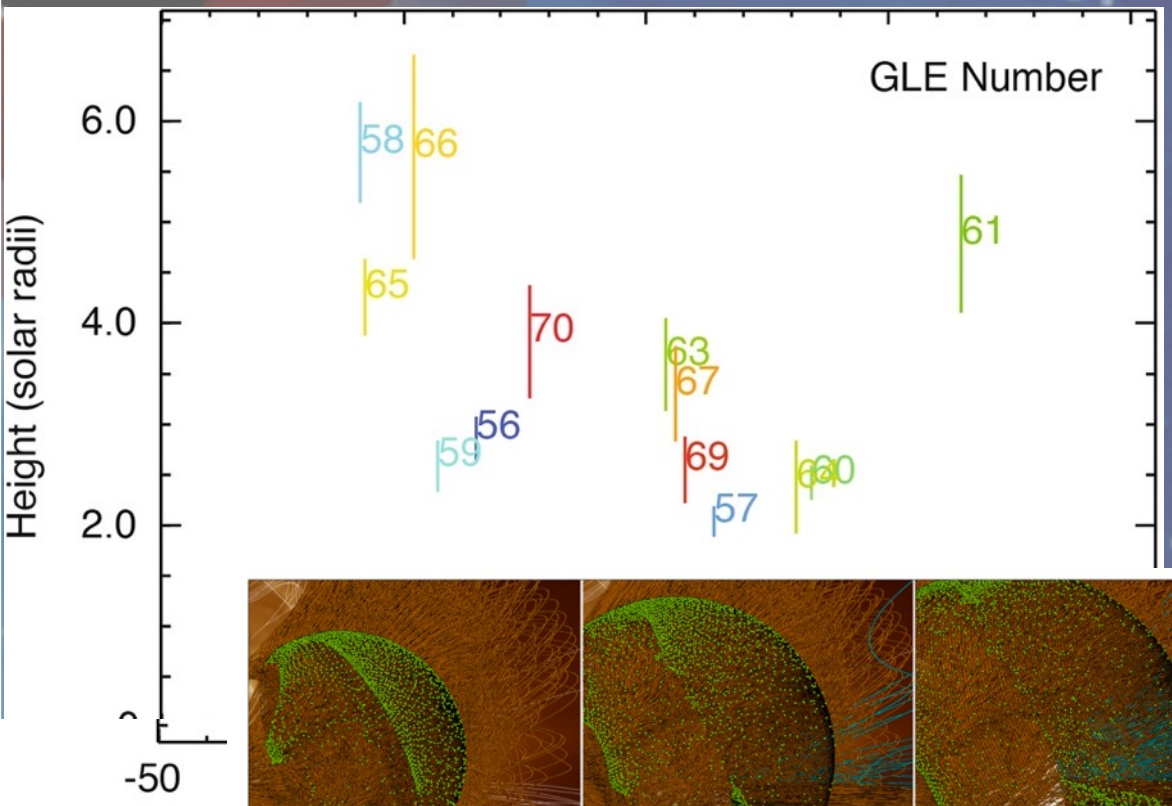


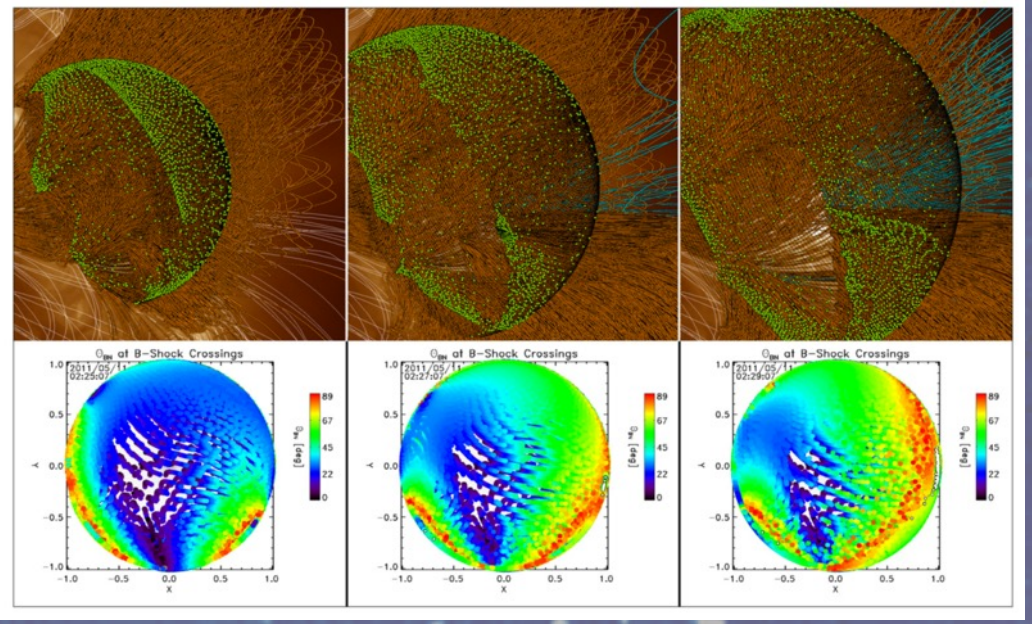


Don't Know

- Variability
  - Dependence on scales

Energization: Shock Acceleration

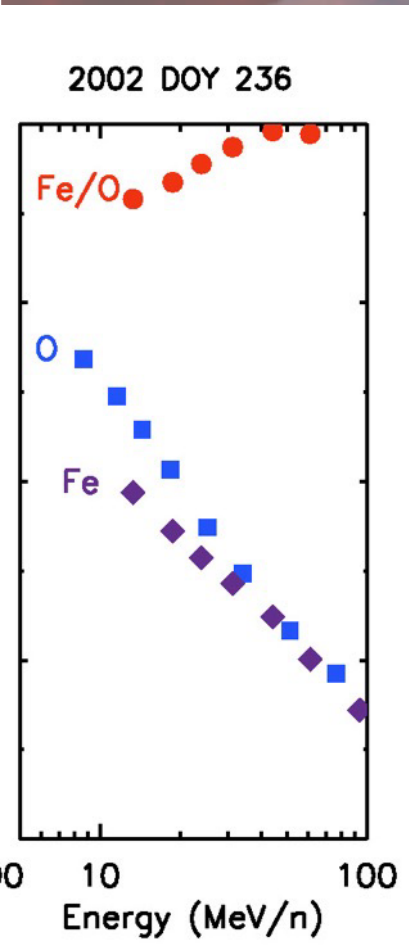


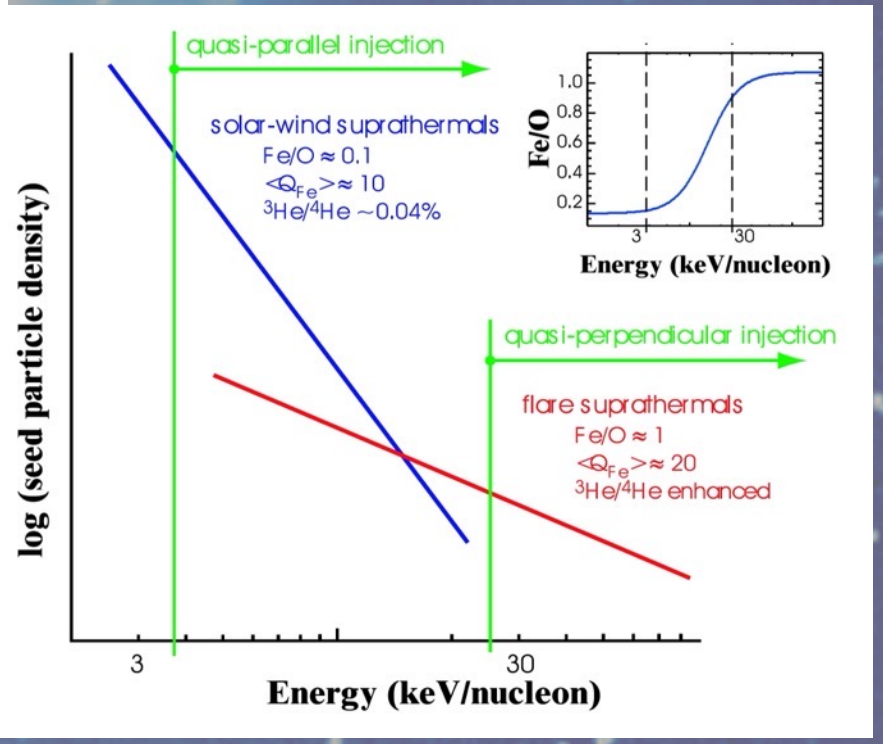


Don't Know

- Variability
  - Dependence on scales
- Conditions near the Sun
  - Shock parameters
  - Turbulence
  - Where particle acceleration starts/ends

Energization: Shock Acceleration





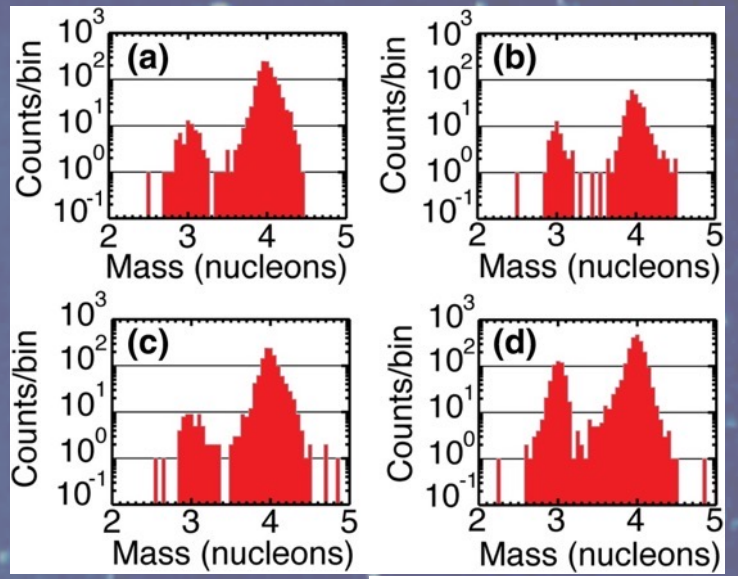
Don't Know

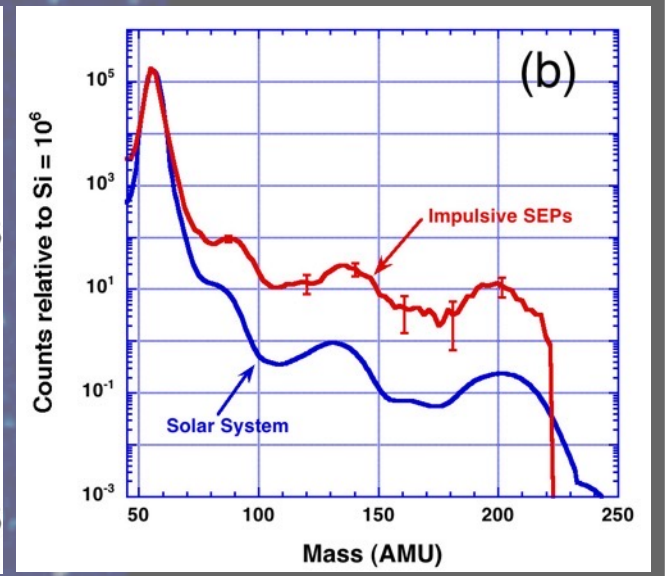
- Variability
  - Dependence on scales
- Conditions near the Sun
  - Shock parameters
  - Turbulence
  - Where particle acceleration starts/ends
- Energy-dependence of composition

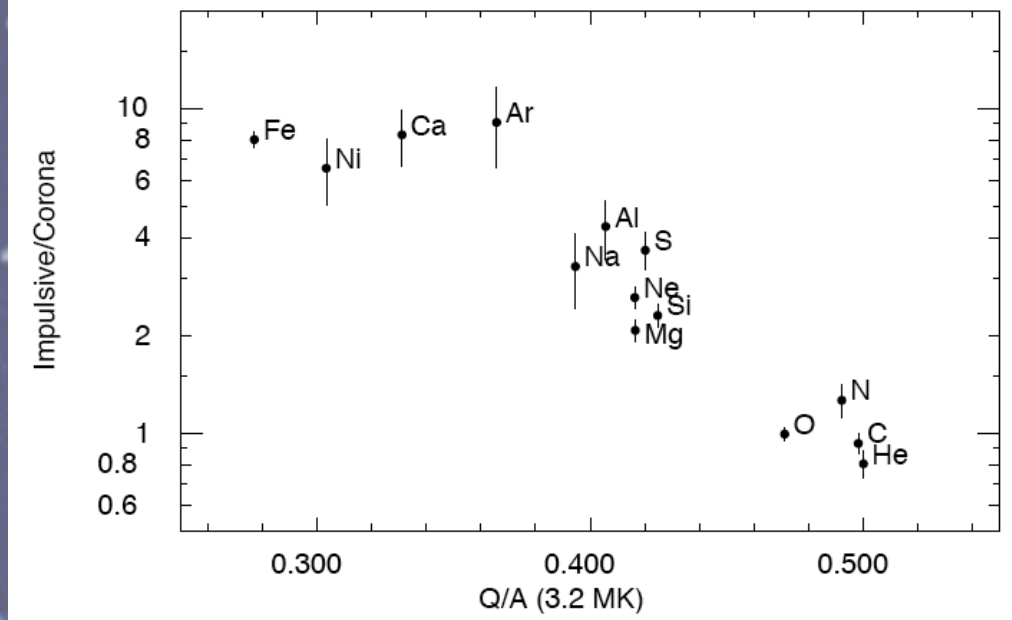
Energization: Reconnection Acceleration

Know

- Event characteristics
  - ^{3}He, Ultra heavy ions



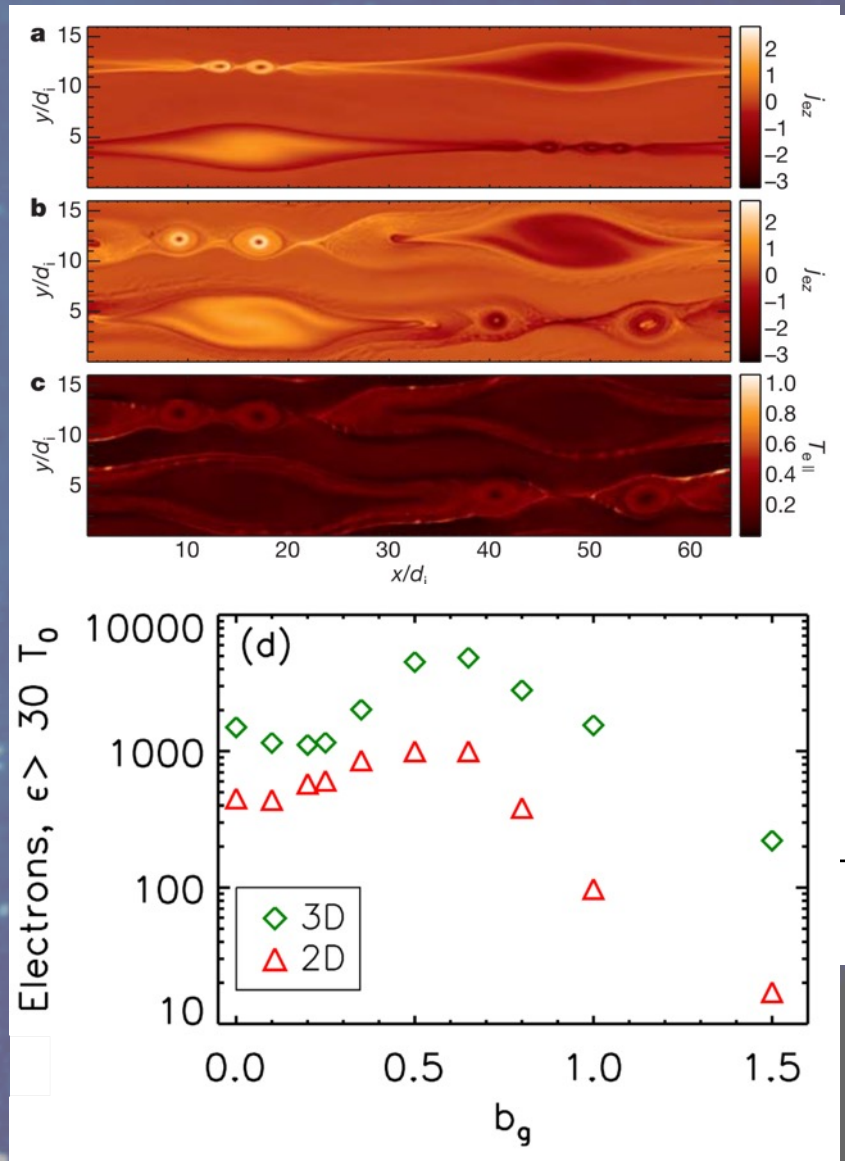


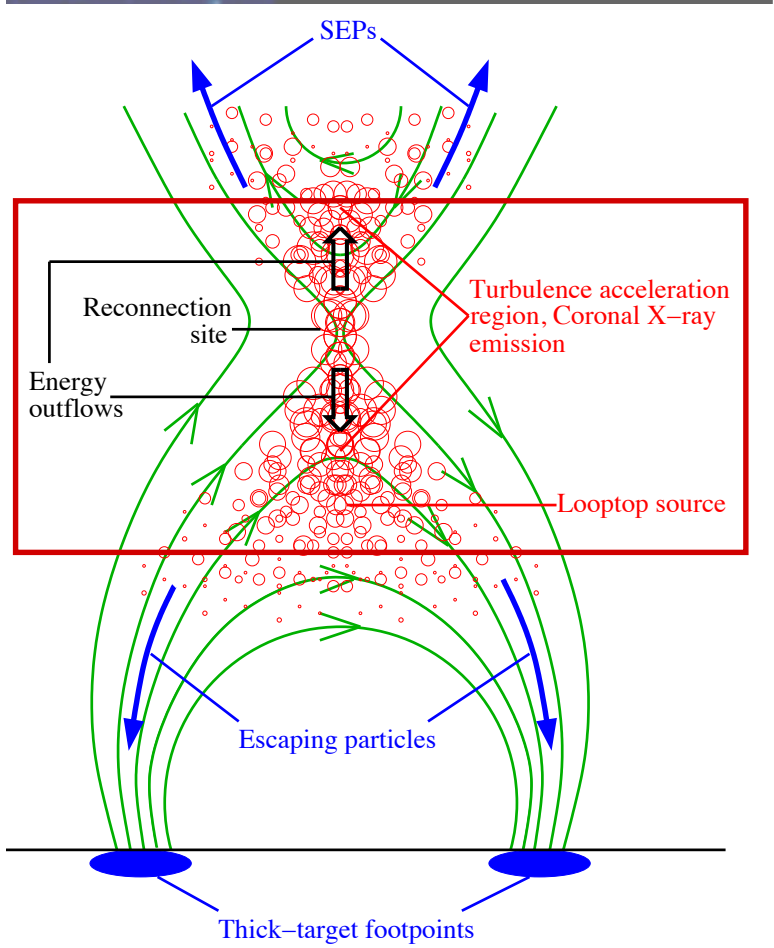


Energization: Reconnection Acceleration

Know

- Event characteristics
  - ^{3}He, Ultra heavy ions
- Some basic ideas
  - Wave-particle interactions
  - Magnetic islands
  - Role of guide field

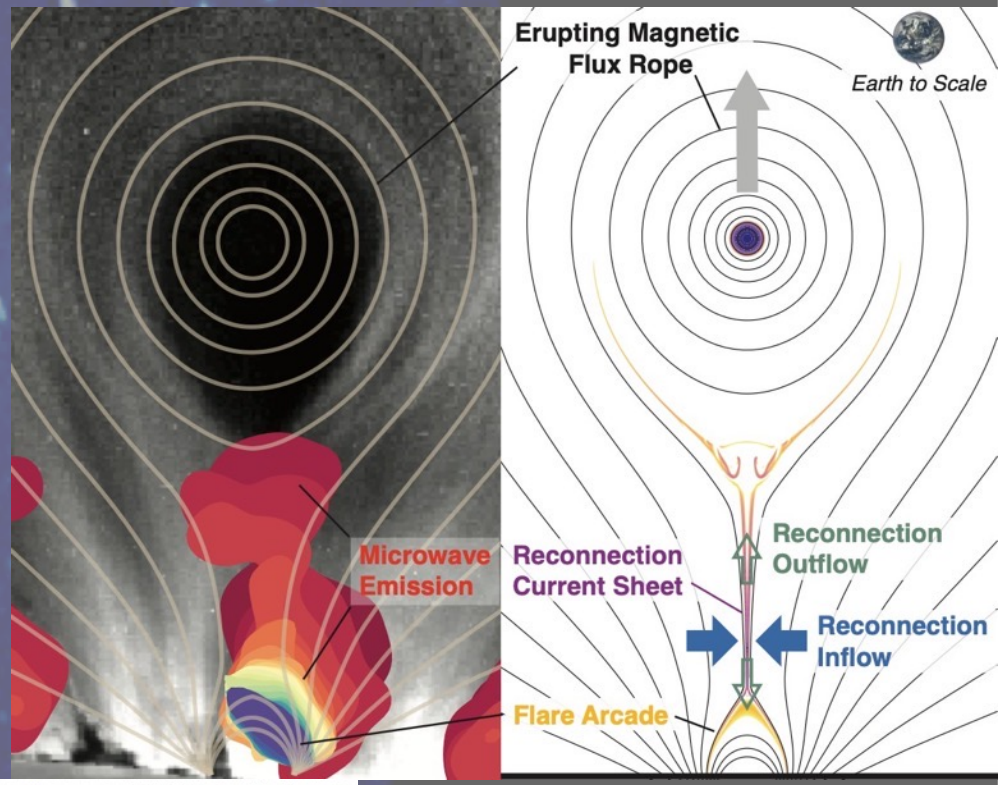


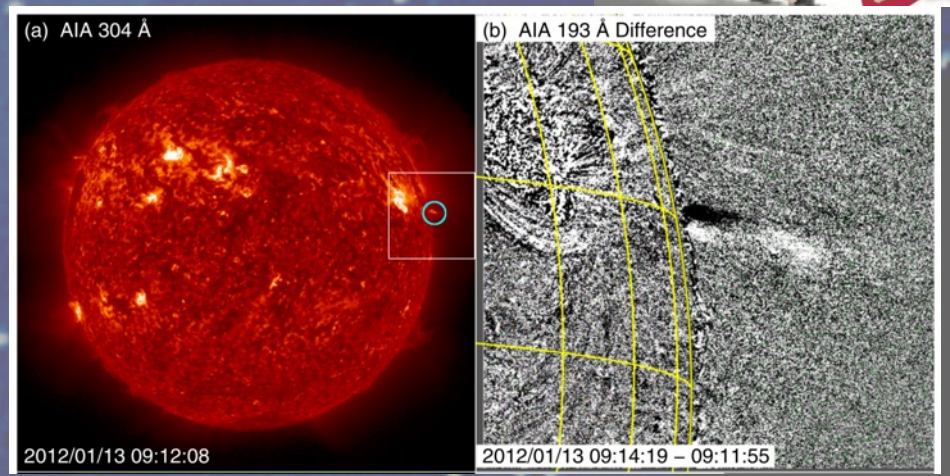


Energization: Reconnection Acceleration

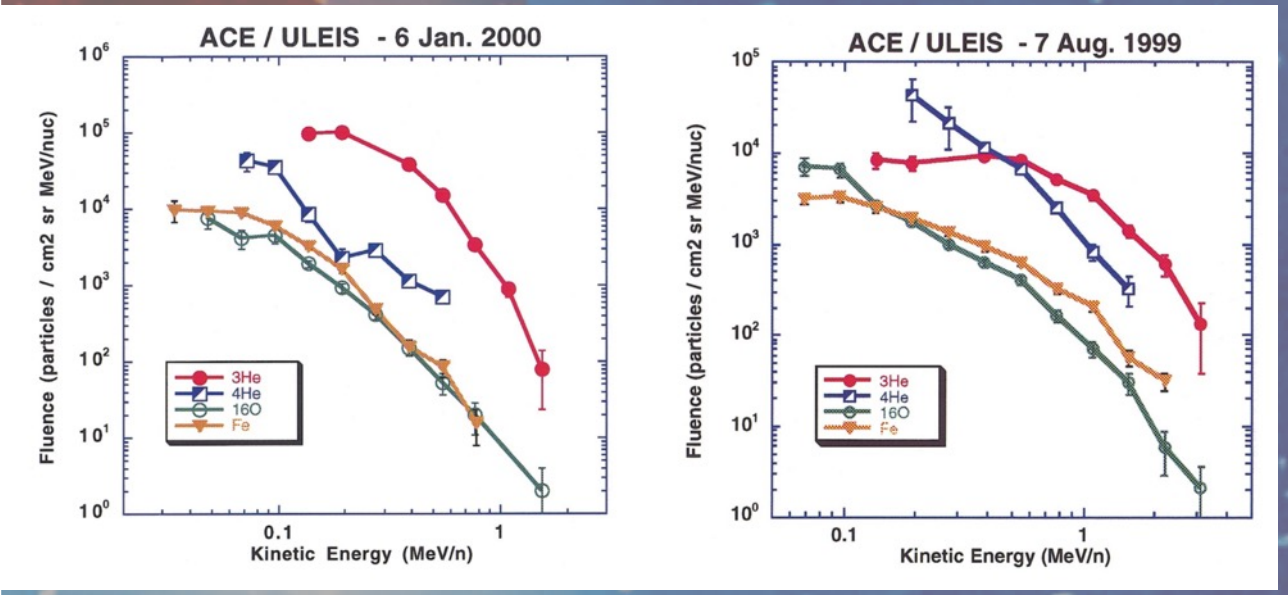
Know

- Event characteristics
  - ^{3}He, Ultra heavy ions
- Some basic ideas
  - Wave-particle interactions
  - Magnetic islands
  - Role of guide field
- Some idea of location
  - Near flares/part of process
  - Jets





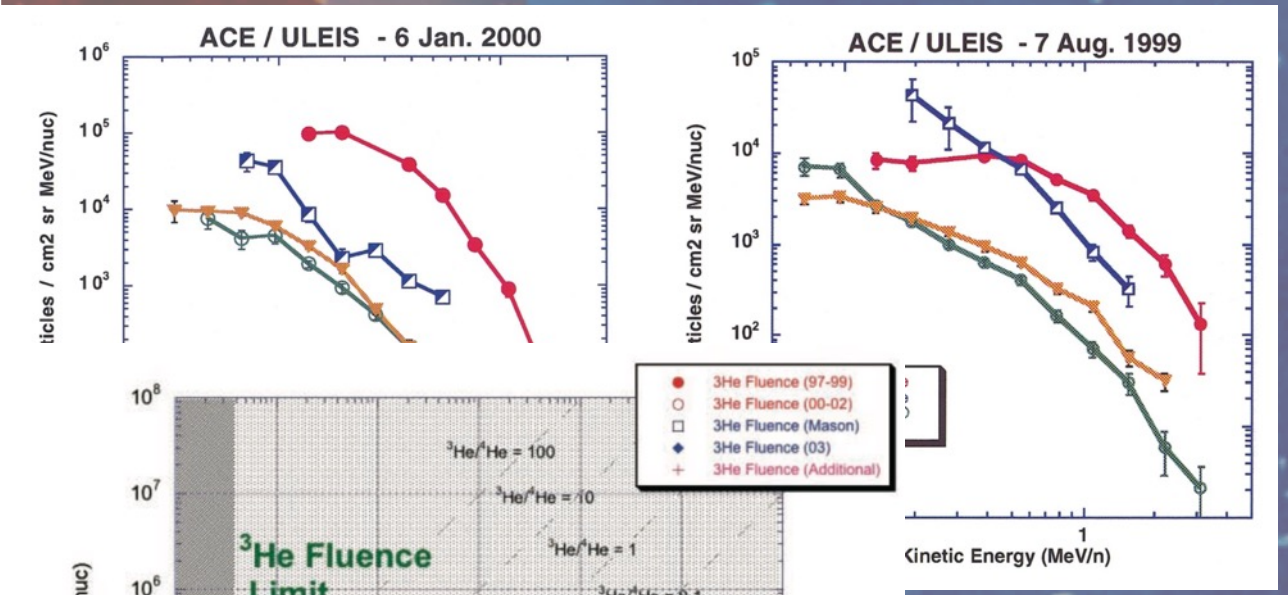
Energization: Reconnection Acceleration

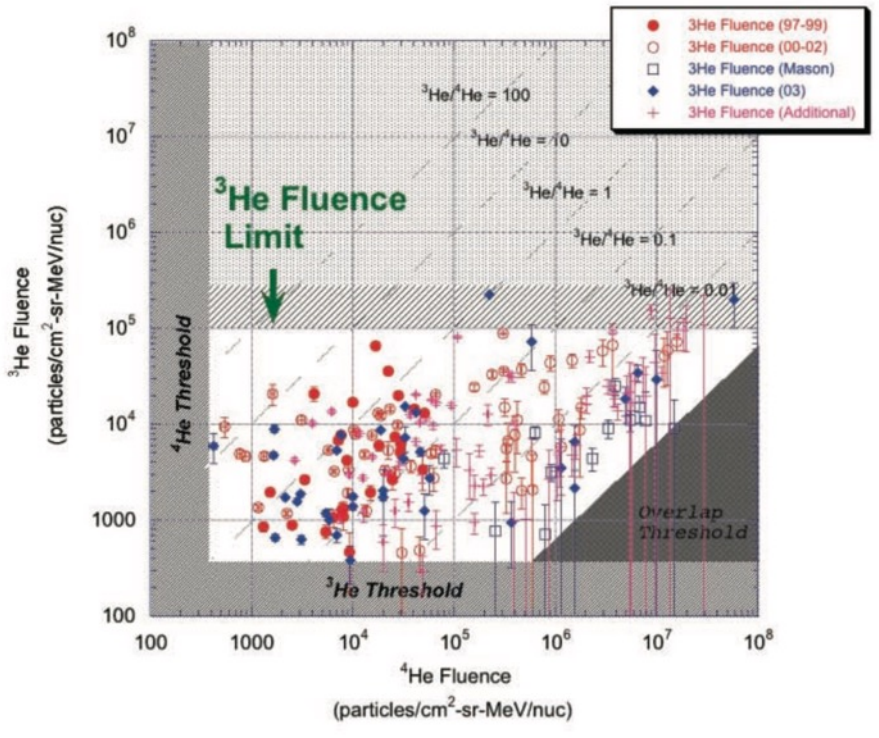


Don't Know

- 'Start' energy

Energization: Reconnection Acceleration

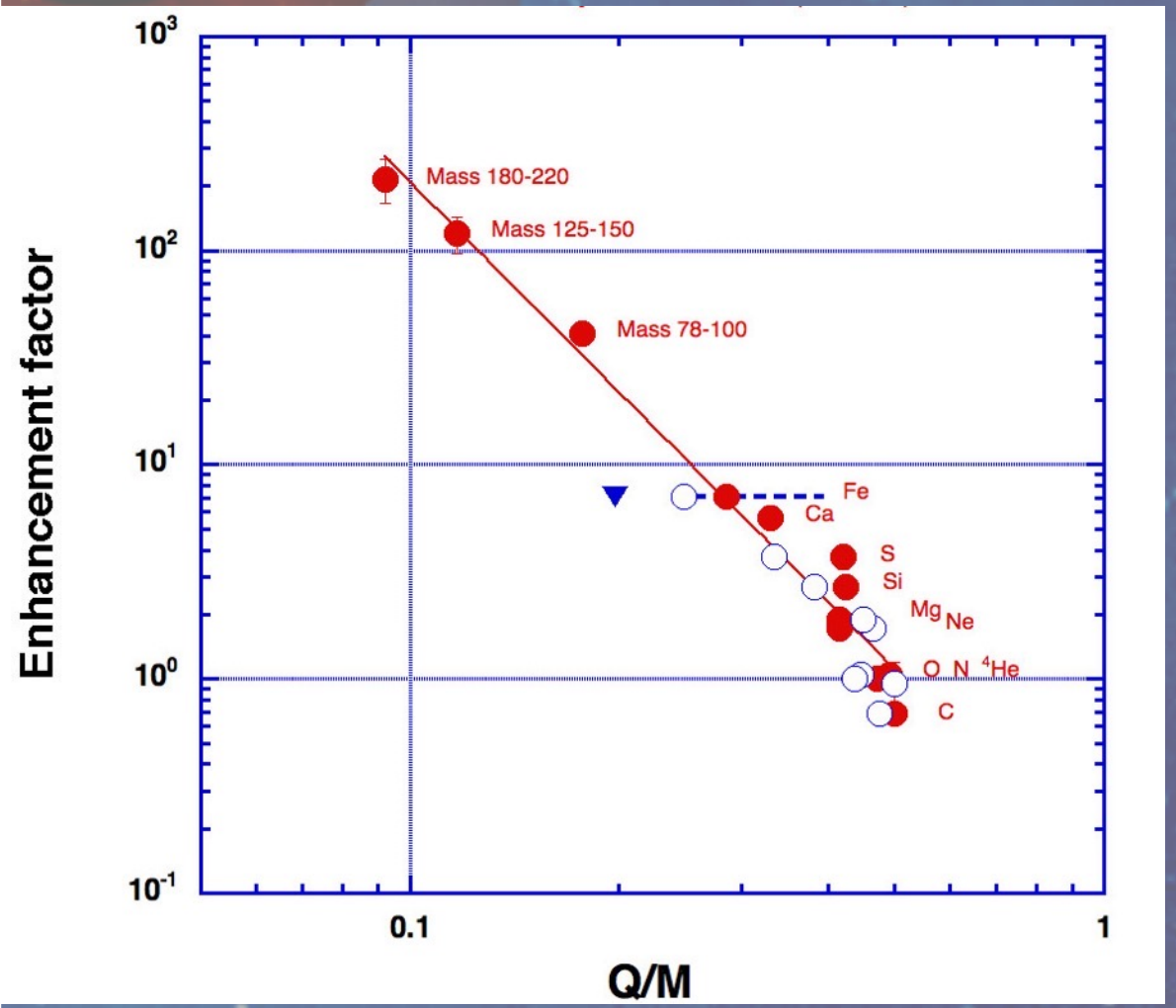




Don't Know

- 'Start' energy
- Variability
  - Spectral features
  - Size of event
  - Composition

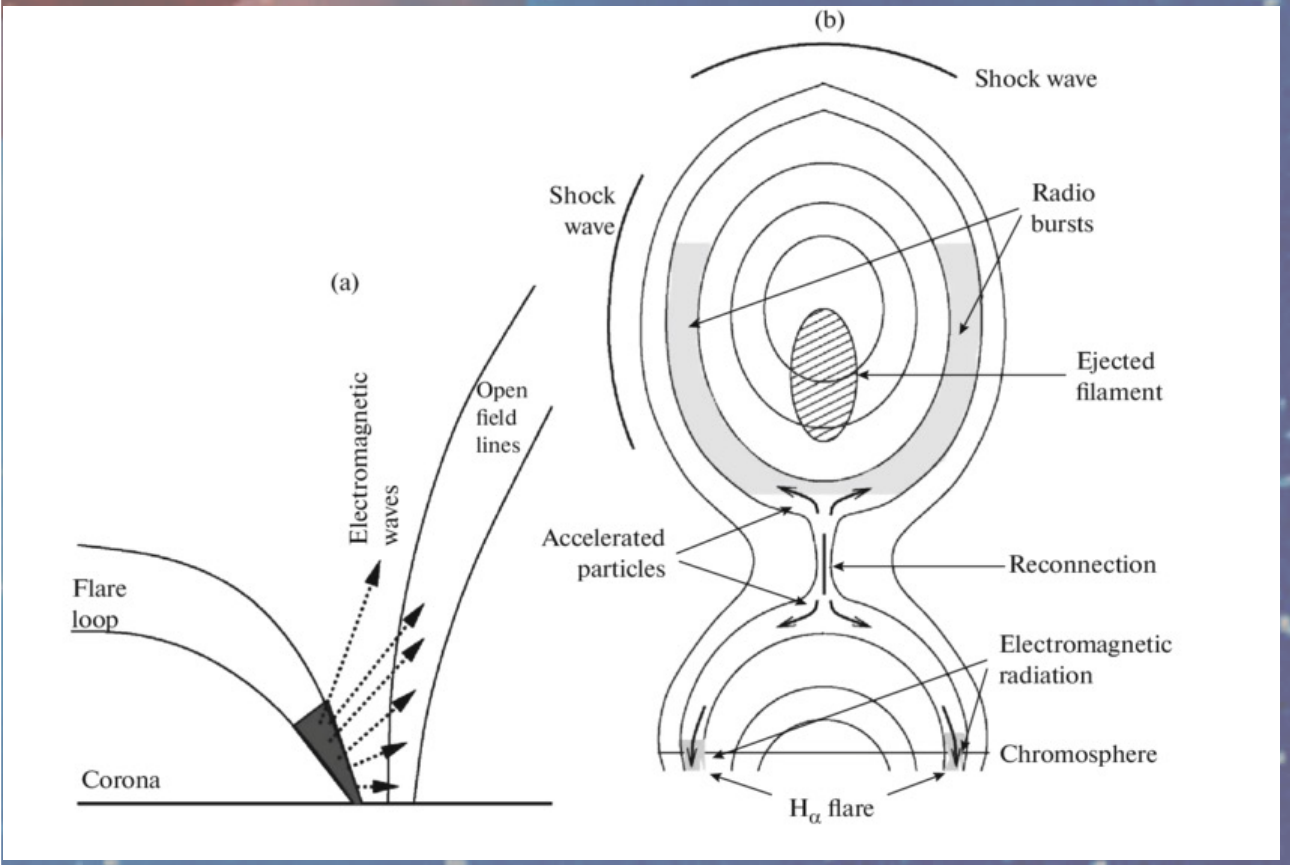
Energization: Reconnection Acceleration



Don't Know

- 'Start' energy
- Variability
  - Spectral features
  - Size of event
  - Composition

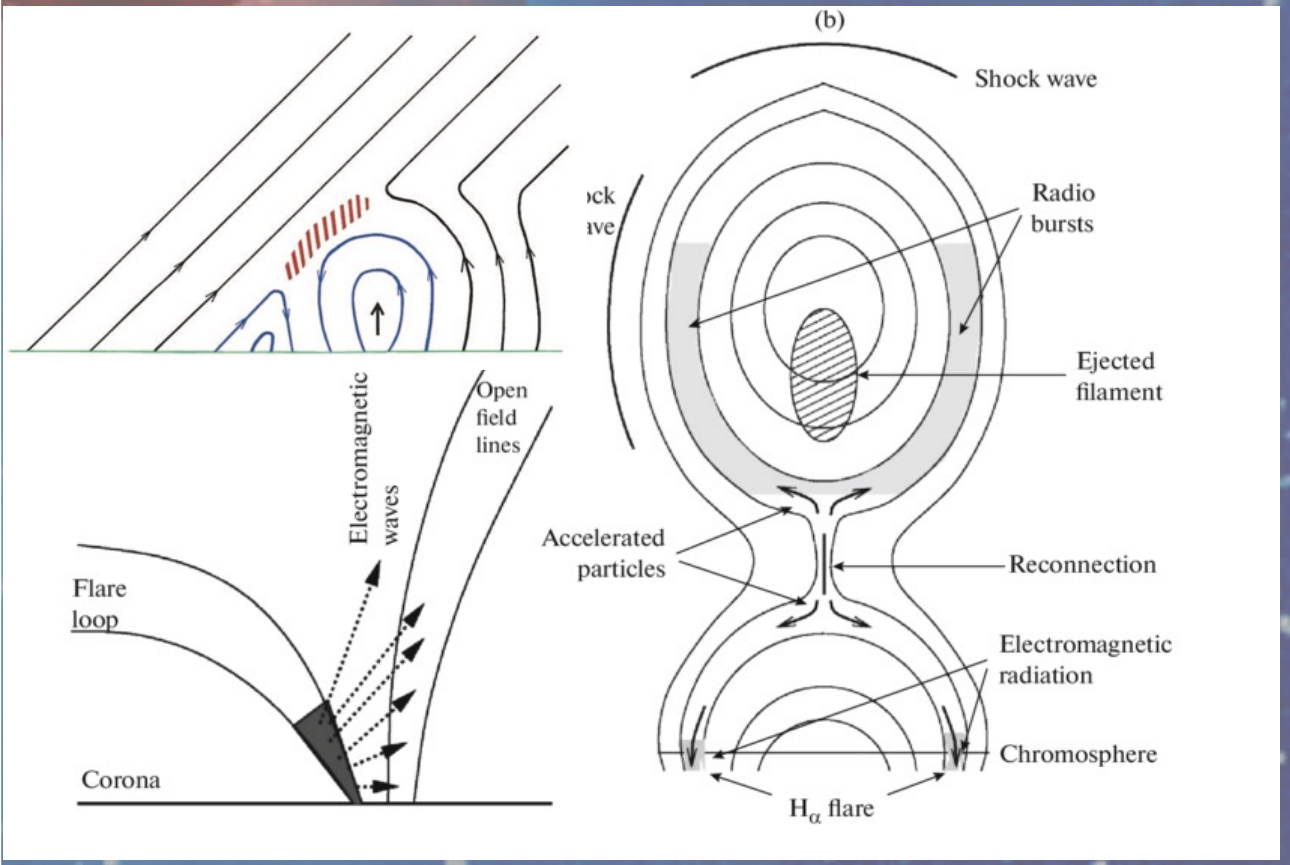
Energization: Reconnection Acceleration



Don't Know

- 'Start' energy
- Variability
  - Spectral features
  - Size of event
  - Composition
- Where exactly
  - Above, below

Energization: Reconnection Acceleration



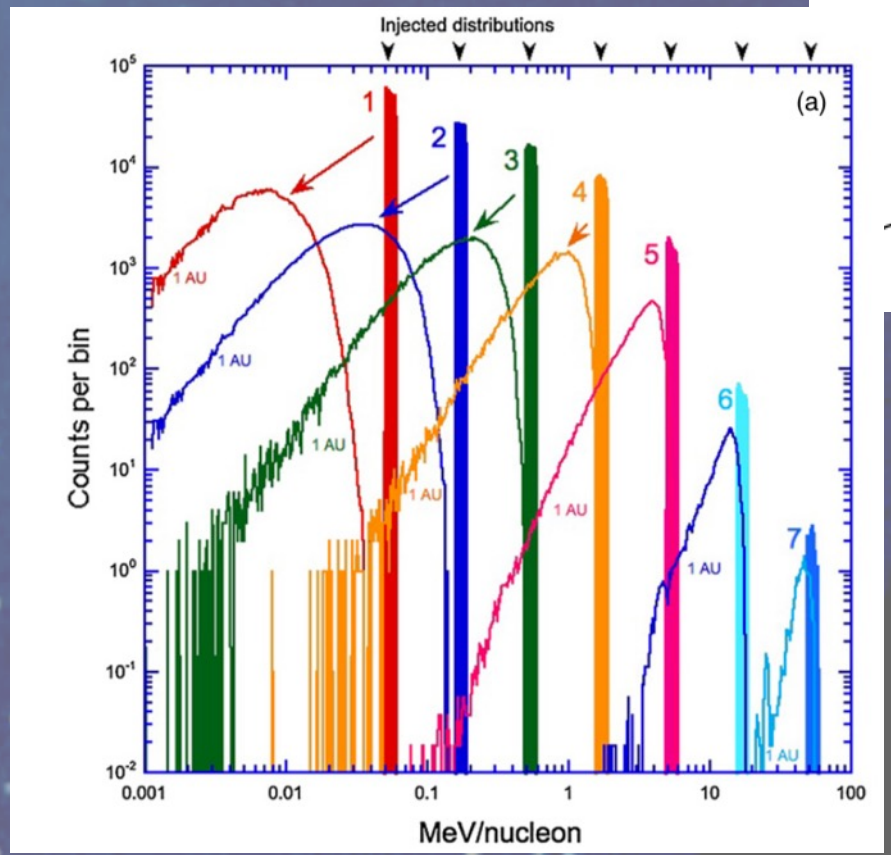
Don't Know

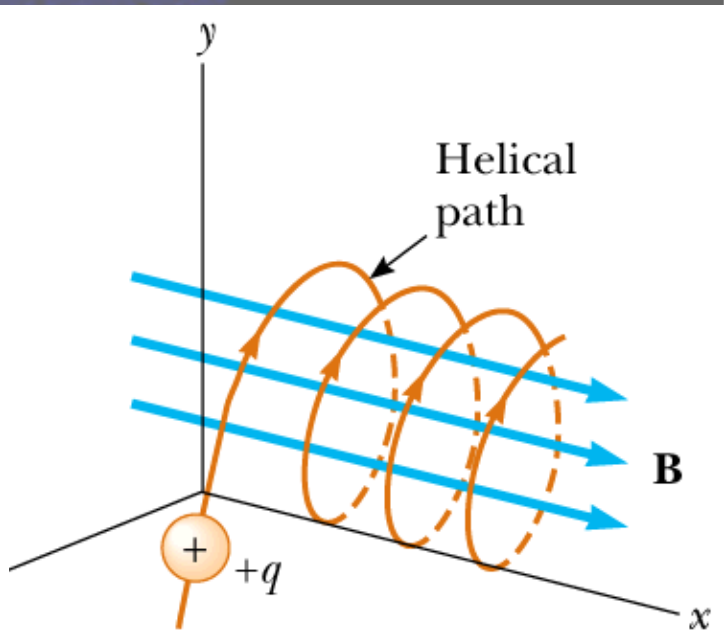
- 'Start' energy
- Variability
  - Spectral features
  - Size of event
  - Composition
- Where exactly
  - Above, below
- Escape from region

Transport: Field Aligned

Know

- Basic ideas
  - Field line connection
  - Adiabatic cooling

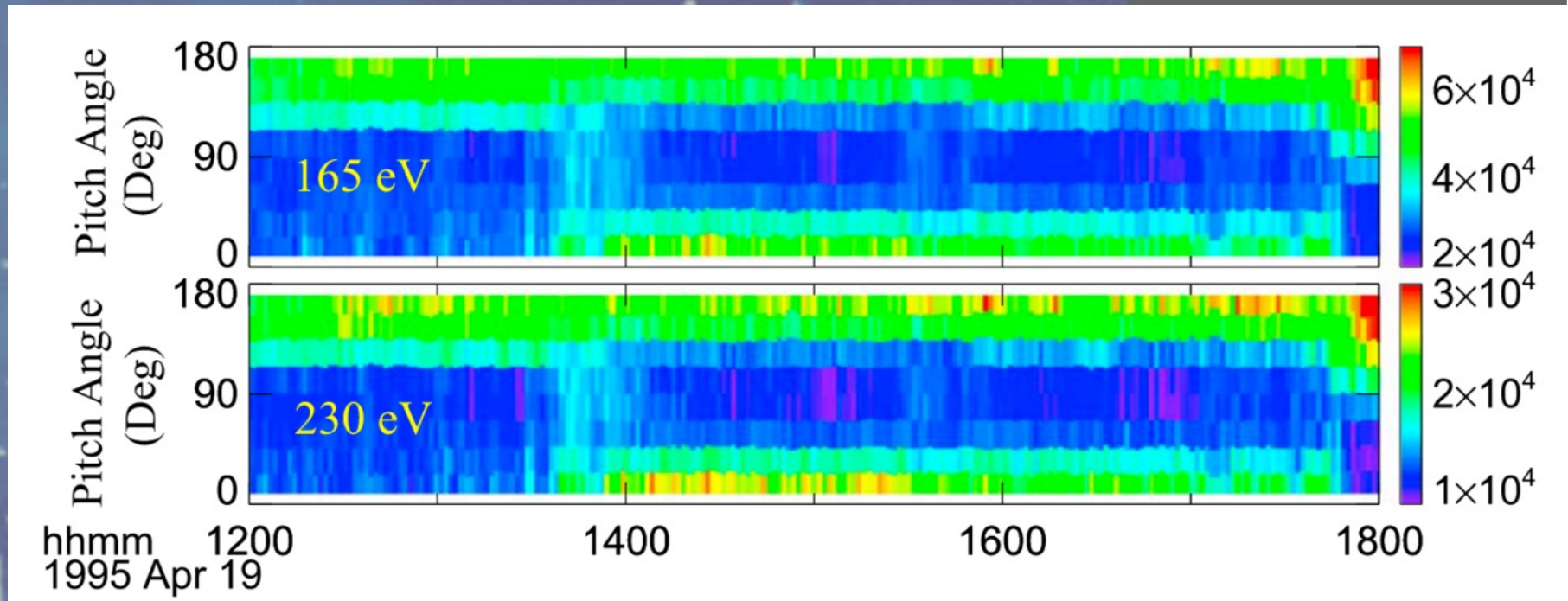




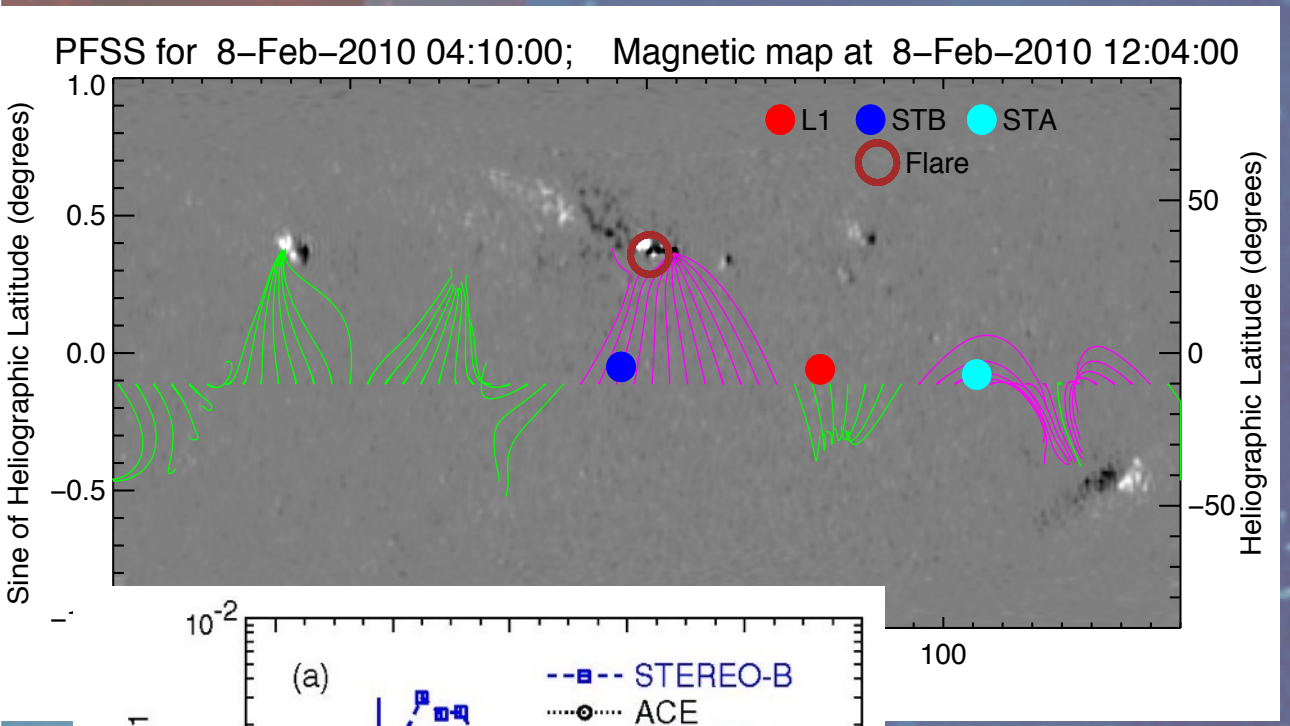
Transport: Field Aligned

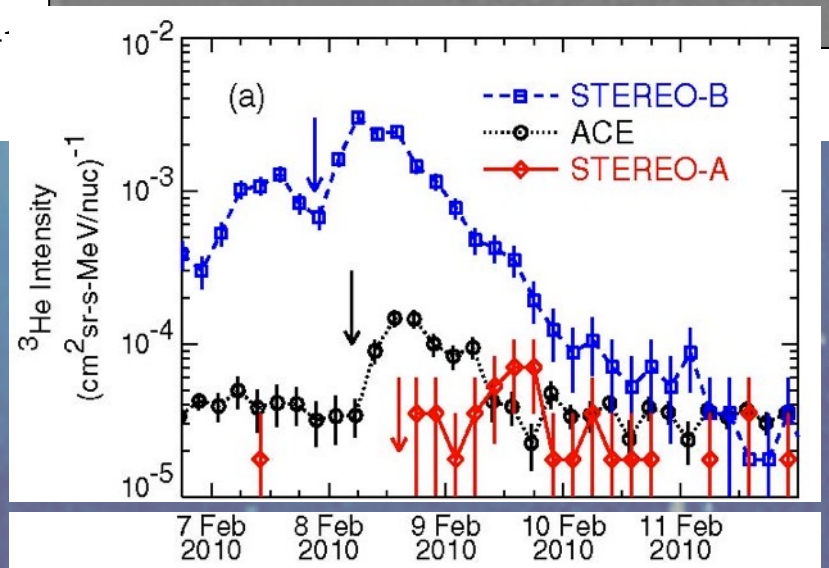
Know

- Basic ideas
  - Field line connection
  - Adiabatic cooling
- Scattering effects
  - Particle PAD



Transport: Field Aligned

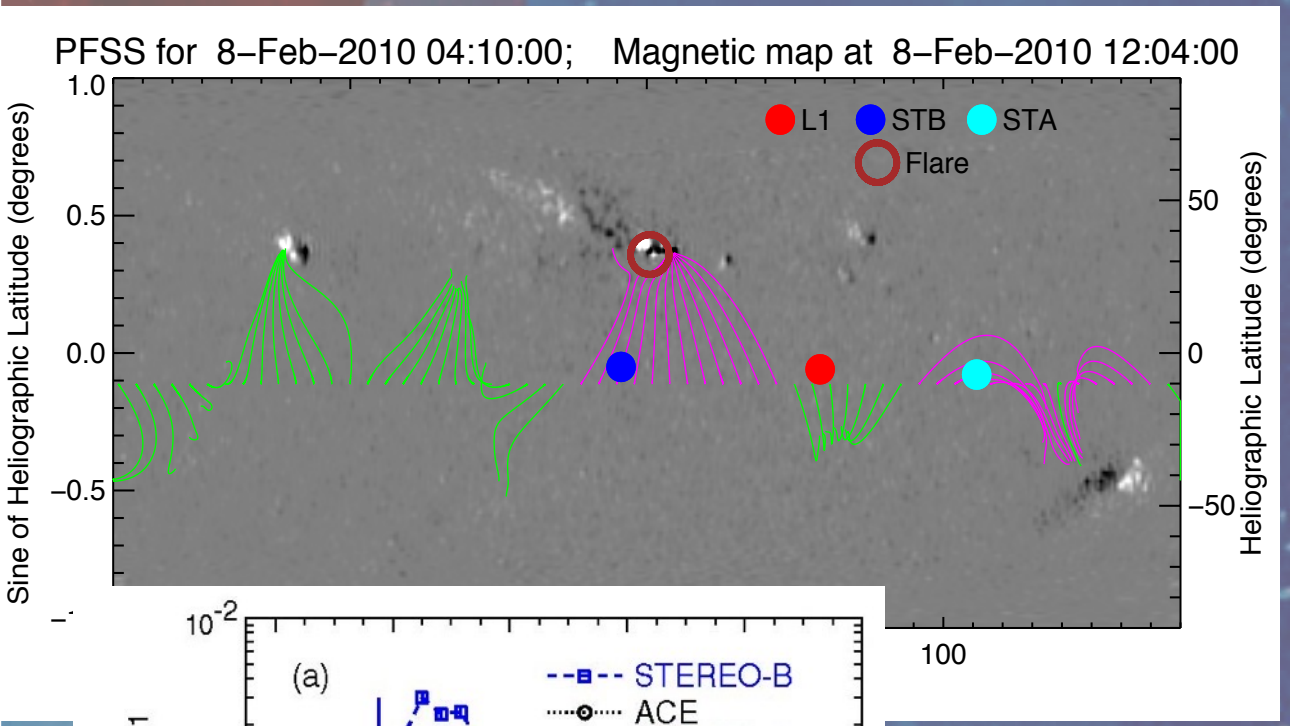


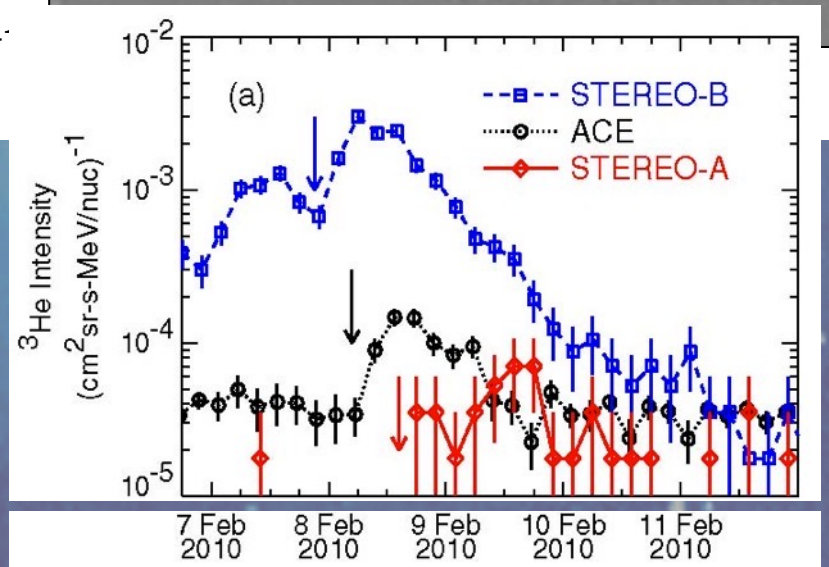


Don't Know

- Where the field is/going
  - Observer-source connection

Transport: Field Aligned





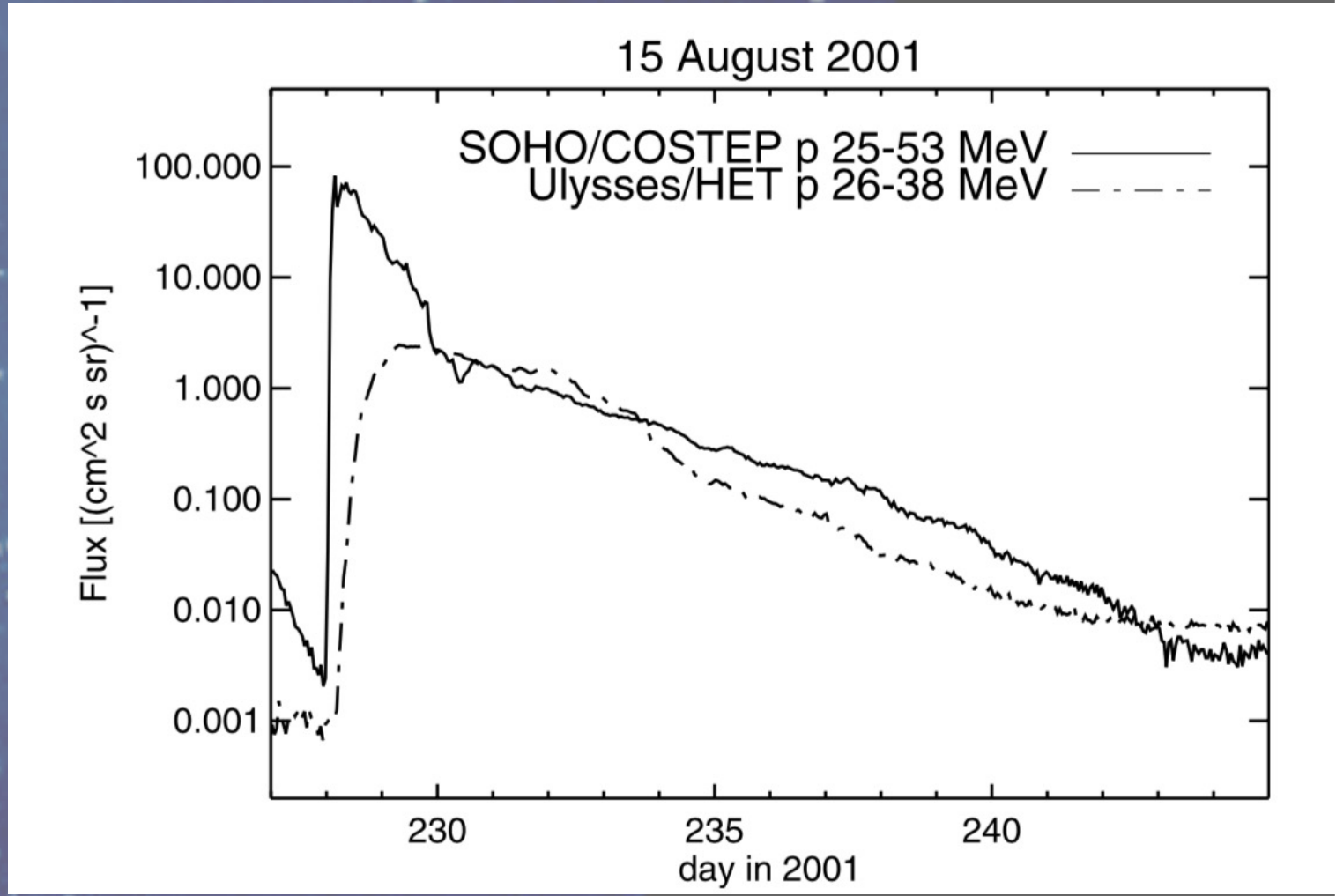
Don't Know

- Where the field is/going
  - Observer-source connection
- Variability of the field

Transport: Cross-field

Know

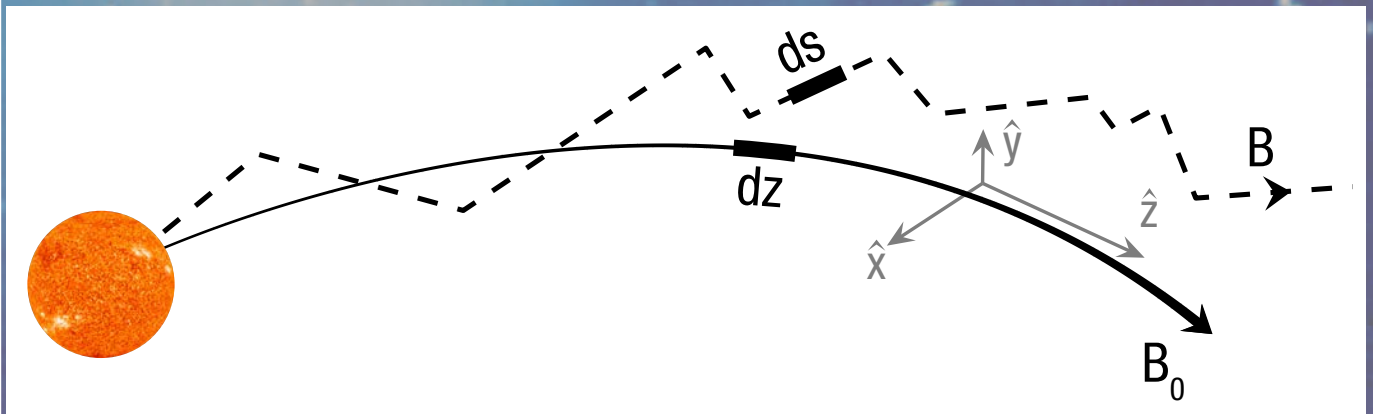
- It happens
  - See events far from source

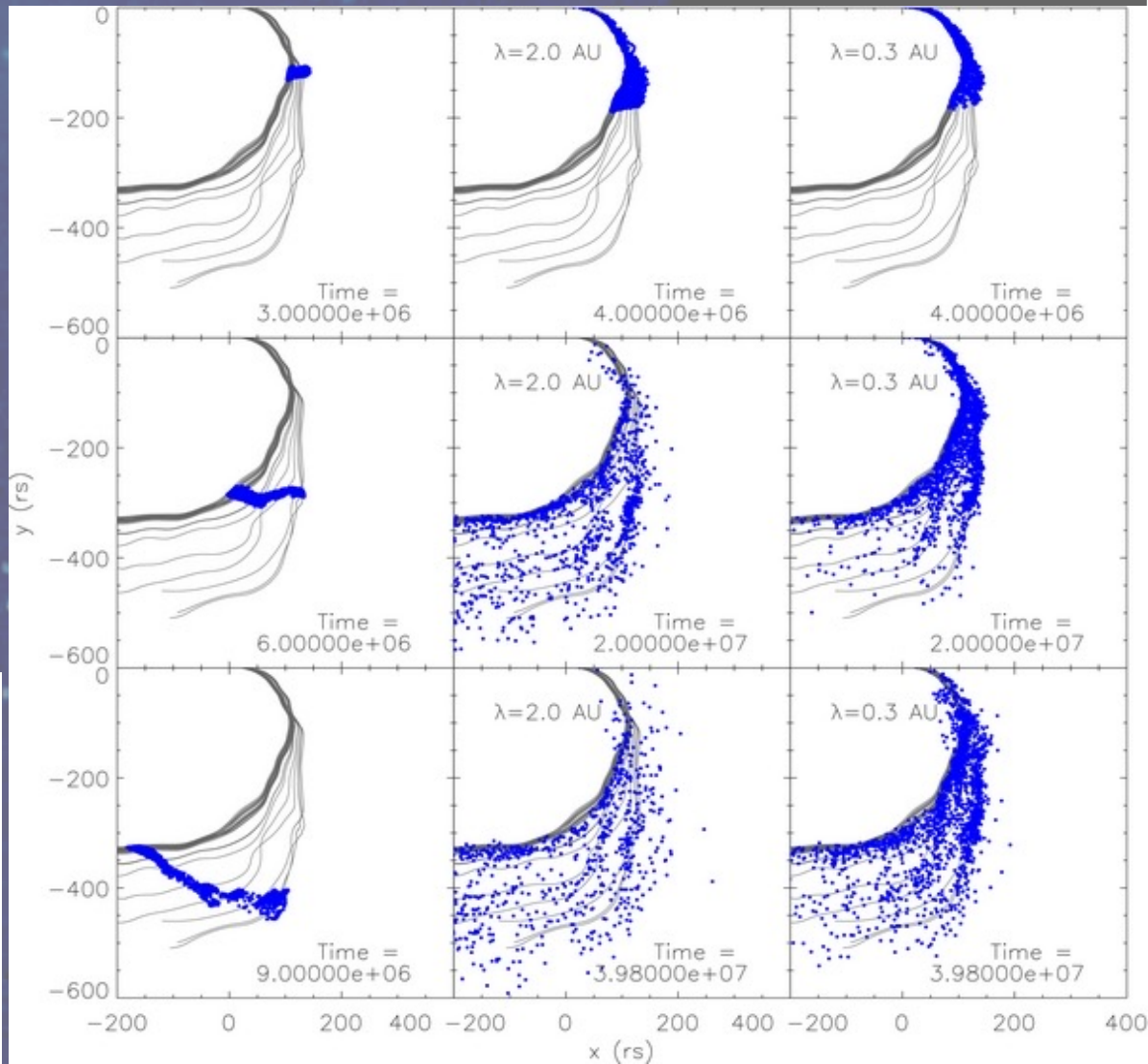


Transport: Cross-field

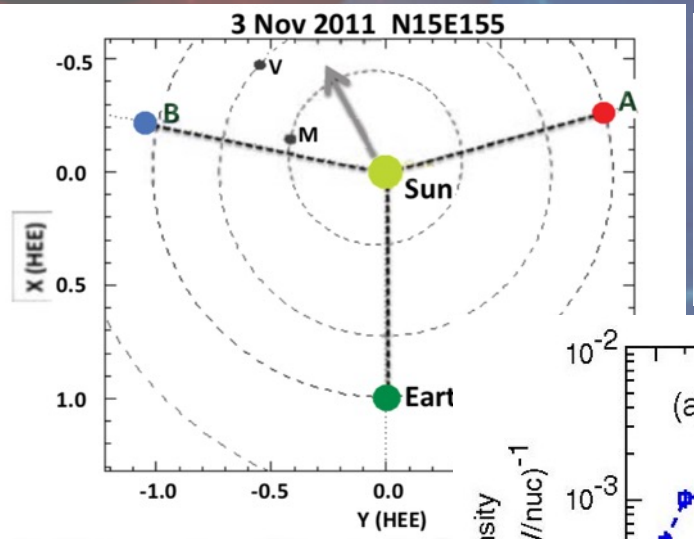
Know

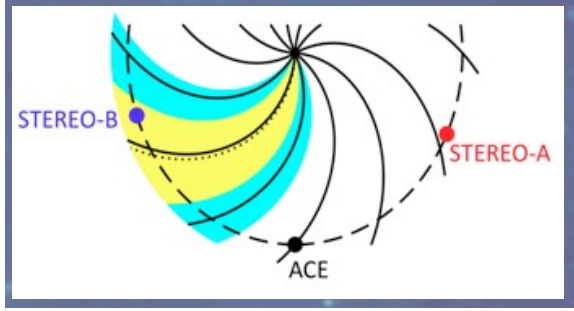
- It happens
  - See events far from source
- Some ideas
  - Fieldline meandering
  - Scattering

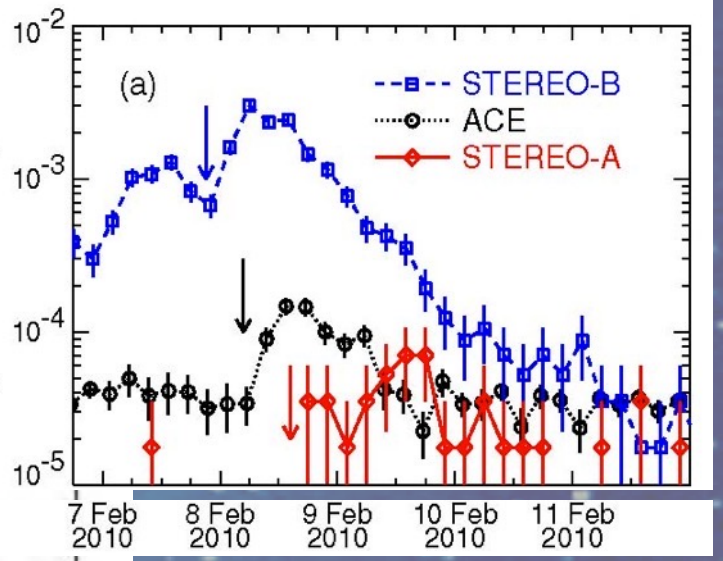


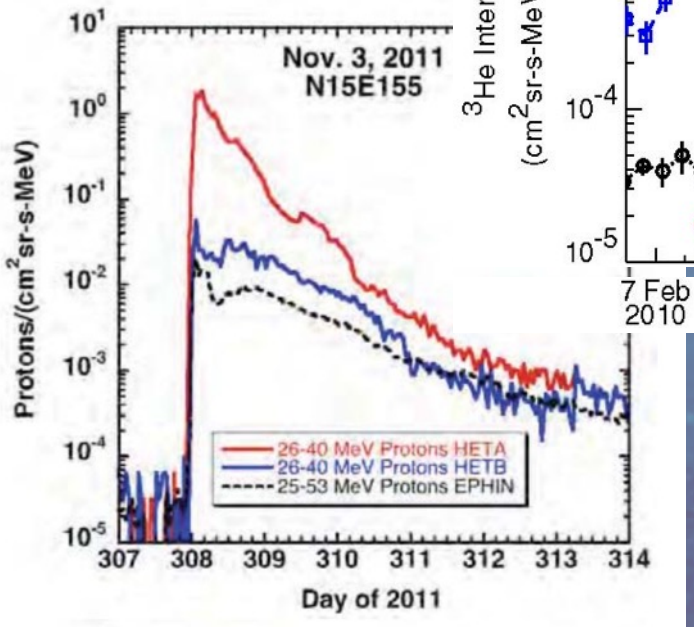


Transport: Cross-field





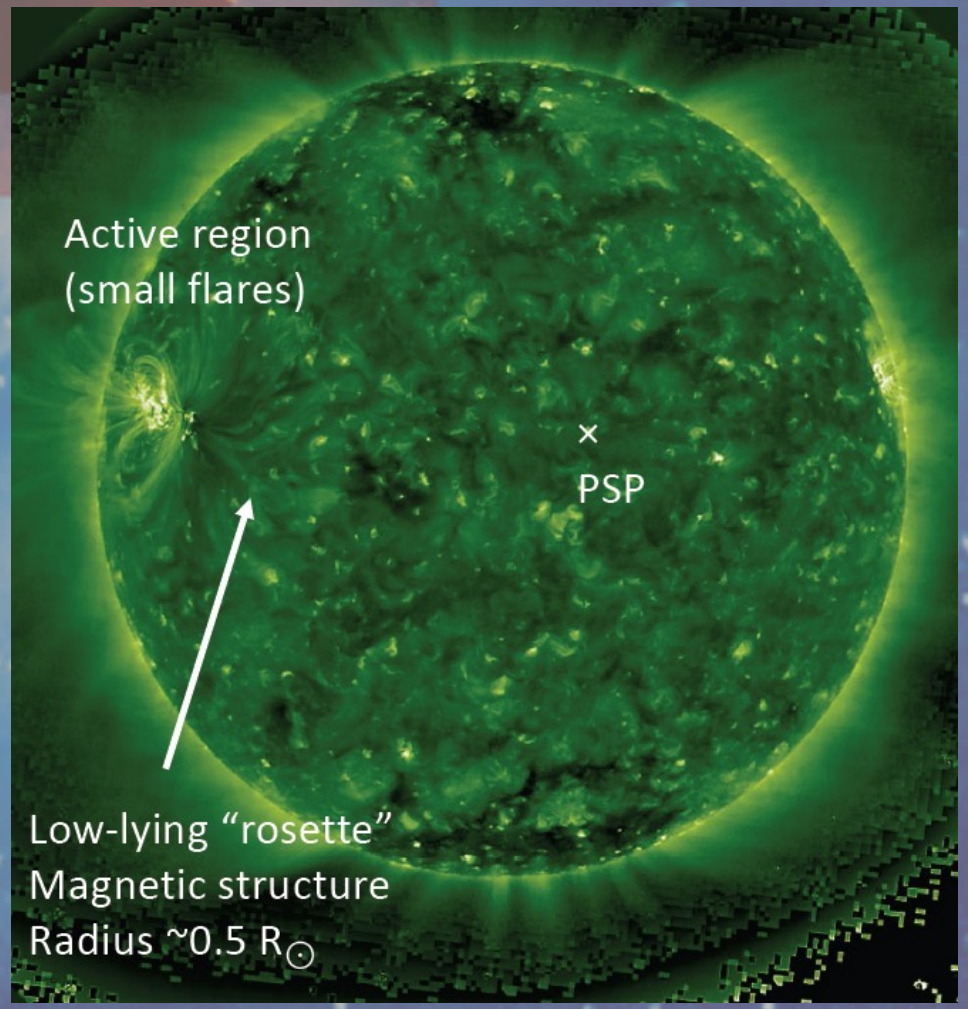




Don't Know

- Puzzling events
  - Circumsolar
  - Wide ^{3}He-rich
  - Distant sources

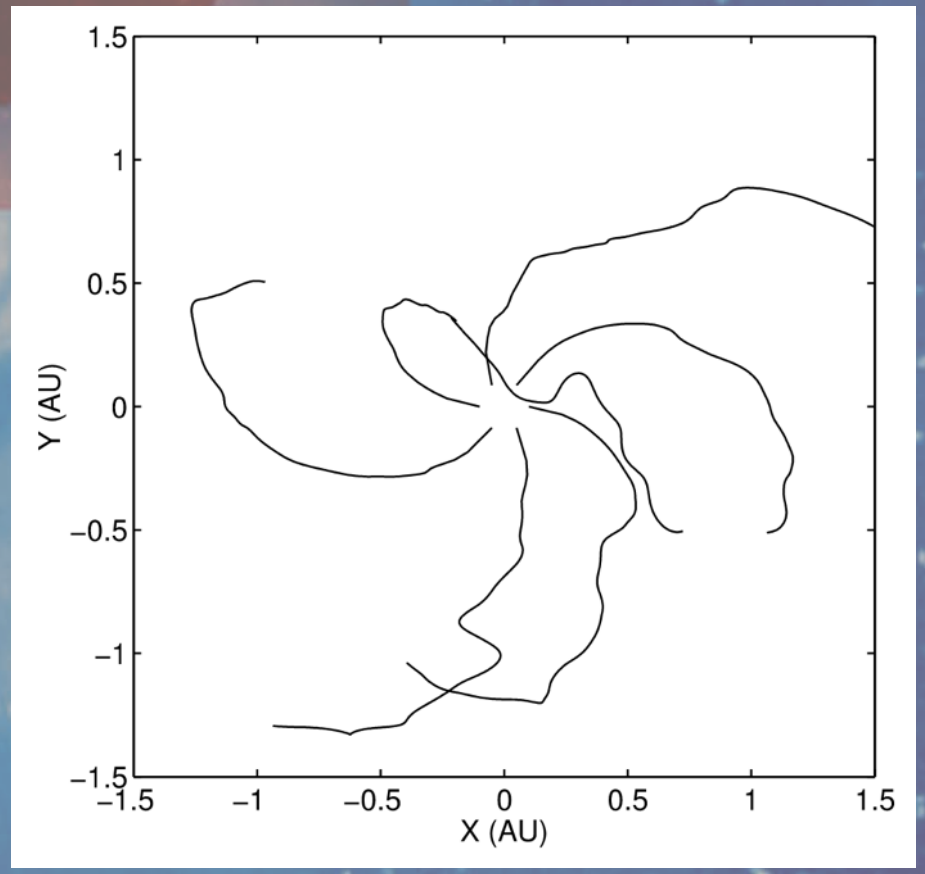
Transport: Cross-field



Don’t Know

- Puzzling events
  - Circumsolar
  - Wide ^{3}He-rich
  - Distant sources

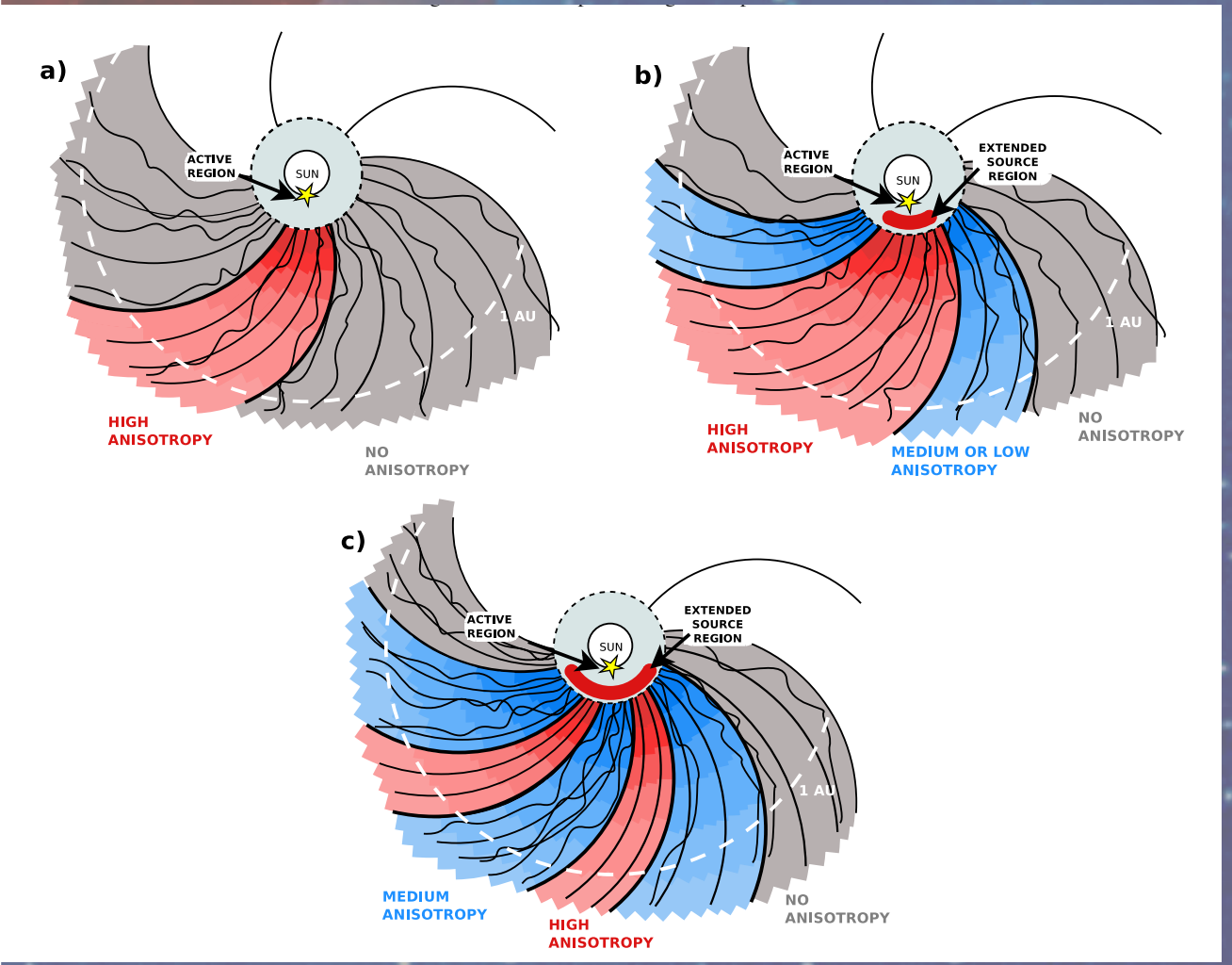
Transport: Cross-field



Don't Know

- Puzzling events
  - Circumsolar
  - Wide ^{3}He-rich
  - Distant sources
- Fields or particles?

Transport: Cross-field



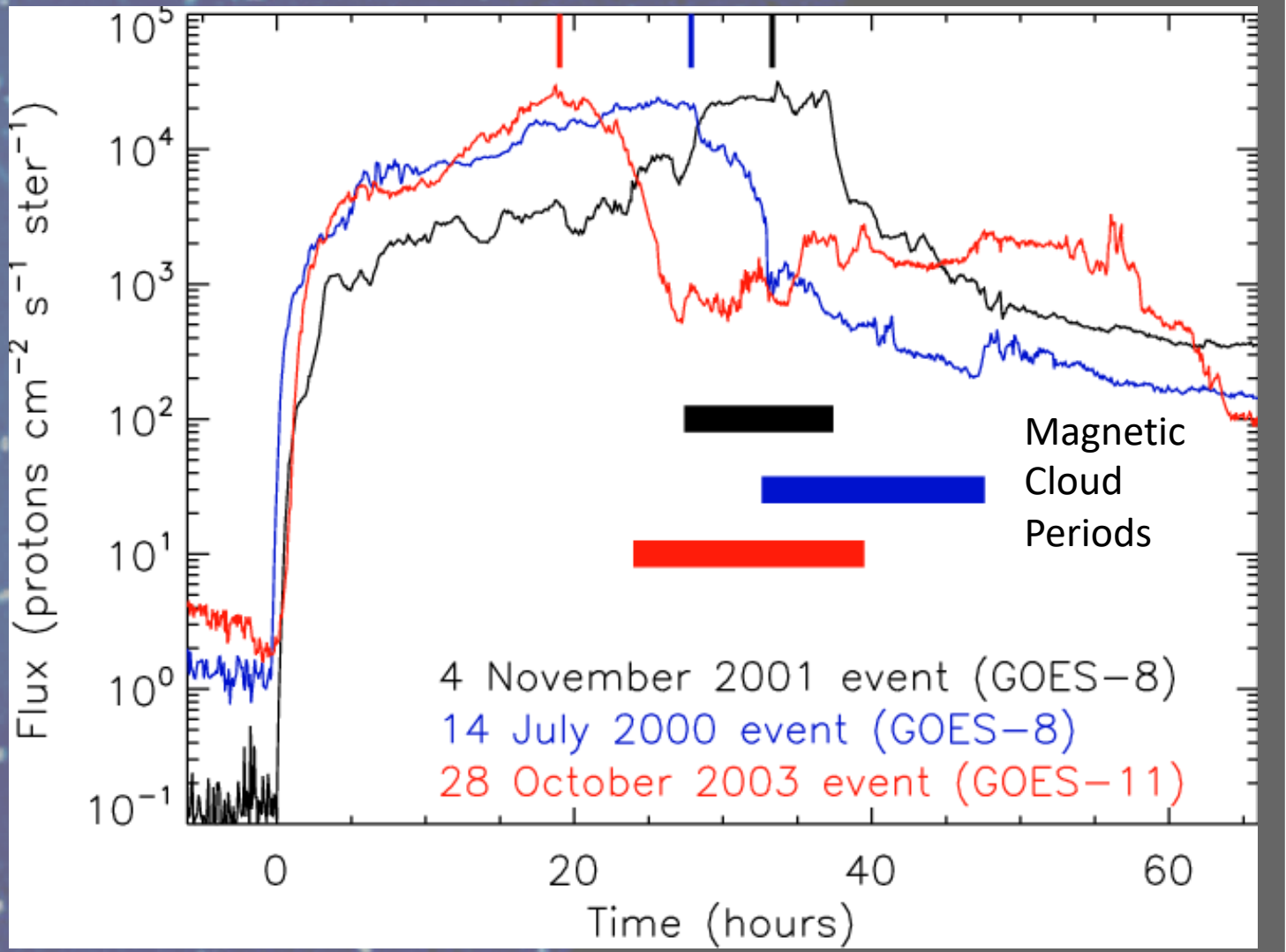
Don't Know

- Puzzling events
  - Circumsolar
  - Wide ^{3}He-rich
  - Distant sources
- Fields or particles?
- Relative roles acceleration vs transport

Conditions: Plasma + Structures

Know

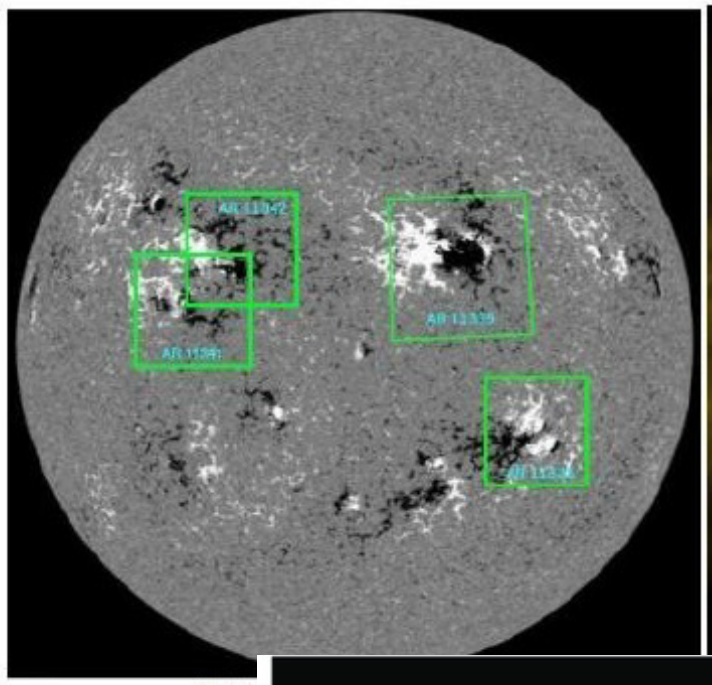
- They affect SEPs
  - Acceleration
  - Transport

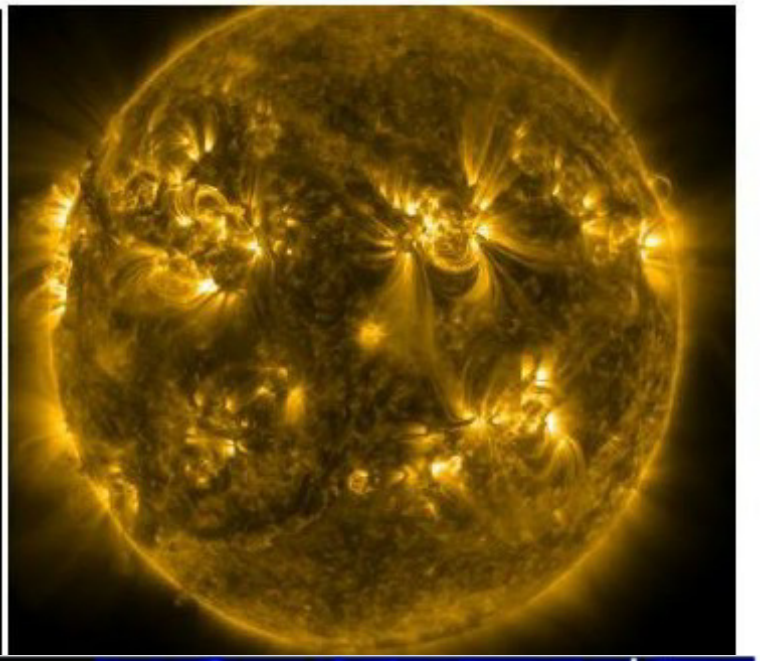


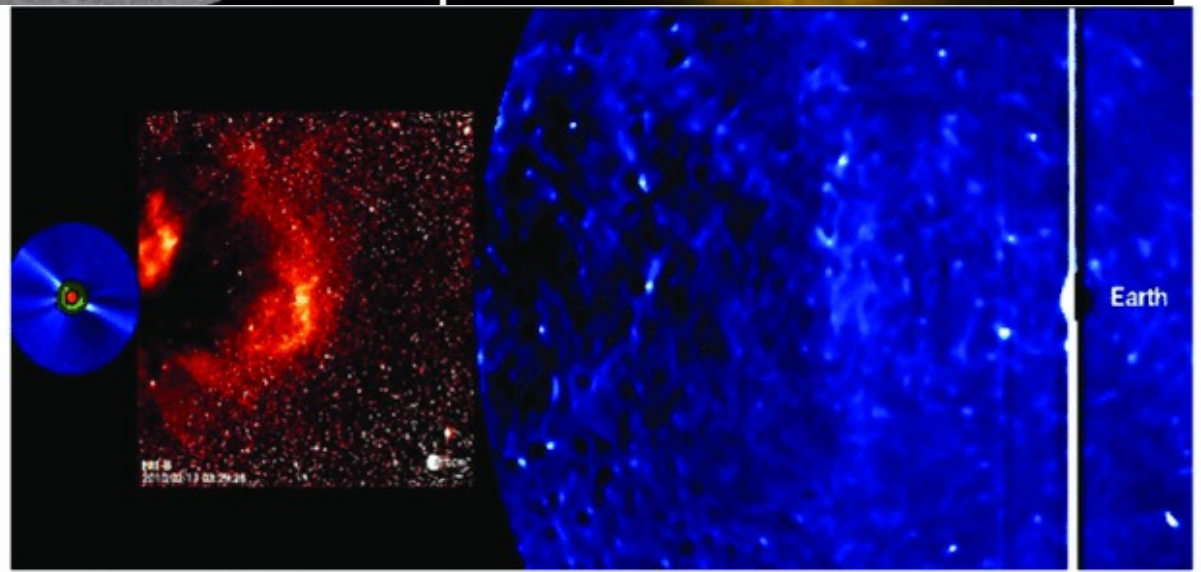
Conditions: Plasma + Structures

Know

- They affect SEPs
  - Acceleration
  - Transport
- Solar conditions
  - B field at the photosphere
  - Coronal holes
- CMEs
  - Near Sun
  - IPM



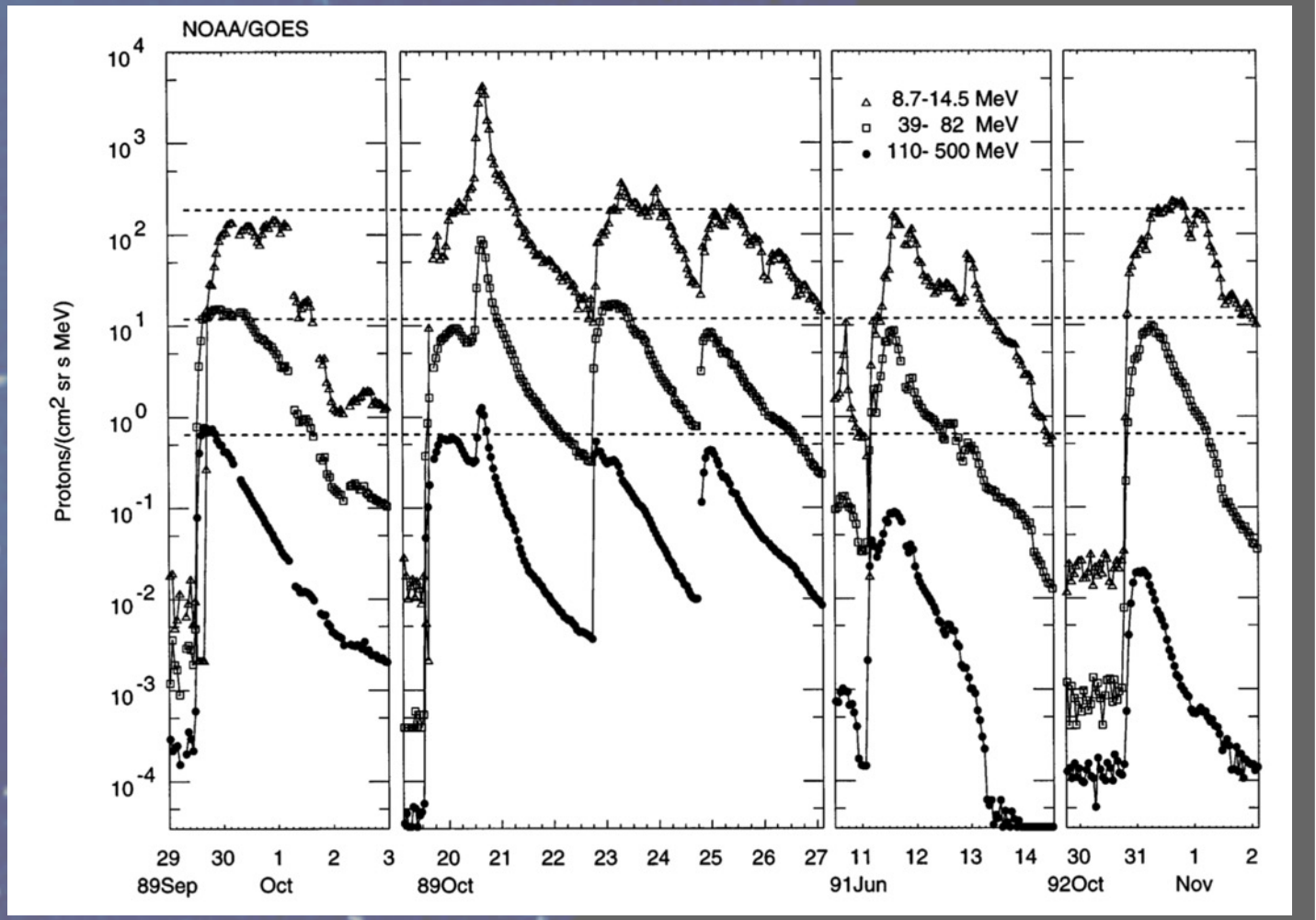




Conditions: Plasma + Structures

Know

- They affect SEPs
  - Acceleration
  - Transport
- Solar conditions
  - B field at the photosphere
  - Coronal holes
- CMEs
  - Near Sun
  - IPM
- Details at some points in IPM
- Streaming limit

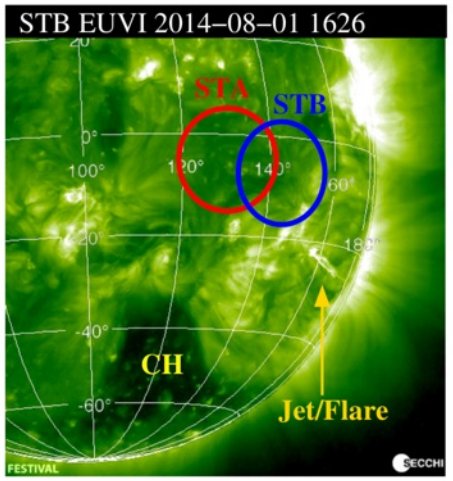


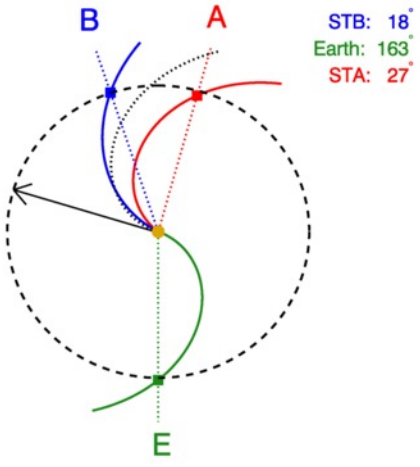
Conditions: Plasma + Structures

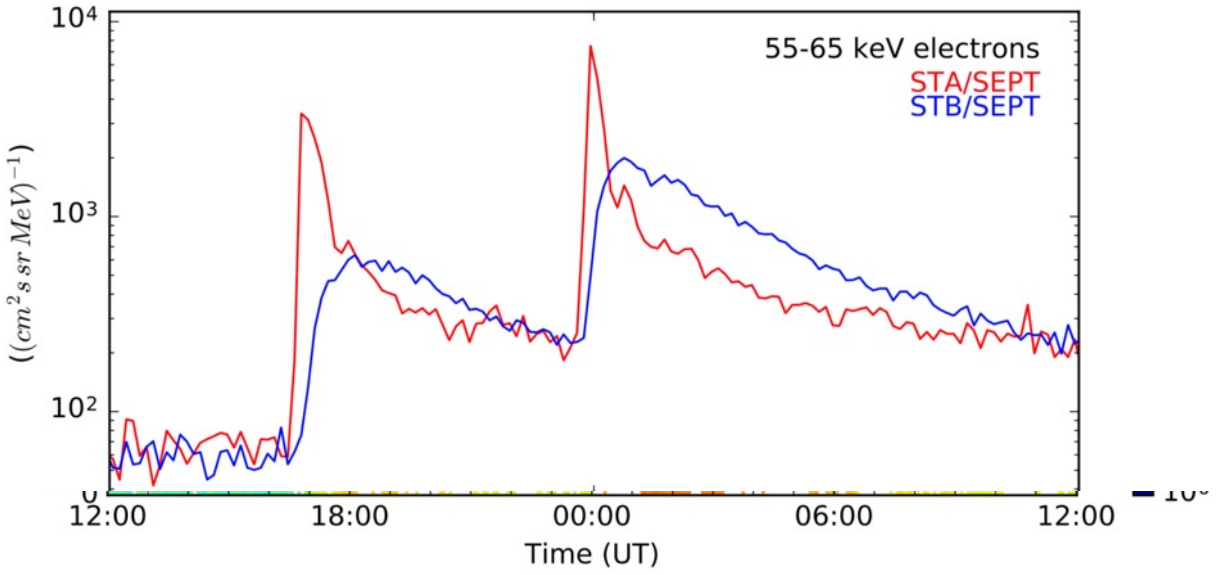
Don't Know

- B field where we aren't measuring
  - Strength, orientation
  - CMEs in the way
- Shock properties where we aren't measuring
  - Near Sun
  - CIRs

Conditions: Plasma + Structures







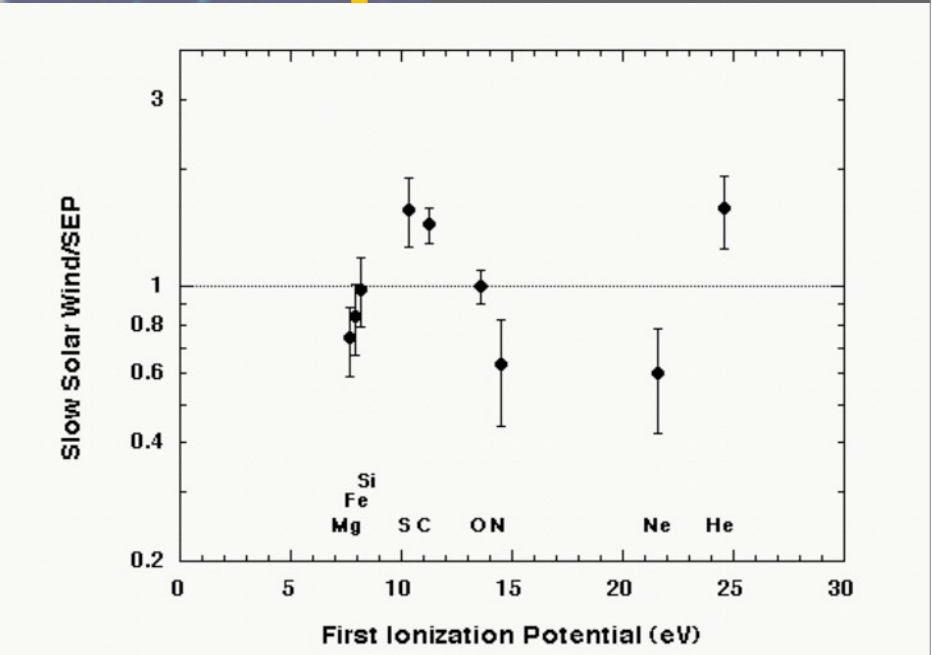
Don't Know

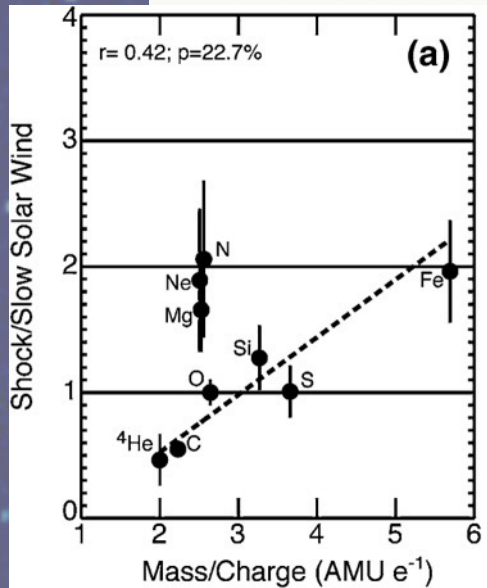
- B field where we aren't measuring
  - Strength, orientation
  - CMEs in the way
- Shock properties where we aren't measuring
  - Near Sun
  - CIRs
- Variability on mesoscales

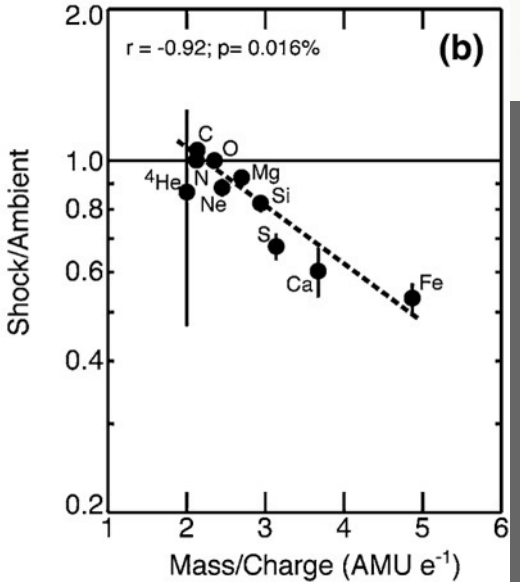
Conditions: Seed Populations

Know

- Suprathermals play a role



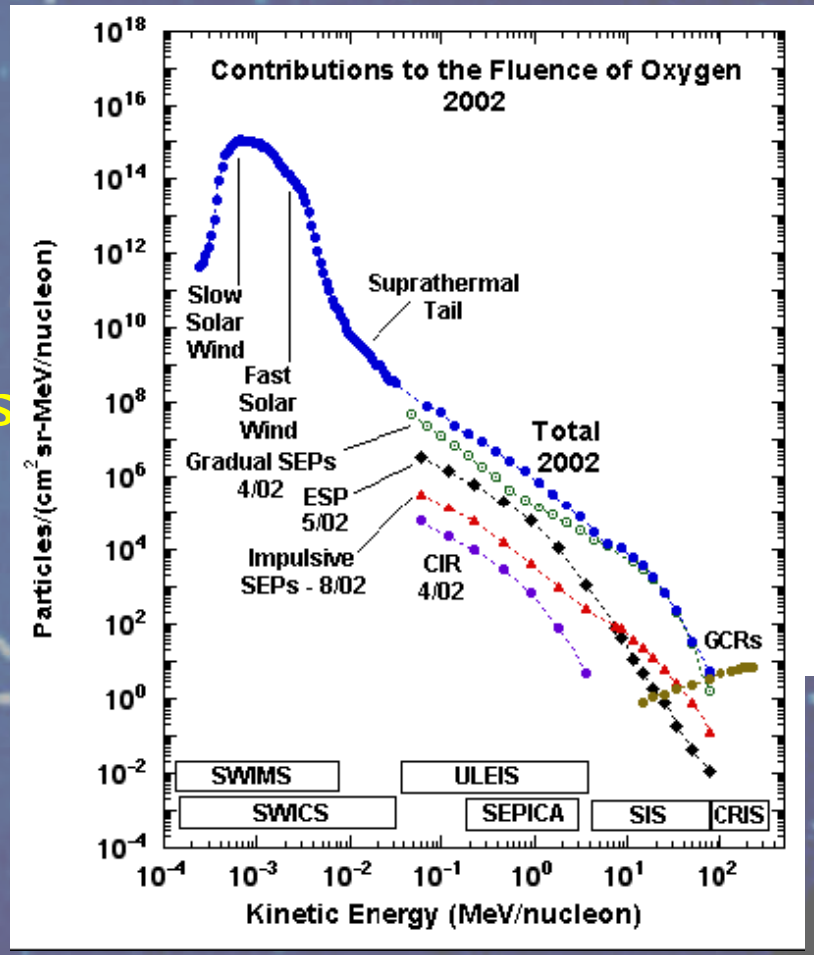


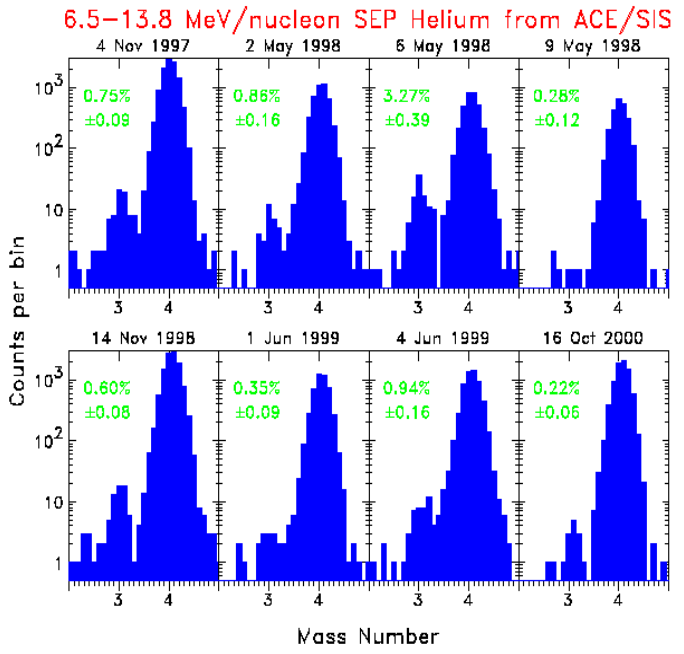


Conditions: Seed Populations

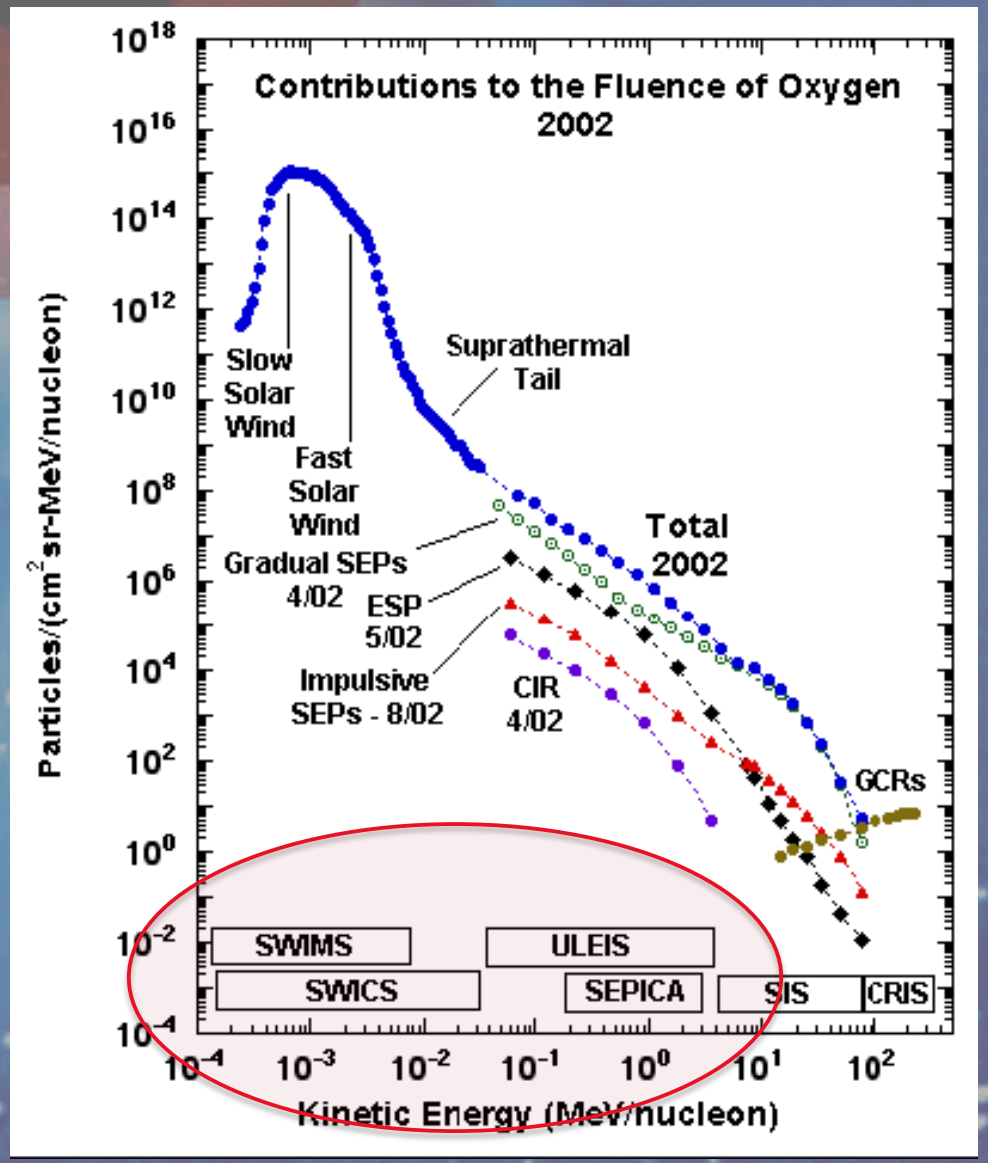
Know

- Suprathermals play a role
- Some of their sources
  - Lower energy portion of events
  - Flare material





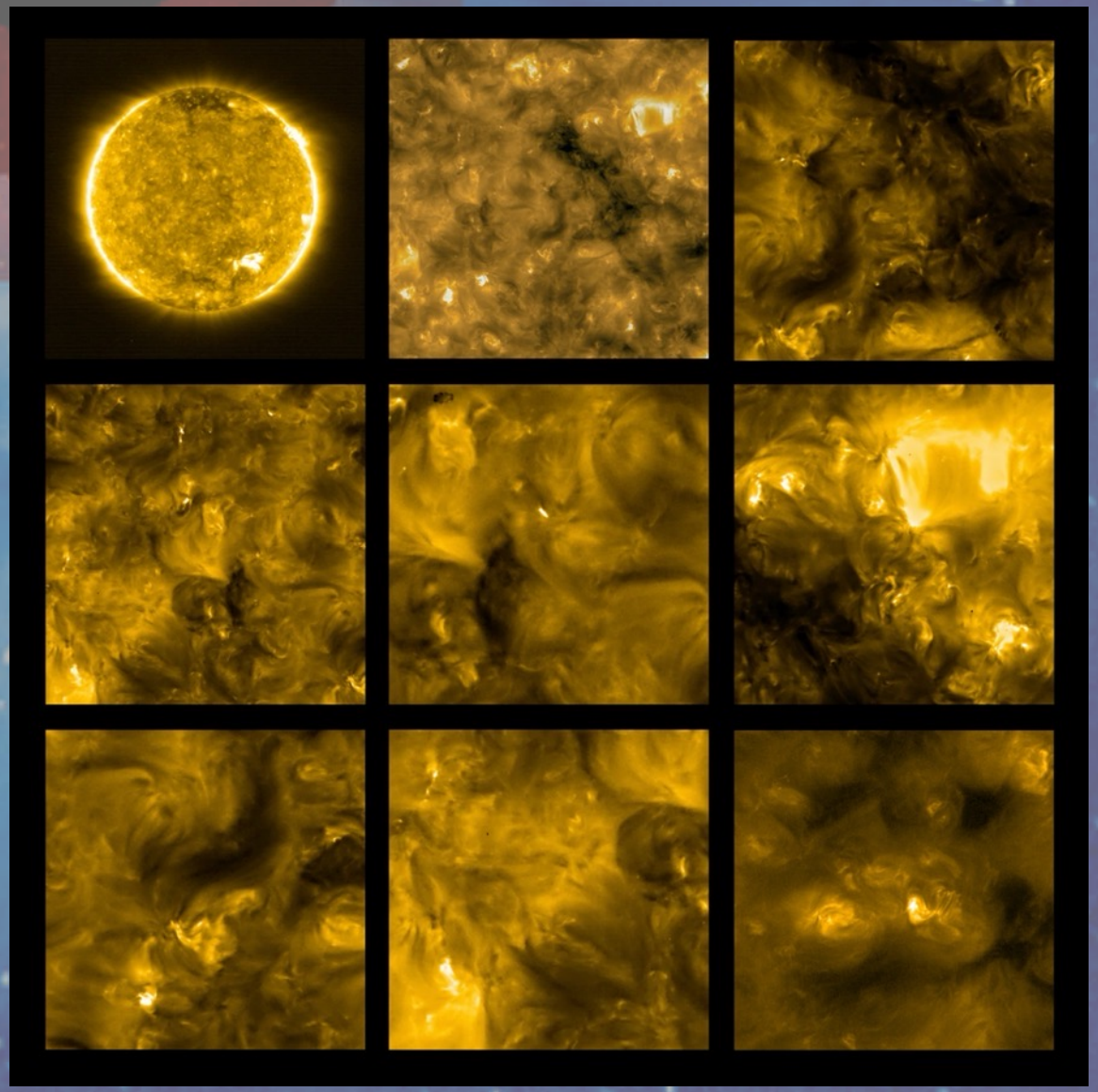
Conditions: Seed Populations



Don't Know

- Variability
  - Composition
  - Spectrum

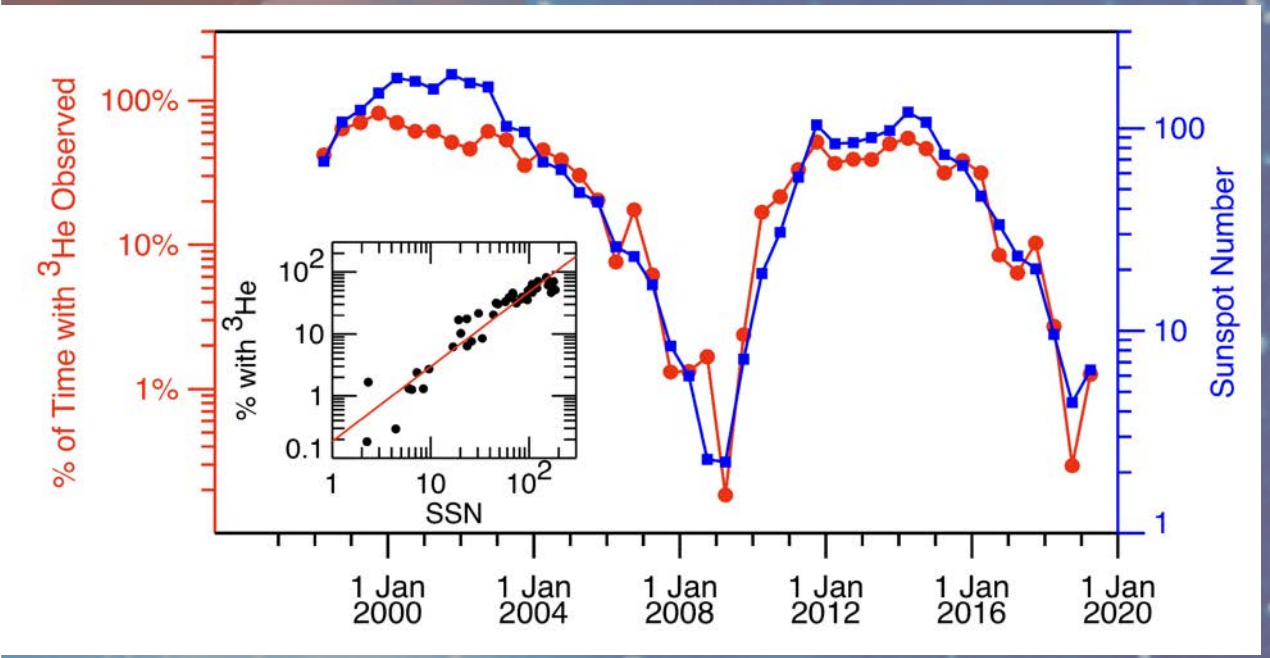
Conditions: Seed Populations



Don’t Know

- Variability
  - Composition
  - Spectrum
- Source
  - Constant/episodic?

Conditions: Seed Populations



Don't Know

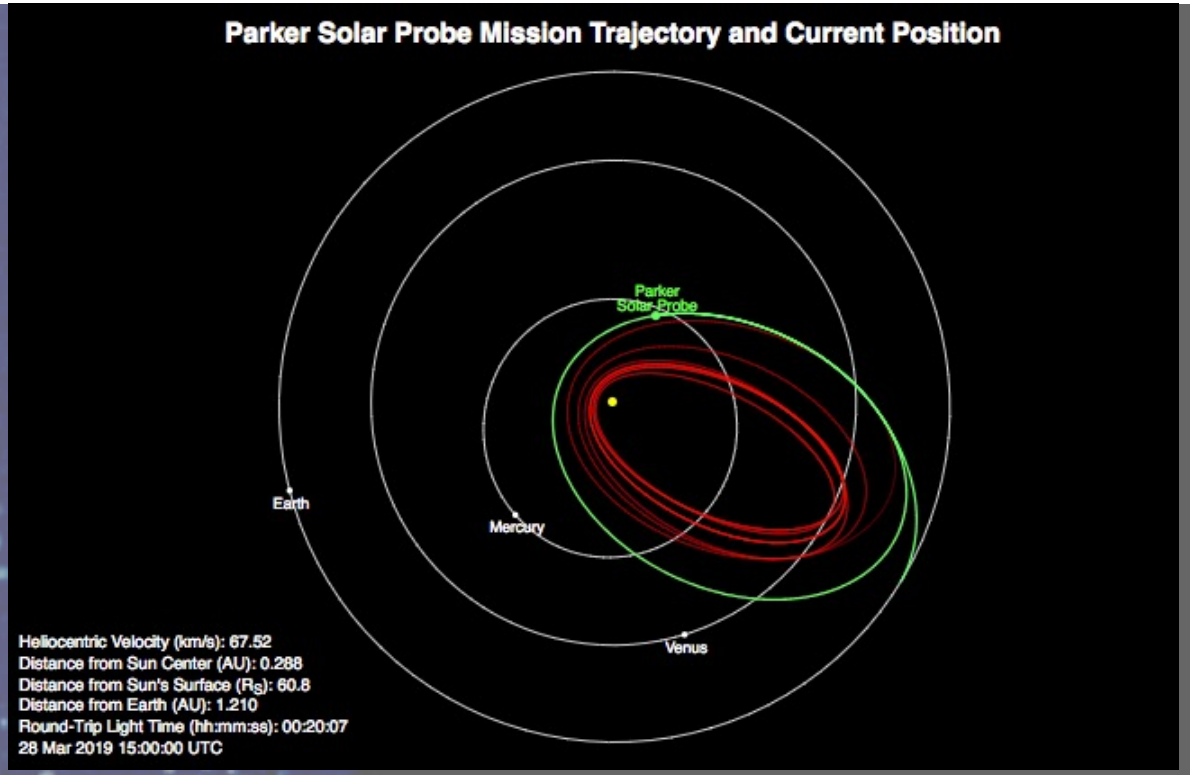
- Variability
  - Composition
  - Spectrum
- Source
  - Constant/episodic?
- Distribution

The Newest Help

- Parker Solar Probe

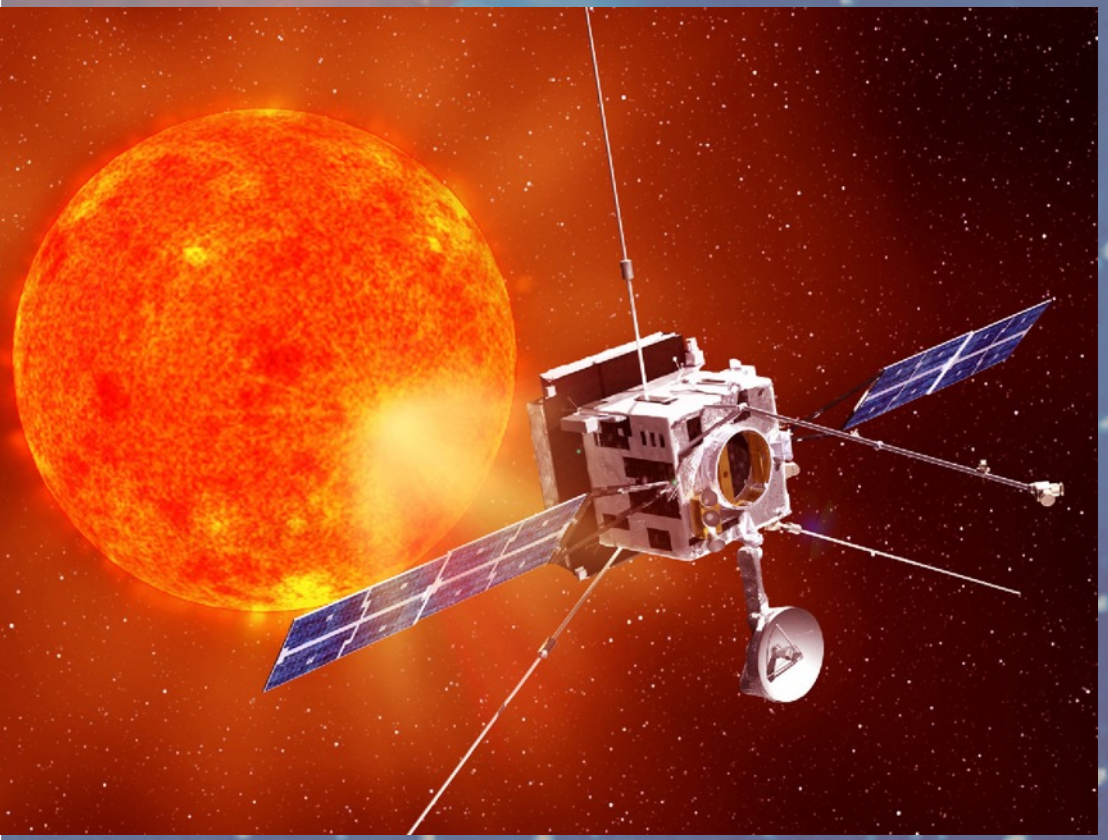
Parker Solar Probe Breaks Record, Becomes Closest Spacecraft to Sun

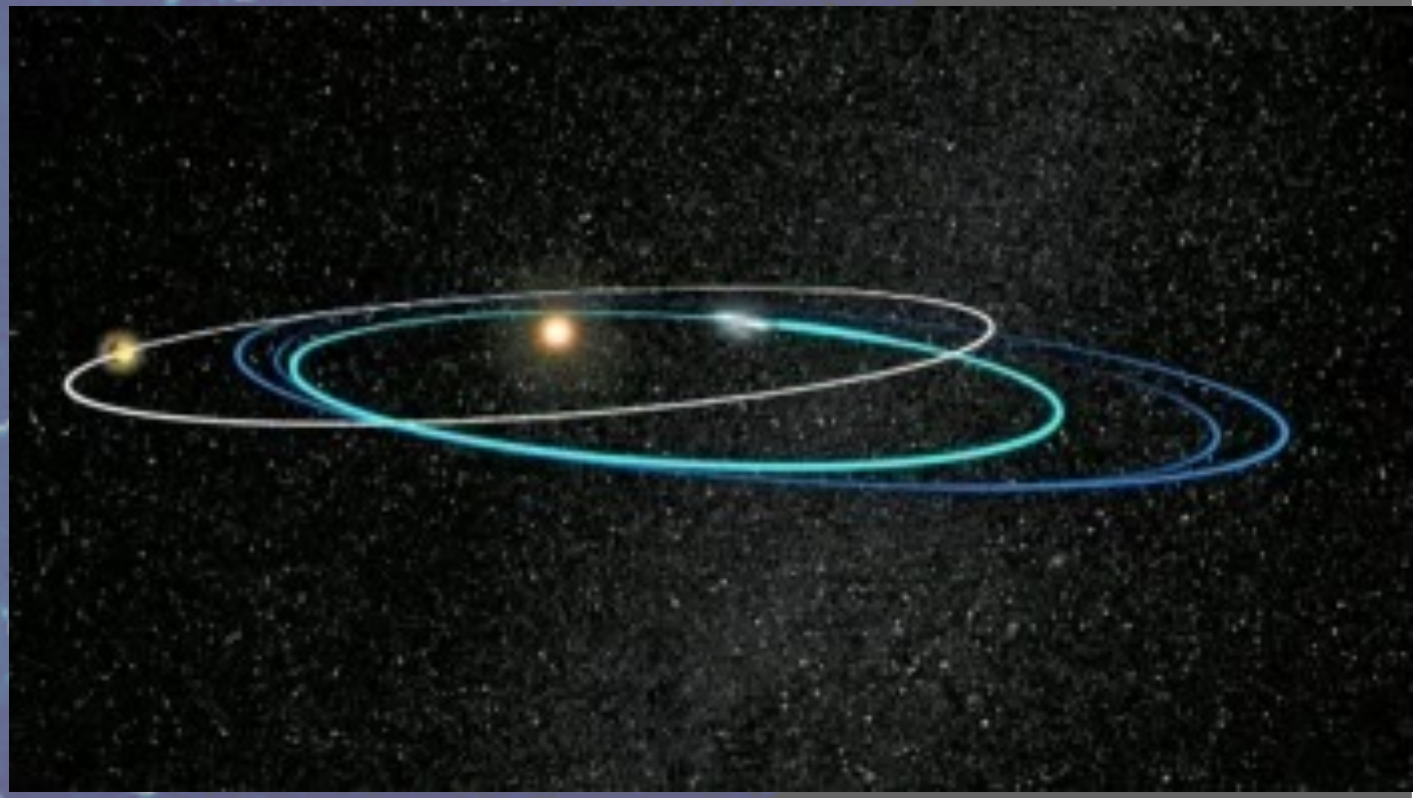
Posted on 10/29/2018 13:06:31

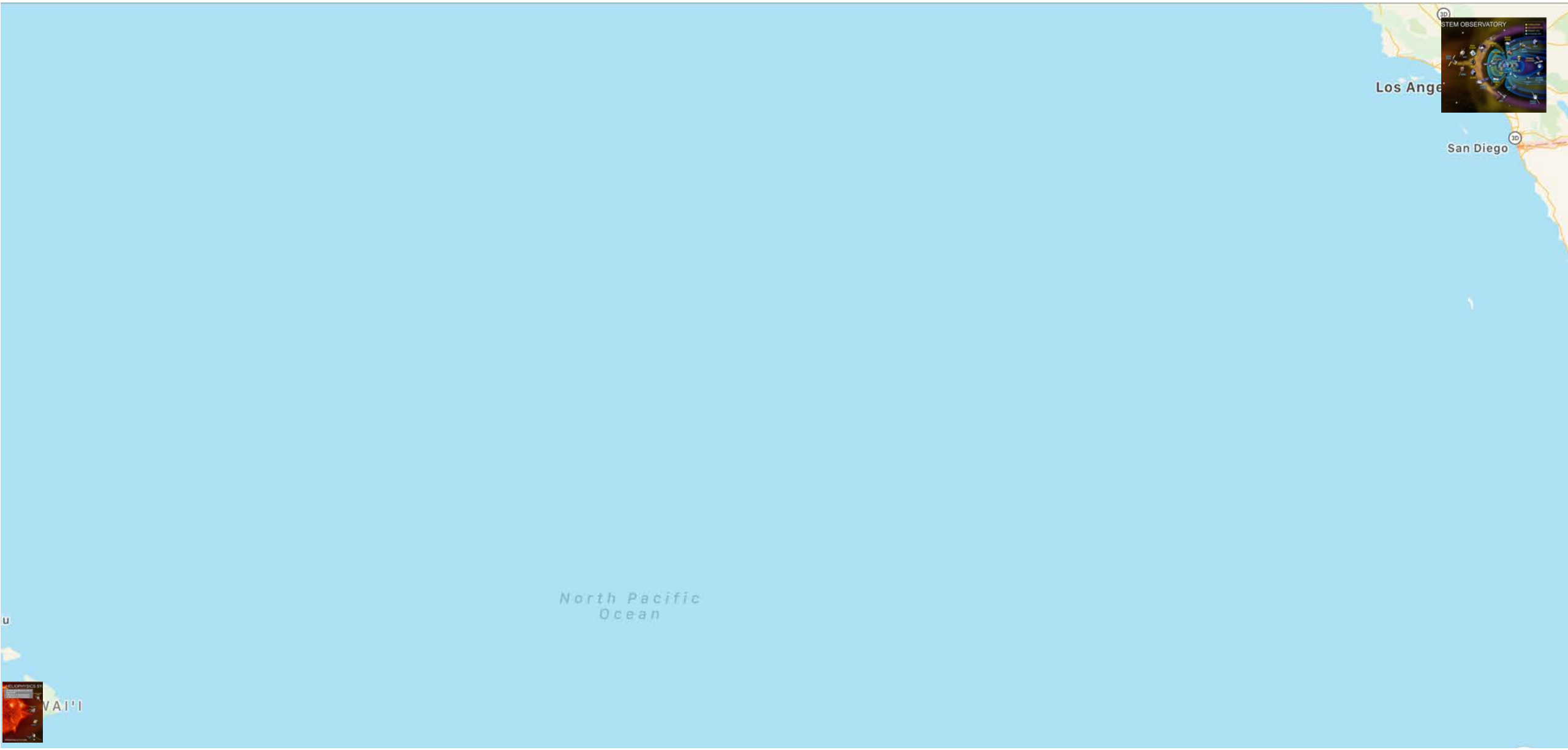


The Newest Help

- Parker Solar Probe
- Solar Orbiter






STEM OBSERVATORY
Los Ange
San Diego
North Pacific
Ocean
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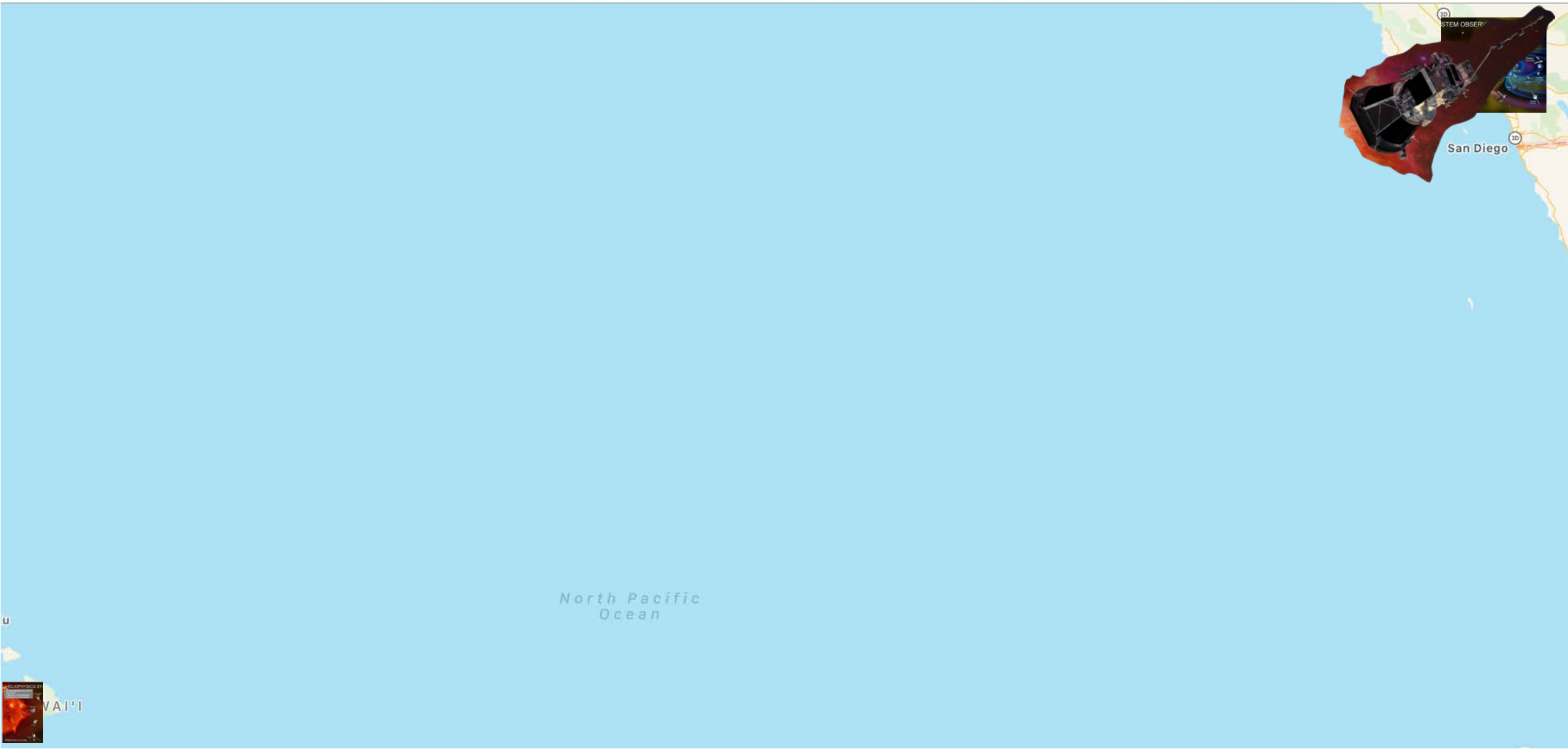
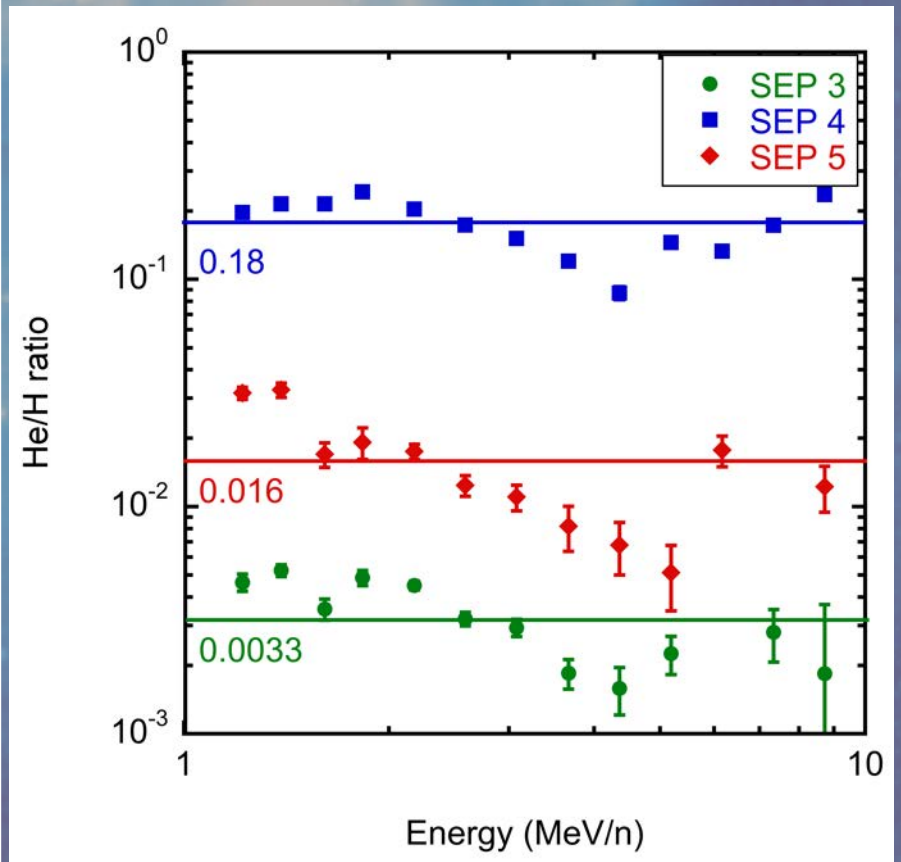
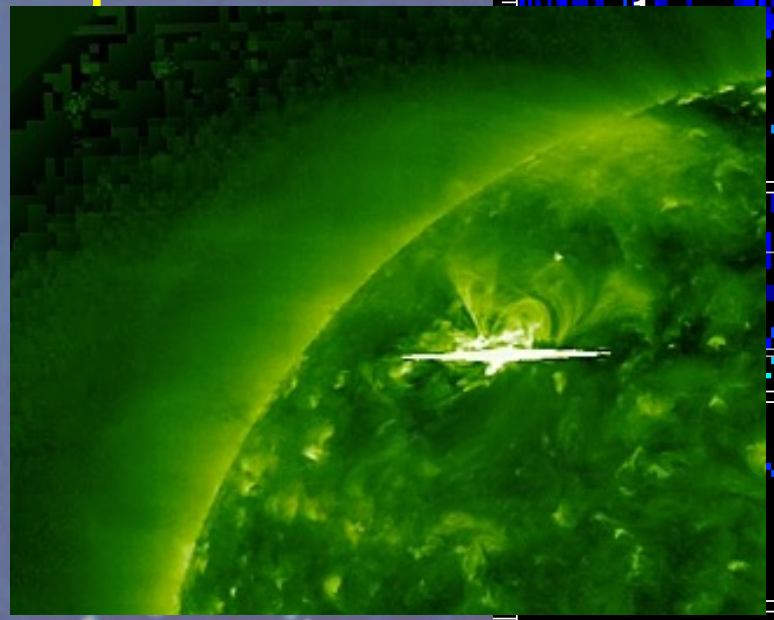
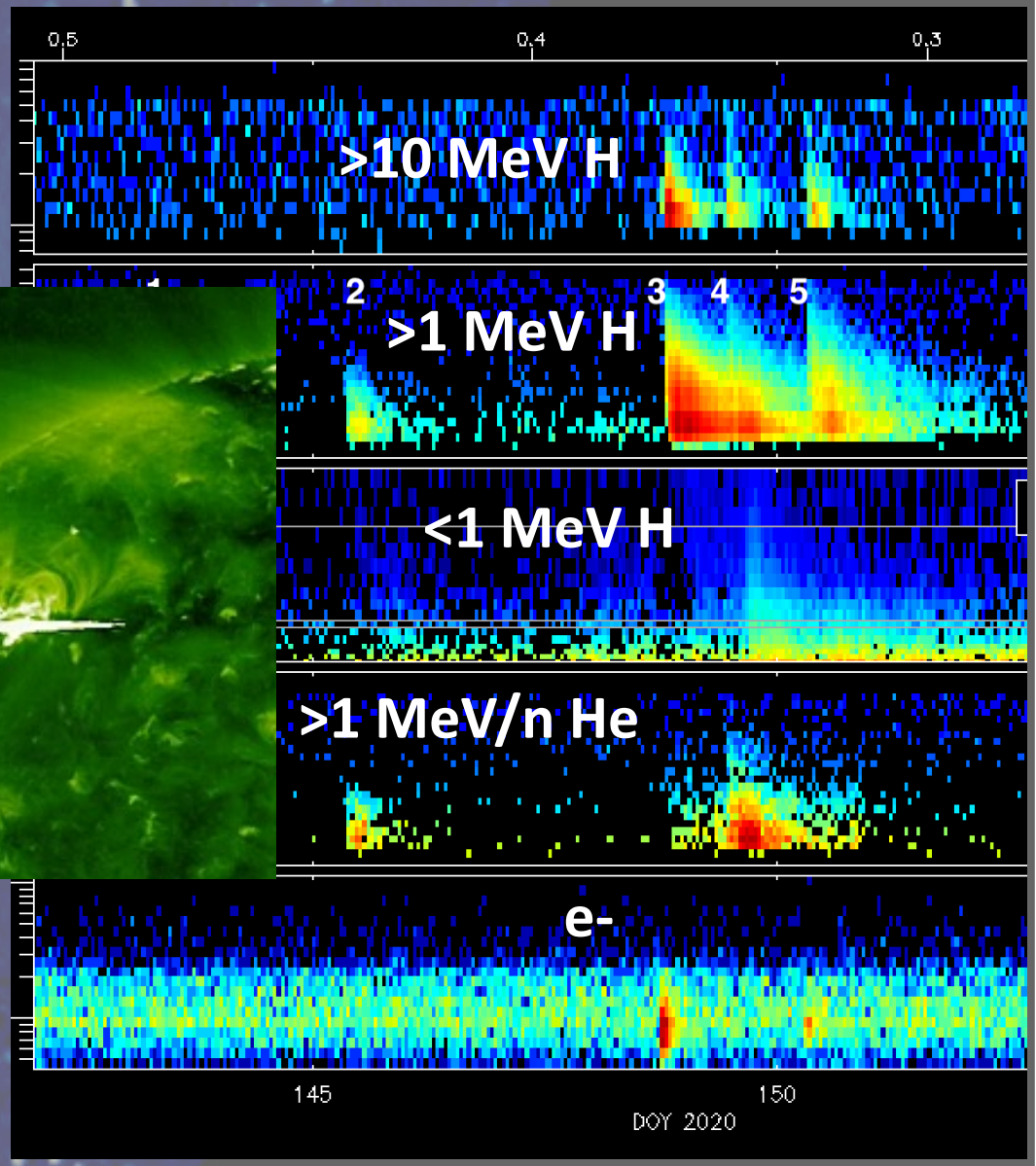

San Diego
North Pacific
Ocean

Still Stuff We Don't Understand

- PSP at 0.35 AU sees series of events
  - Same source, different composition

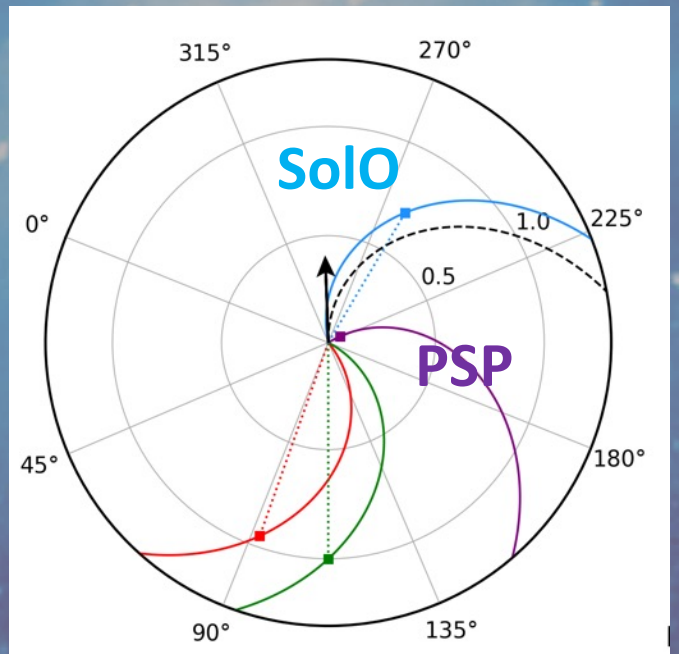


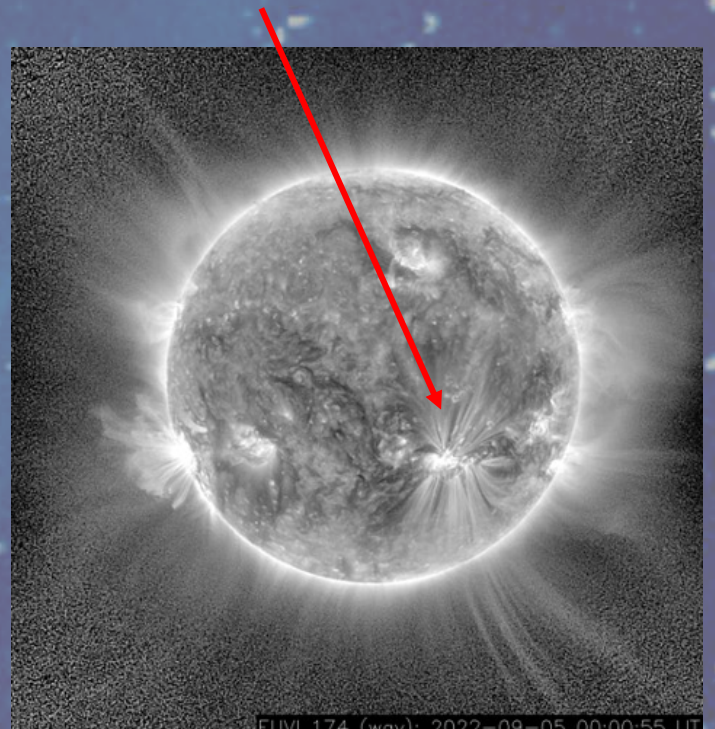


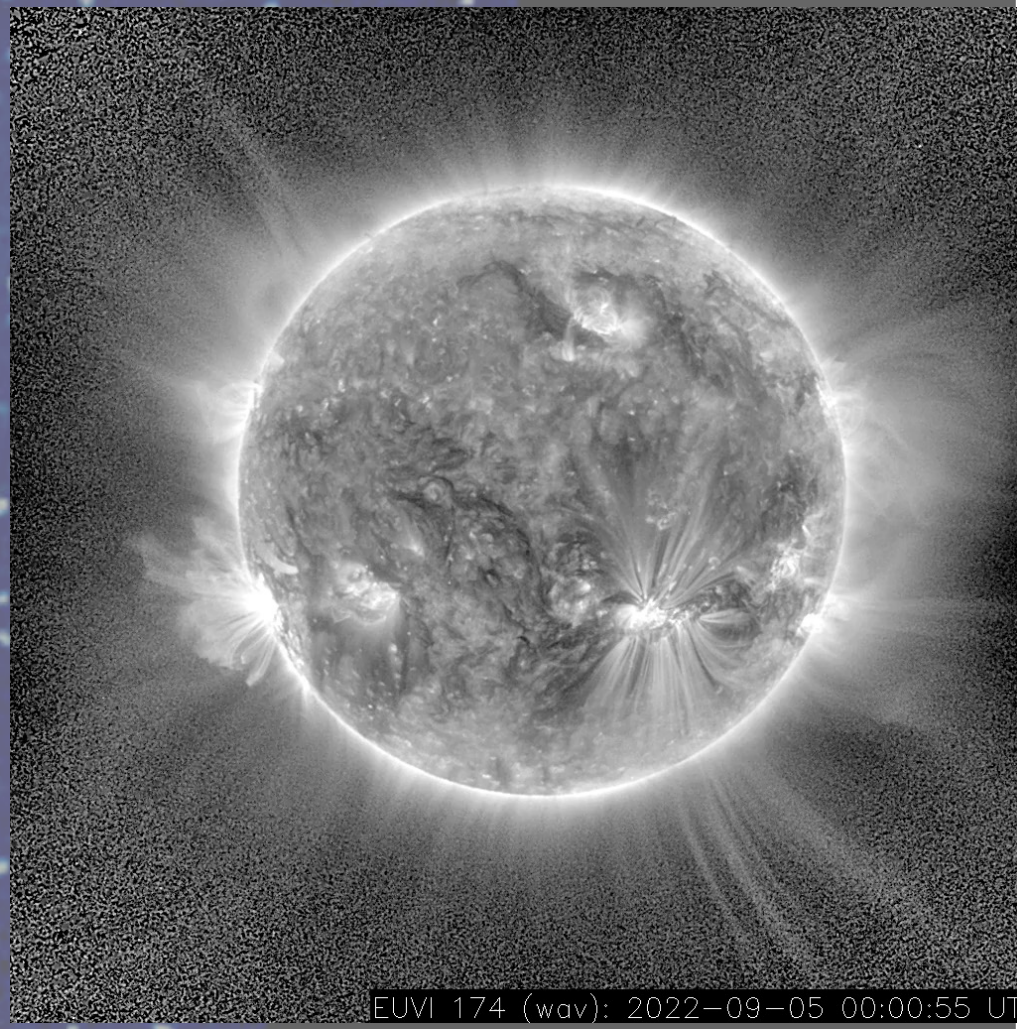


Stuff We're Just Starting to Look At

- AR13088 was at W180S10
- PSP W118 & 15 R_S
- SolO W149 & 0.7 AU
  - SolO/EUI had nice view of AR

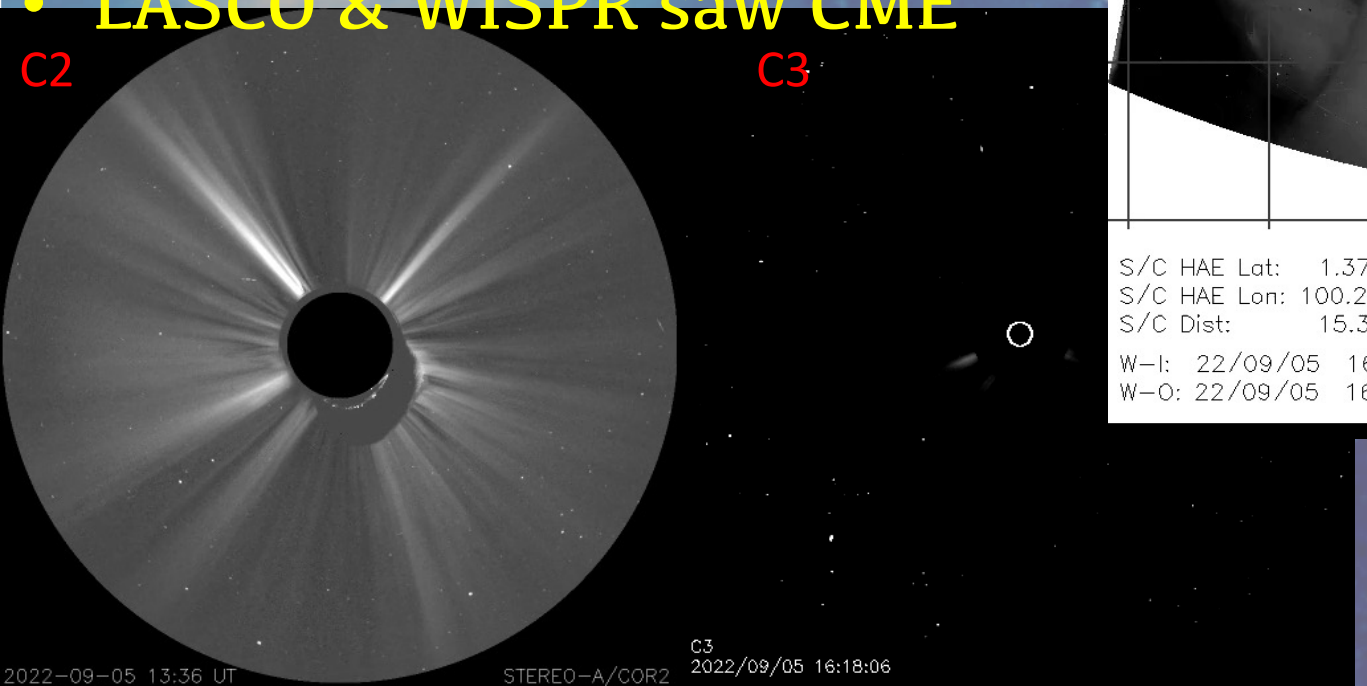


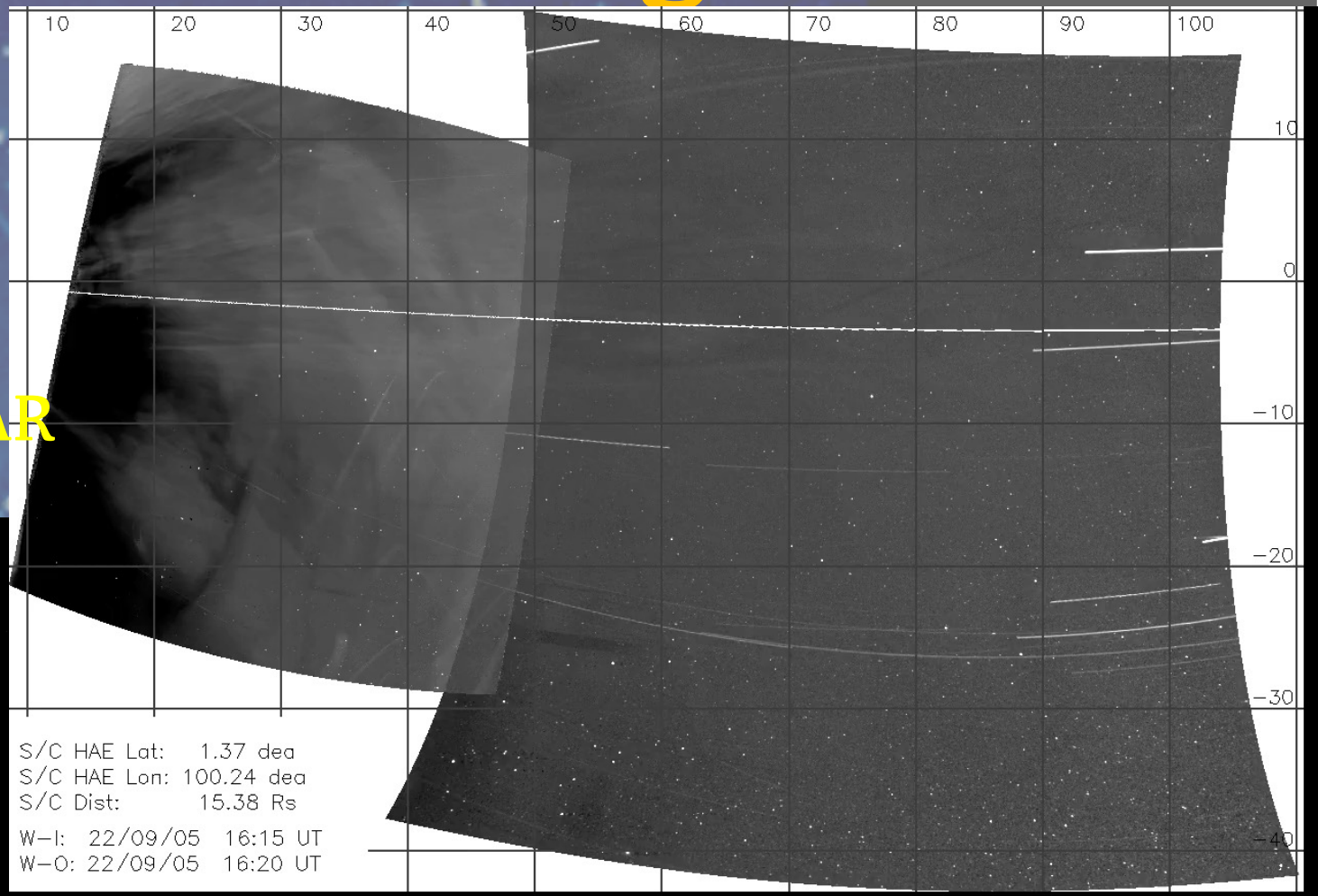




Stuff We're Just Starting to Look At

- AR13088 was at W180S10
- PSP W118 & 15 R_S
- SolO W149 & 0.7 AU
  - SolO/EUI had nice view of AR
- LASCO & WISPR saw CME





WISPR

2400-2900 km/s at 15 R_S

Stuff We're Just Starting to Look At

- AR13088 was at W180S10
- PSP W118 & 15 R_S
- SolO W149 & 0.7 AU
  - SolO/EUI had nice view of AR
- LASCO & WISPR saw CME
- SolO sees Fe-rich event
- PSP sees Fe-poor event