SOLAR WIND DATA

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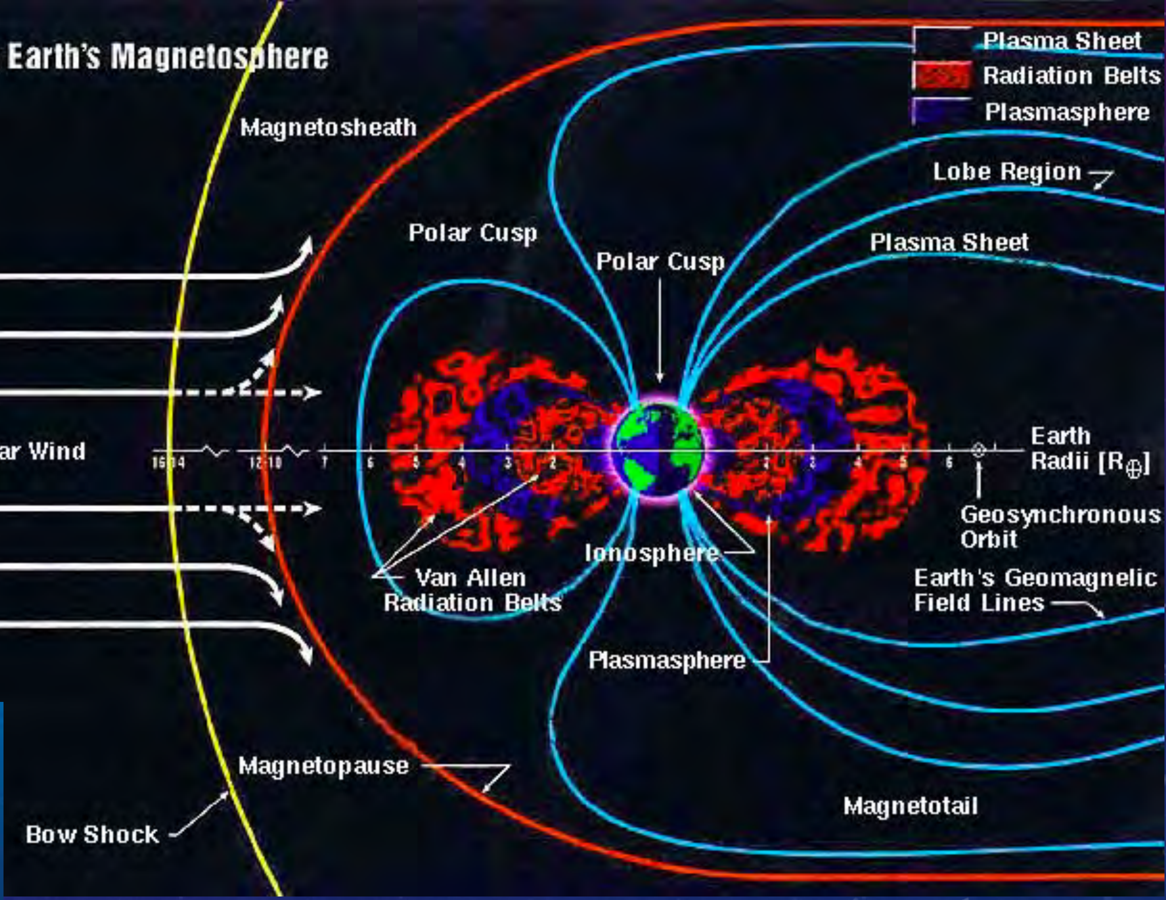
MATERIAL FROM THE SUN

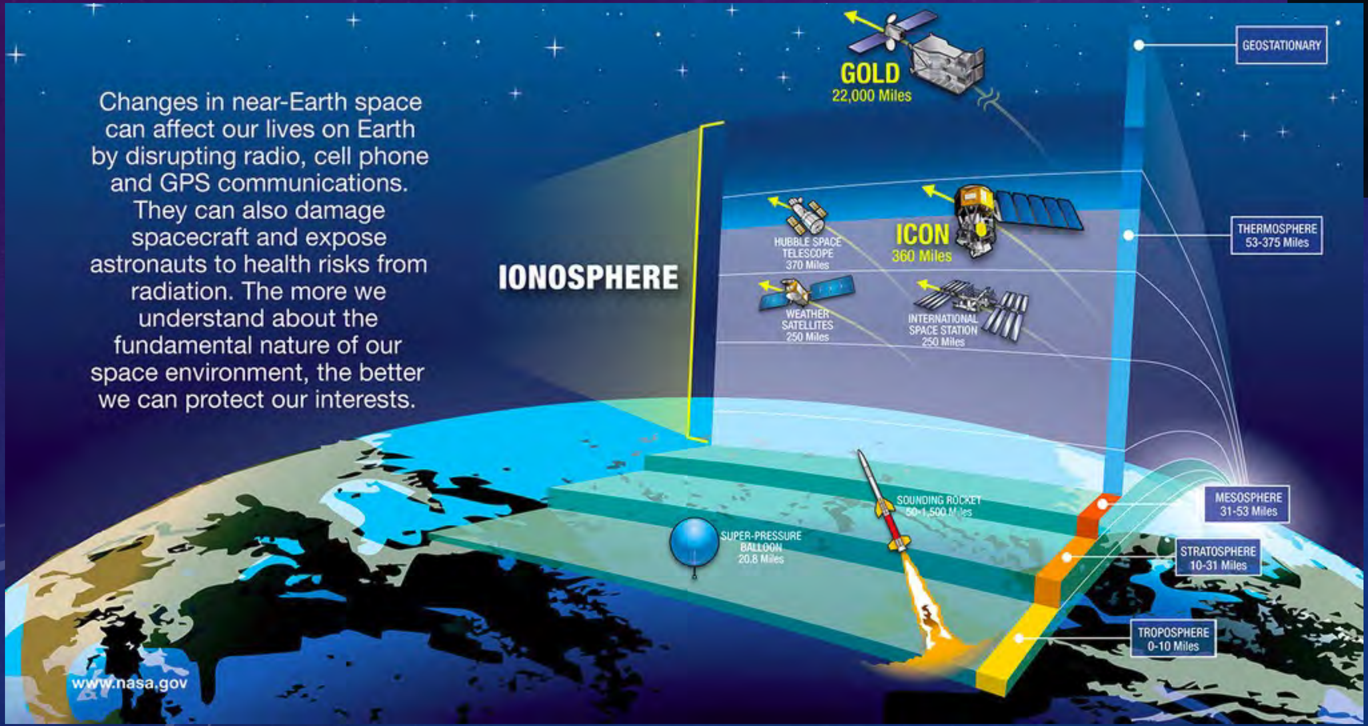
PLASMAS

- Plasma is any grouping of particles which contains some particles that are electrically charged
  - The grouping of particles contains equal numbers of positive and negative charge particles and is quasi-neutral (electrically neutral).
  - The charged particles are mostly governed by electric and magnetic fields (as well as gravity, to a lesser degree)
  - Plasmas mostly exist as collisionless plasmas, where the density of particles is so low that they don’t interact and hence recombine (there are counter examples)
- The solar wind is made up of a collisionless plasma with the solar magnetic field embedded within it.

PLASMAS (CONT.)

- Most of the energy for ionizing particles comes from the Sun
- The largest source of plasma in the heliosphere is the Sun.
- Must understand electric and magnetic forces to study the space environment




Changes in near-Earth space can affect our lives on Earth by disrupting radio, cell phone and GPS communications. They can also damage spacecraft and expose astronauts to health risks from radiation. The more we understand about the fundamental nature of our space environment, the better we can protect our interests.

MOTION OF CHARGED PARTICLES

- Charged particle motion is moderated by electric and magnetic fields as we saw in the Lorentz force

$$\bar{F}_L = q(\bar{E} + \bar{v}x\bar{B}) + \bar{F} = m\frac{d\bar{v}}{dt}$$

- Where we have an additional term, **F**, which accounts for other forces that arise in the space environment
- Particle motion in the presence of a magnetic field is not uniform, it varies parallel and perpendicular to the field.
- Forces can include gravity, pressure gradients (thermal and magnetic), collisional drag (currents), magnetic fields, electric fields, etc.

CHECK YOUR UNDERSTANDING

- Which one of the following is not a force that affects solar plasma
  - a) Magnetic Forces
  - b) Electric Forces
  - c) Gravitational Forces
  - d) Tension Forces
  - e) Pressure Forces

- Which one has the lower magnitude, do you think?

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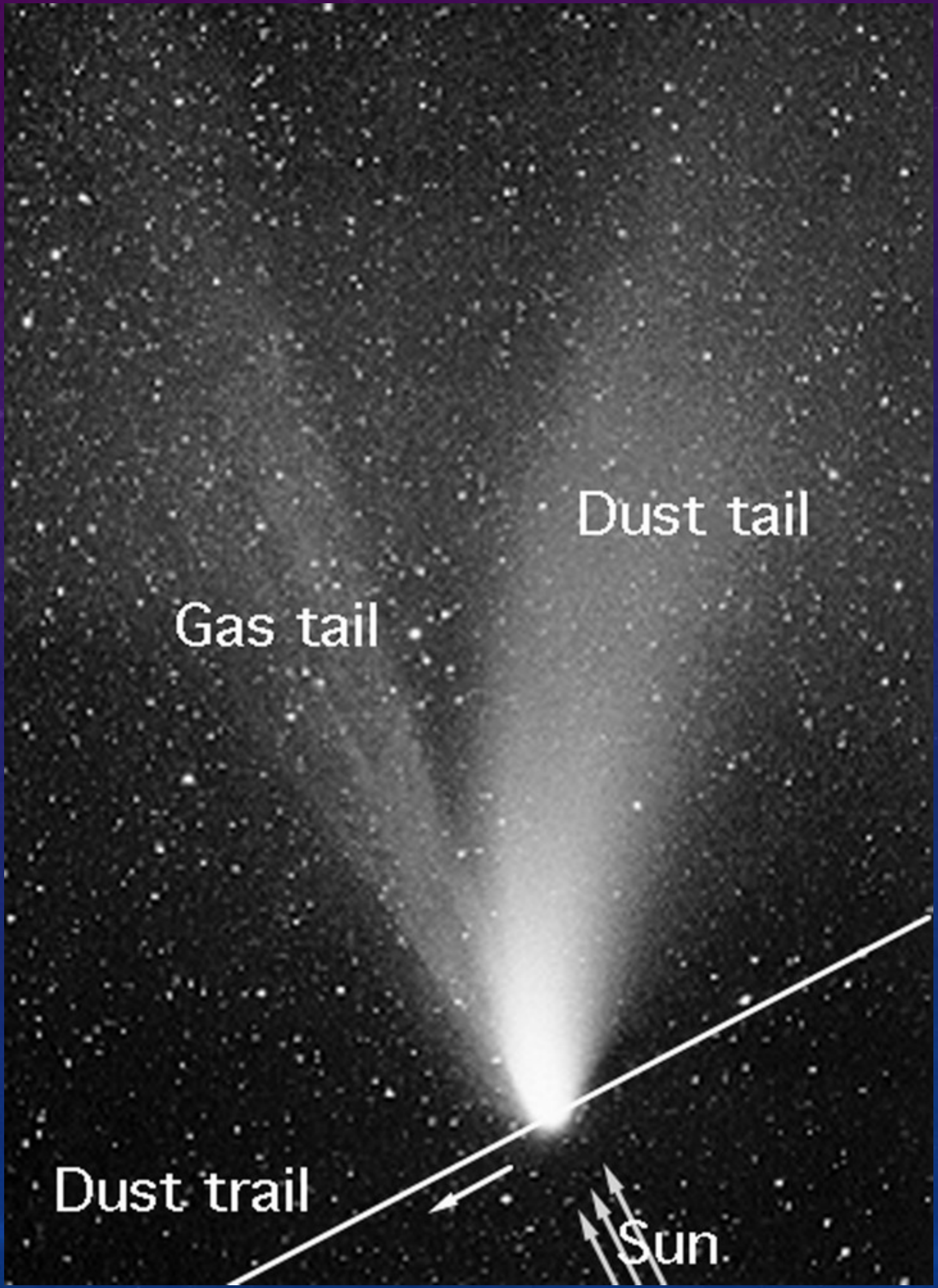
HOW DID WE FIND OUT THE SOLAR WIND EXISTED

THE SOLAR WIND

- First postulated by Richard Carrington and George Fitzgerald after observations of solar flare and the subsequent geomagnetic storm in 1859
- Ludwig Biermann explained the anti-sunward directed comet tail as being driven by the solar wind in 1951.
- Eugene Parker later coined the term “solar wind” and derived that the solar wind must be supersonic to overcome gravity.



CHECK YOUR UNDERSTANDING

- Which of the comets tail was a clue to the existence of the solar wind?
  - a) Dust Tail
  - b) Gas Tail

CHECK YOUR UNDERSTANDING

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Gene parker in 1958 postulated the the hot solar corona could not be contained due to the low pressure in the heliosphere or interstellar space. Therefore, the corona must expand out continuous and fill the heliosphere with a wind. Comet observations also showed evidence of a solar wind.

Apollo 11 Solar Wind Composition (SWC) Experiment being deployed by Buzz Aldrin
Courtesy NASA

THE FIRST SOLAR WIND MEASUREMENTS

- On July 21, 1969, on Mare Tranquillitatis, Buzz Aldrin deployed the Solar Wind Composition (SWC) experiment on the lunar surface. After exposing it for just under an hour and a half, they rolled it up, and stored it to return it to Earth.
- Foils were made of Aluminum (15 µm) in 1969 and later added Platinum to subsequent missions
- The SWC paved the way for future first measurements of charge states and elemental abundances of solar wind ions in 1982 (Gloeckler and Geiss 1989)
- Launch of Ulysses/SWICS in 1990 provided the first opportunity to measure both the solar wind ion and elemental abundances (Gloeckler et al. 1992). ACE/SWICS launched in 1997 (Gloeckler et al. 1998). STEREO/PLASTIC launched in 2006 (Galvin et a. 2008)
- Genesis provided another sample return opportunity in 2004, the first since the Apollo missions (Burnett et al. 2003)

APOLLO SWC RESULTS

For more info on Apollo SWC, see Geiss et al. 2004

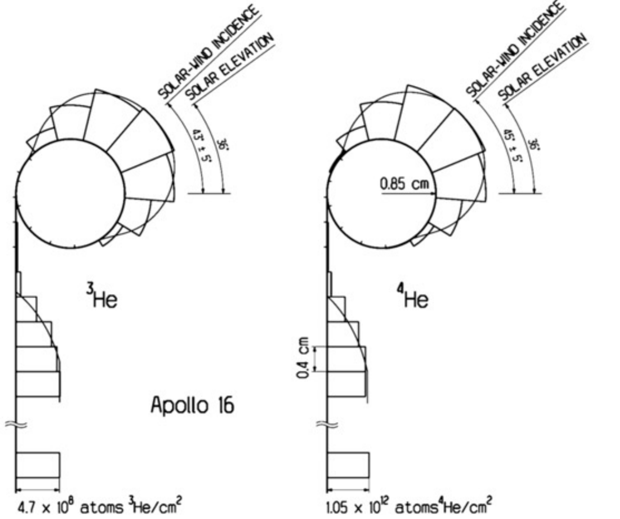


Figure 9. Concentrations of ^{3}He and ^{4}He in the uppermost part of the exposed Apollo 16 SWC foil. The two helium isotopes came virtually from the same direction. The positions of foil pieces around the reel were determined by a red marker on the reel (see Figure 4). The particle distributions around the reel and on the uppermost straight portion of the foil were found to be compatible with beams of ^{3}He and ^{4}He with high Mach number. The curves correspond to high Mach number flows integrated over the exposure time.

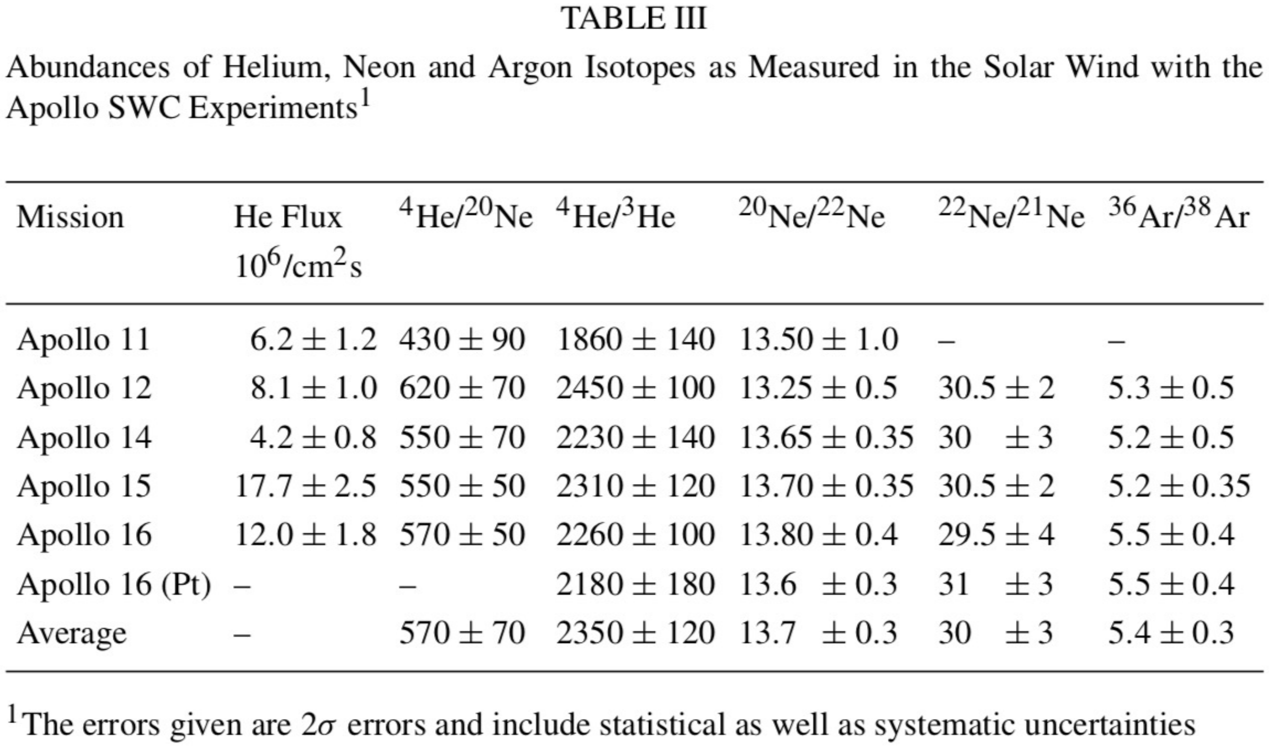


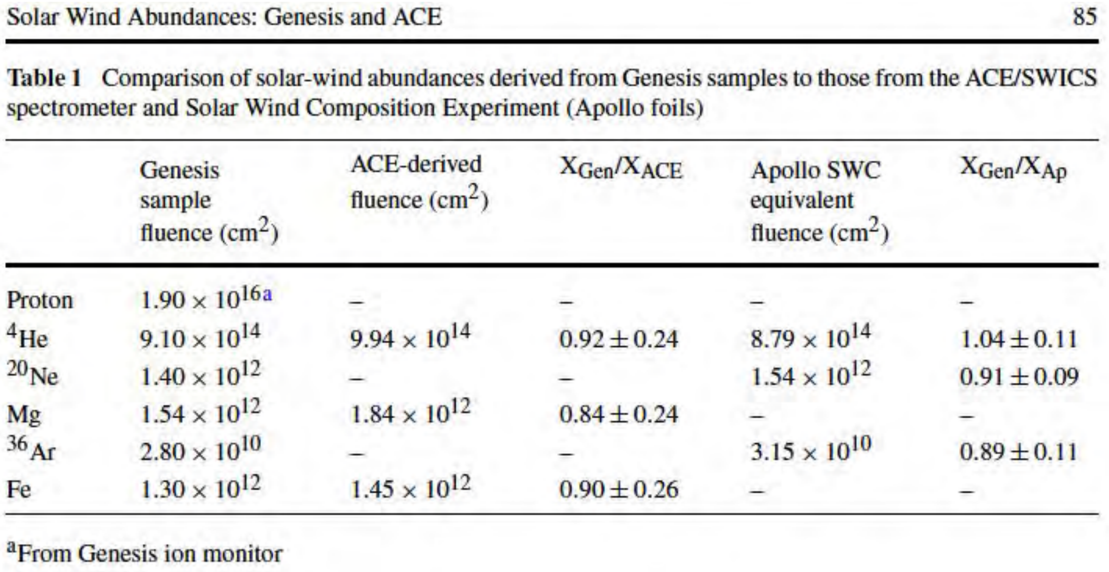
TABLE III

Abundances of Helium, Neon and Argon Isotopes as Measured in the Solar Wind with the Apollo SWC Experiments[1]

Mission	He Flux 10^6/cm^{2}s	^{4}He/^{20}Ne	^{4}He/^{3}He	^{20}Ne/^{22}Ne	^{22}Ne/^{21}Ne	^{36}Ar/^{38}Ar
Apollo 11	6.2 ± 1.2	430 ± 90	1860 ± 140	13.50 ± 1.0	–	–
Apollo 12	8.1 ± 1.0	620 ± 70	2450 ± 100	13.25 ± 0.5	30.5 ± 2	5.3 ± 0.5
Apollo 14	4.2 ± 0.8	550 ± 70	2230 ± 140	13.65 ± 0.35	30 ± 3	5.2 ± 0.5
Apollo 15	17.7 ± 2.5	550 ± 50	2310 ± 120	13.70 ± 0.35	30.5 ± 2	5.2 ± 0.35
Apollo 16	12.0 ± 1.8	570 ± 50	2260 ± 100	13.80 ± 0.4	29.5 ± 4	5.5 ± 0.4
Apollo 16 (Pt)	–	–	2180 ± 180	13.6 ± 0.3	31 ± 3	5.5 ± 0.4
Average	–	570 ± 70	2350 ± 120	13.7 ± 0.3	30 ± 3	5.4 ± 0.3

[1] The errors given are 2σ errors and include statistical as well as systematic uncertainties

Figure 6. Astronaut Don Lind testing the deployment of the SWC instrument at 1/6 g in a B-707 airplane of NASA.



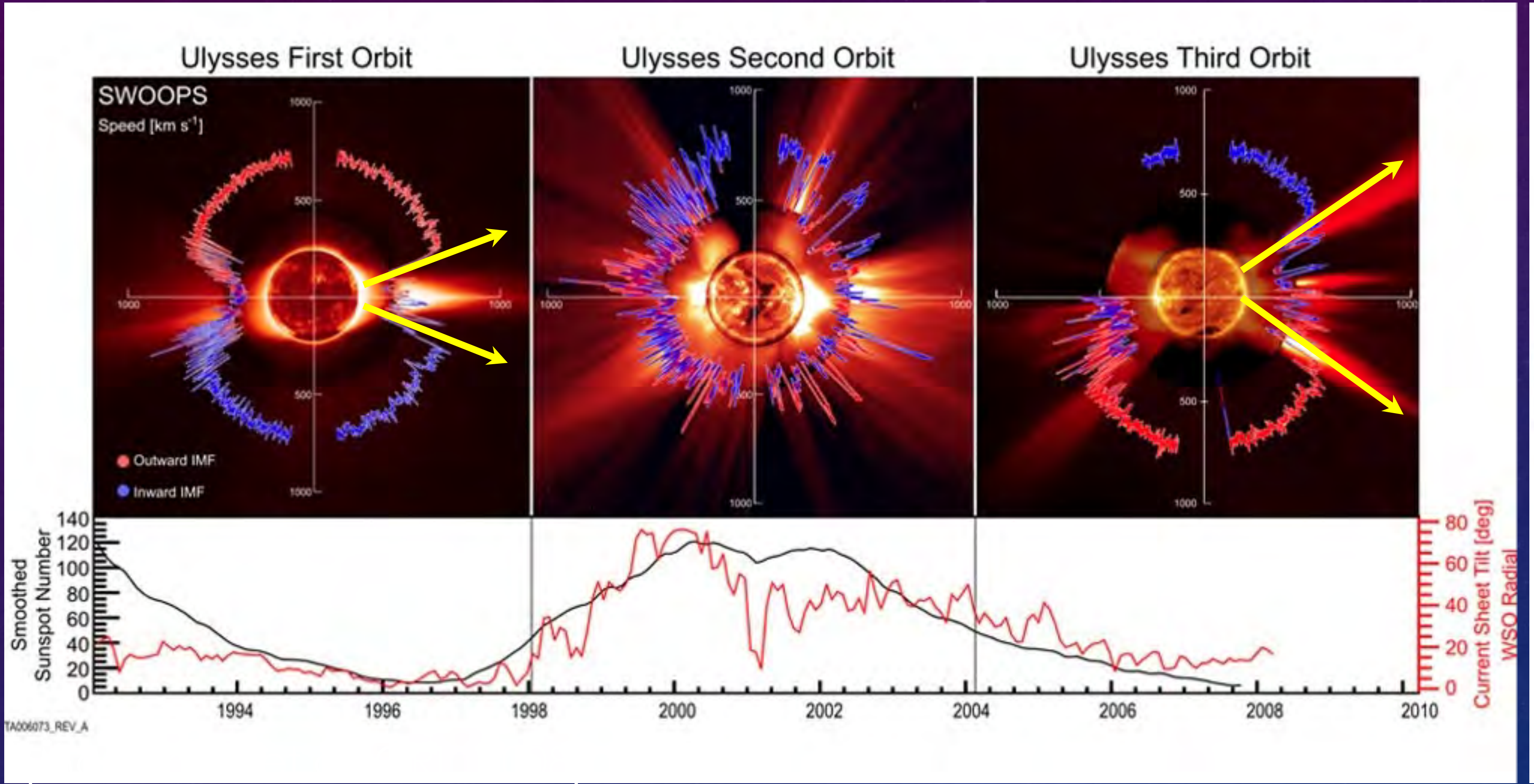
Solar Wind Abundances: Genesis and ACE 85

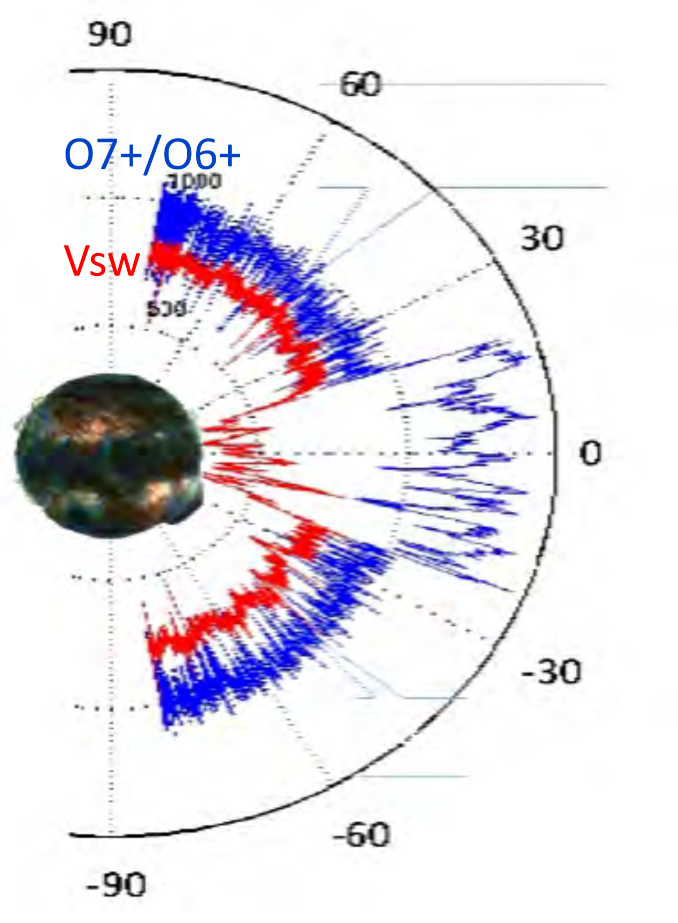
Table 1 Comparison of solar-wind abundances derived from Genesis samples to those from the ACE/SWICS spectrometer and Solar Wind Composition Experiment (Apollo foils)

	Genesis sample fluence (cm^2)	ACE-derived fluence (cm^2)	X_{Gen}/X_{ACE}	Apollo SWC equivalent fluence (cm^2)	X_{Gen}/X_{Ap}
Proton	1.90×10^{16}[a]	–	–	–	–
^{4}He	9.10×10^{14}	9.94×10^{14}	0.92 ± 0.24	8.79×10^{14}	1.04 ± 0.11
^{20}Ne	1.40×10^{12}	–	–	1.54×10^{12}	0.91 ± 0.09
Mg	1.54×10^{12}	1.84×10^{12}	0.84 ± 0.24	–	–
^{36}Ar	2.80×10^{10}	–	–	3.15×10^{10}	0.89 ± 0.11
Fe	1.30×10^{12}	1.45×10^{12}	0.90 ± 0.26	–	–

[a] From Genesis ion monitor

THE GLOBAL VIEW OF THE SOLAR WIND

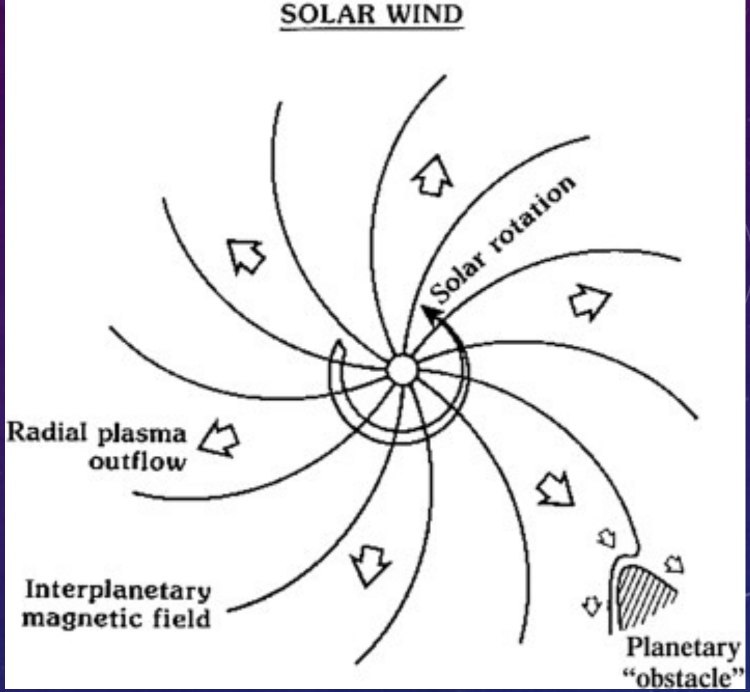


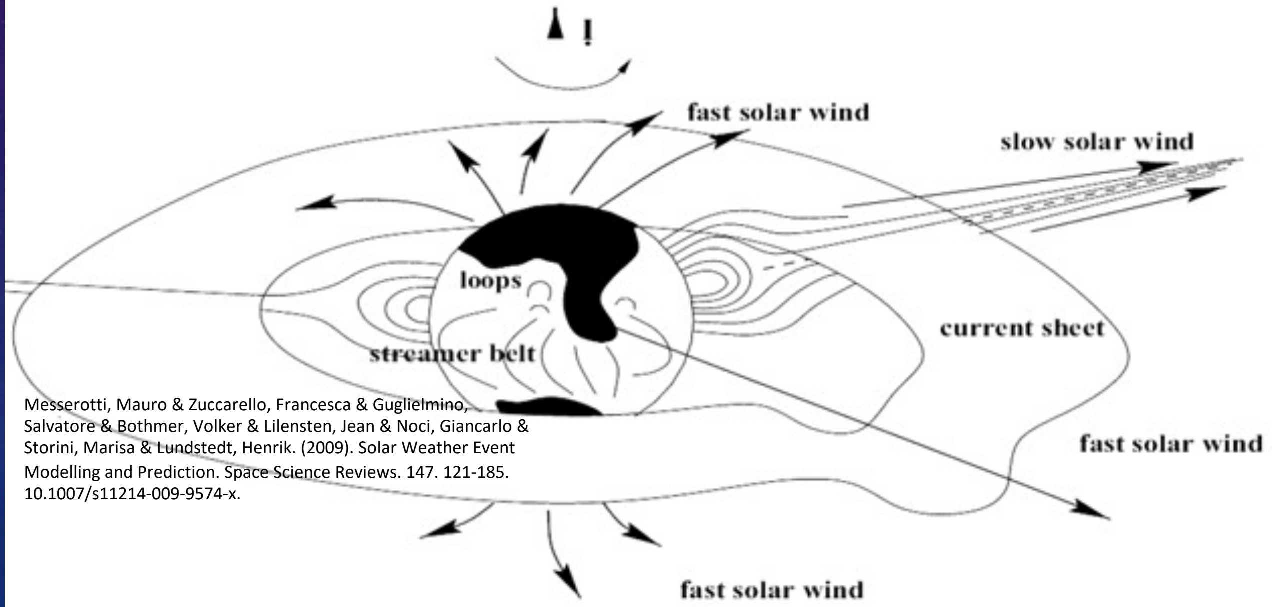


The solar dynamo drives the solar cycle and moderates the magnetic field in the corona. The solar wind is driven out of the corona and the distribution and characteristics of the wind vary with the solar cycle.

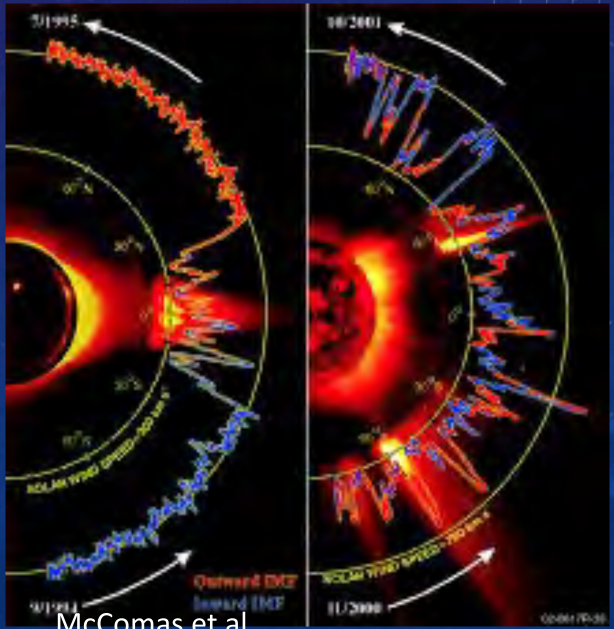
THE SOLAR WIND

- The solar wind is released out of the solar corona on the open fields in corona holes into the fast solar wind and from regions near the streamer belt as the slow solar wind.
- The Sun’s rotation, the radial flow of the solar wind, and the fact that the solar magnetic field is frozen into the solar wind, results in the field being dragged out into a spiral pattern as the Sun rotates. This is the Parker Spiral.





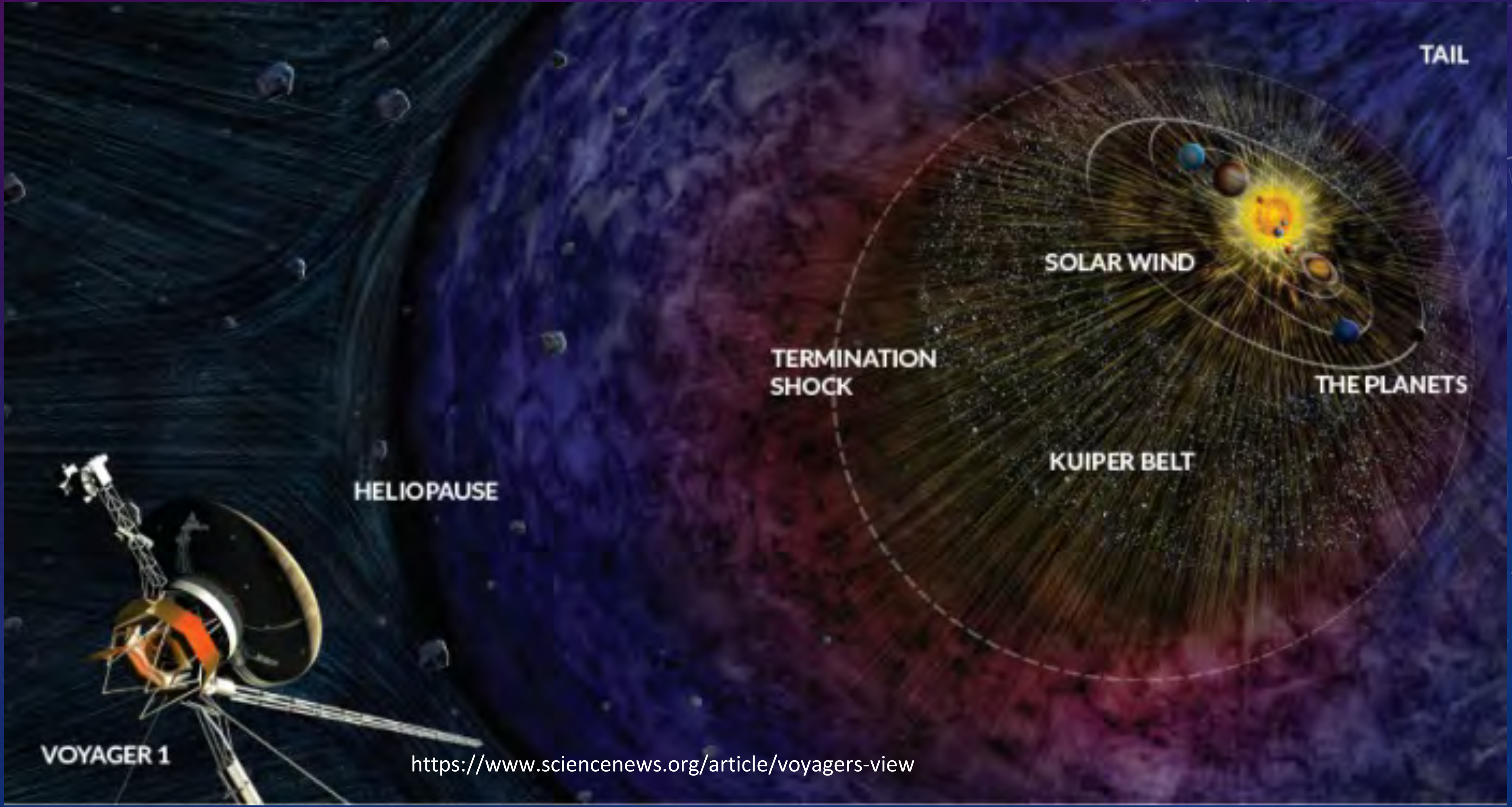
Messerotti, Mauro & Zuccarello, Francesca & Guglielmino, Salvatore & Bothmer, Volker & Lilensten, Jean & Noci, Giancarlo & Storini, Marisa & Lundstedt, Henrik. (2009). Solar Weather Event Modelling and Prediction. Space Science Reviews. 147. 121-185. 10.1007/s11214-009-9574-x.



McComas et al.

THE HELIOSPHERE

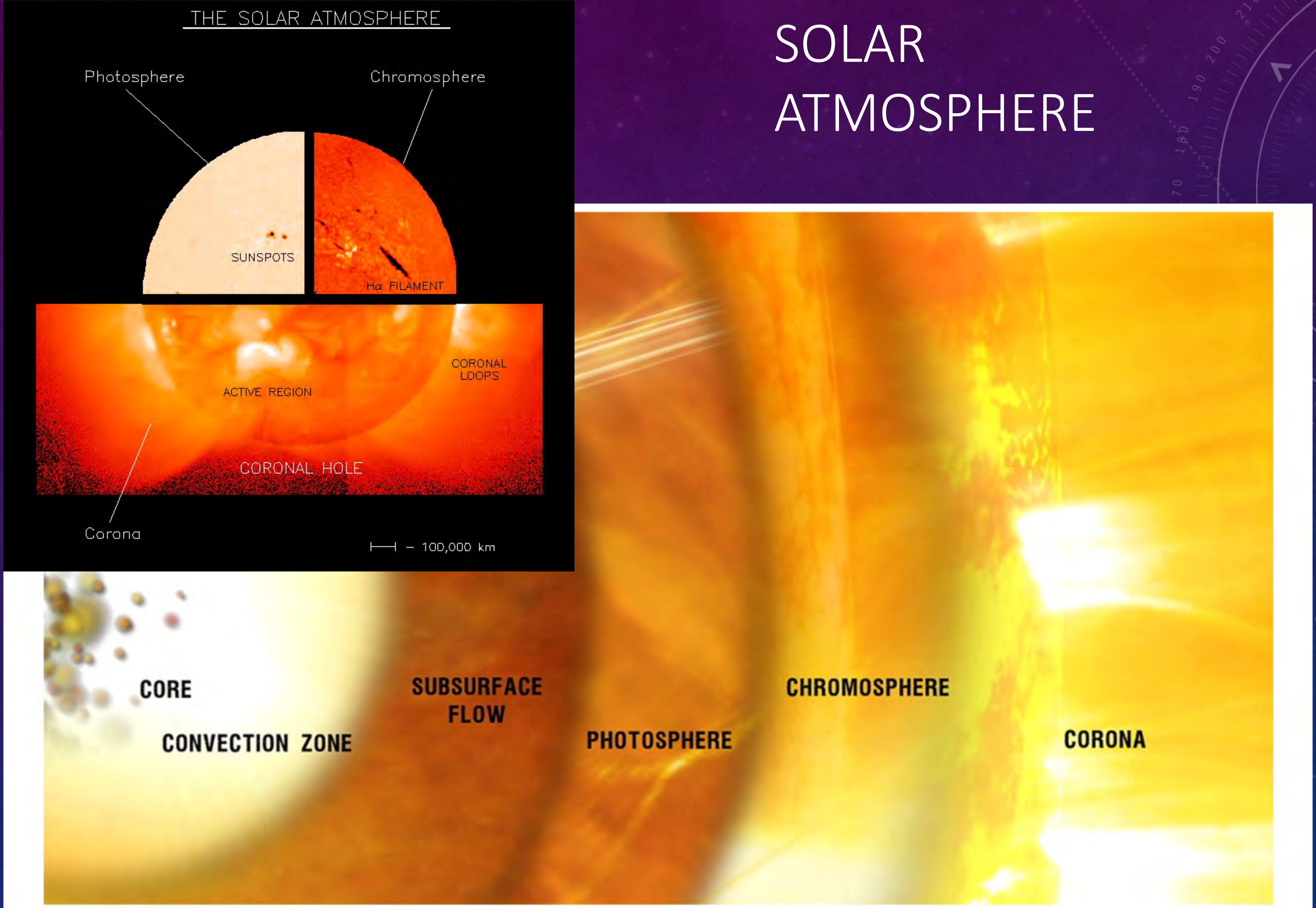
- The Sun’s hot, high-pressure atmosphere cannot be contained by the Sun’s magnetic field and gravity and flows out into the solar system as the solar wind. The region where the solar wind pressure dominates interstellar space is called the heliosphere.



https://www.sciencenews.org/article/voyagers-view

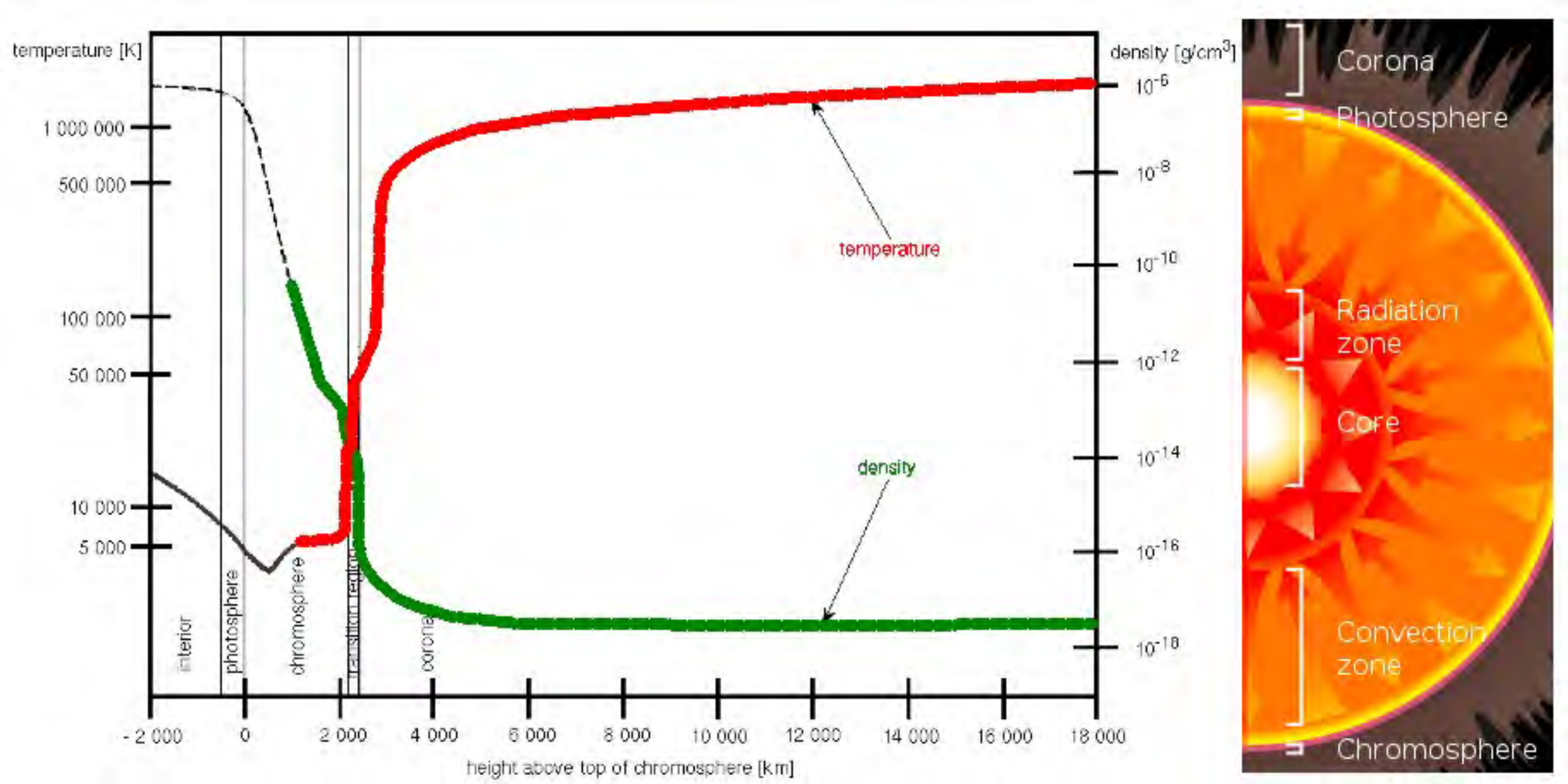
WHAT’S GOING ON WITH THE SUN

SOLAR ATMOSPHERE

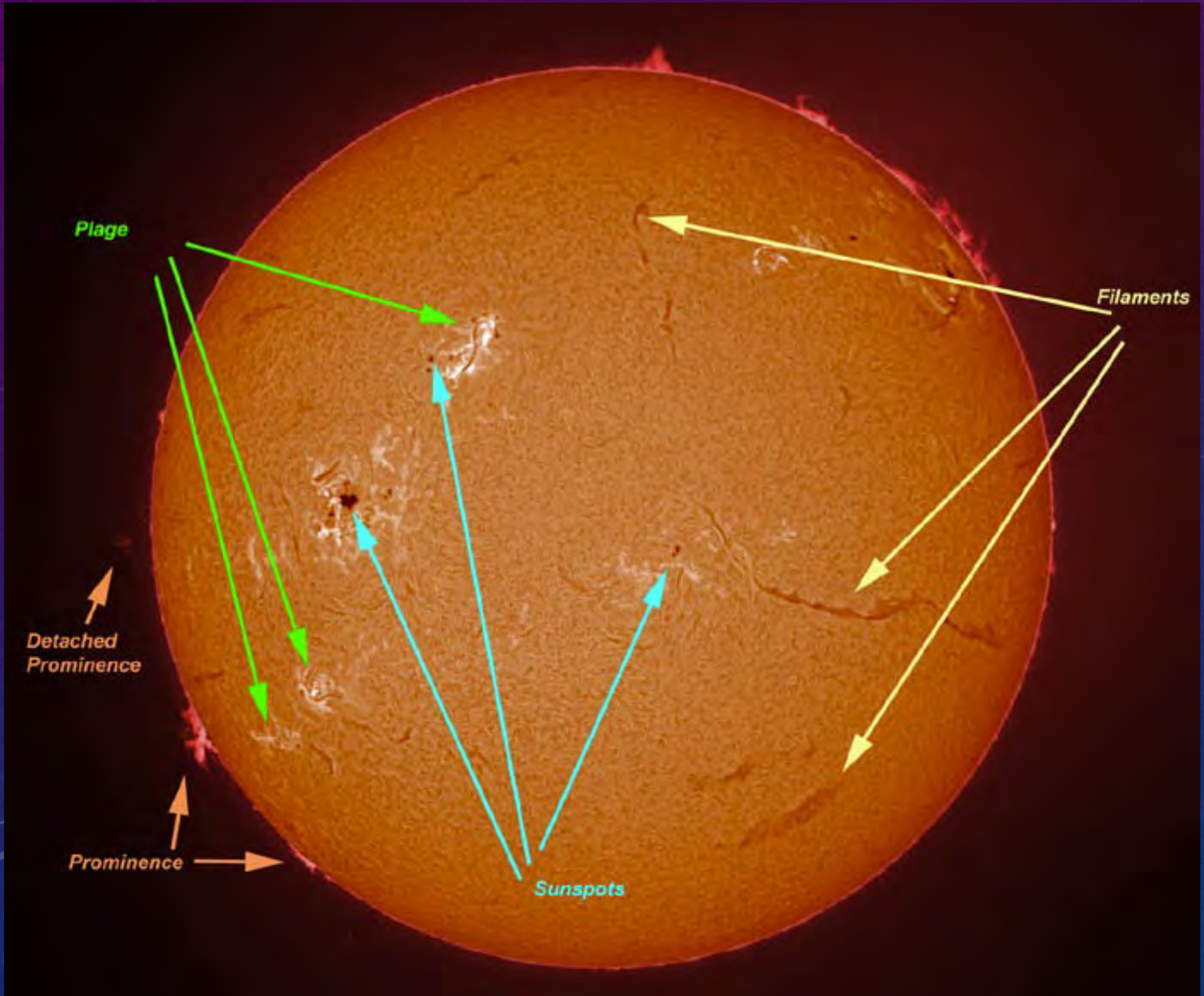


The sun is composed of the five different layers seen in this image. CREDIT: NASA's Goddard Space Flight Center

SOLAR TEMPERATURE PROFILE



CHROMOSPHERIC STRUCTURES



- Sunspots
  - Cooler regions that appear darker than the surrounding material
  - Strong magnetic fields ~1000s of Gauss reduce heat conduction into umbra
  - Appear in pairs-with opposite polarity
  - Umbra—dark core
  - Penumbra—lighter surrounding regions
- Sunspot Number (R) is a measure of solar activity

$$R = k(10g + s)$$

g=number of sunspot groups

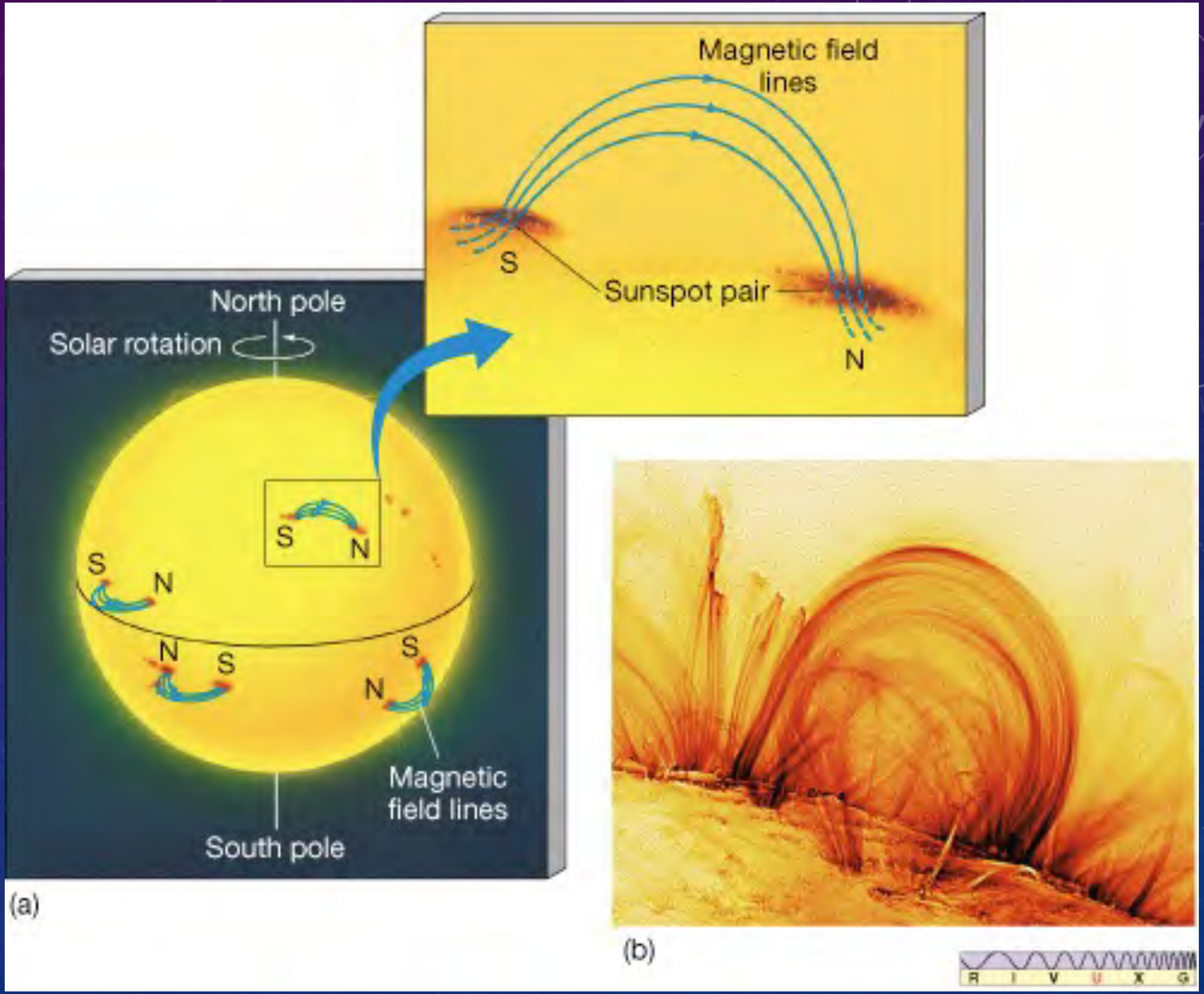
k=scaling factor depending on specific observatory (<1)

R= sunspot number calculated

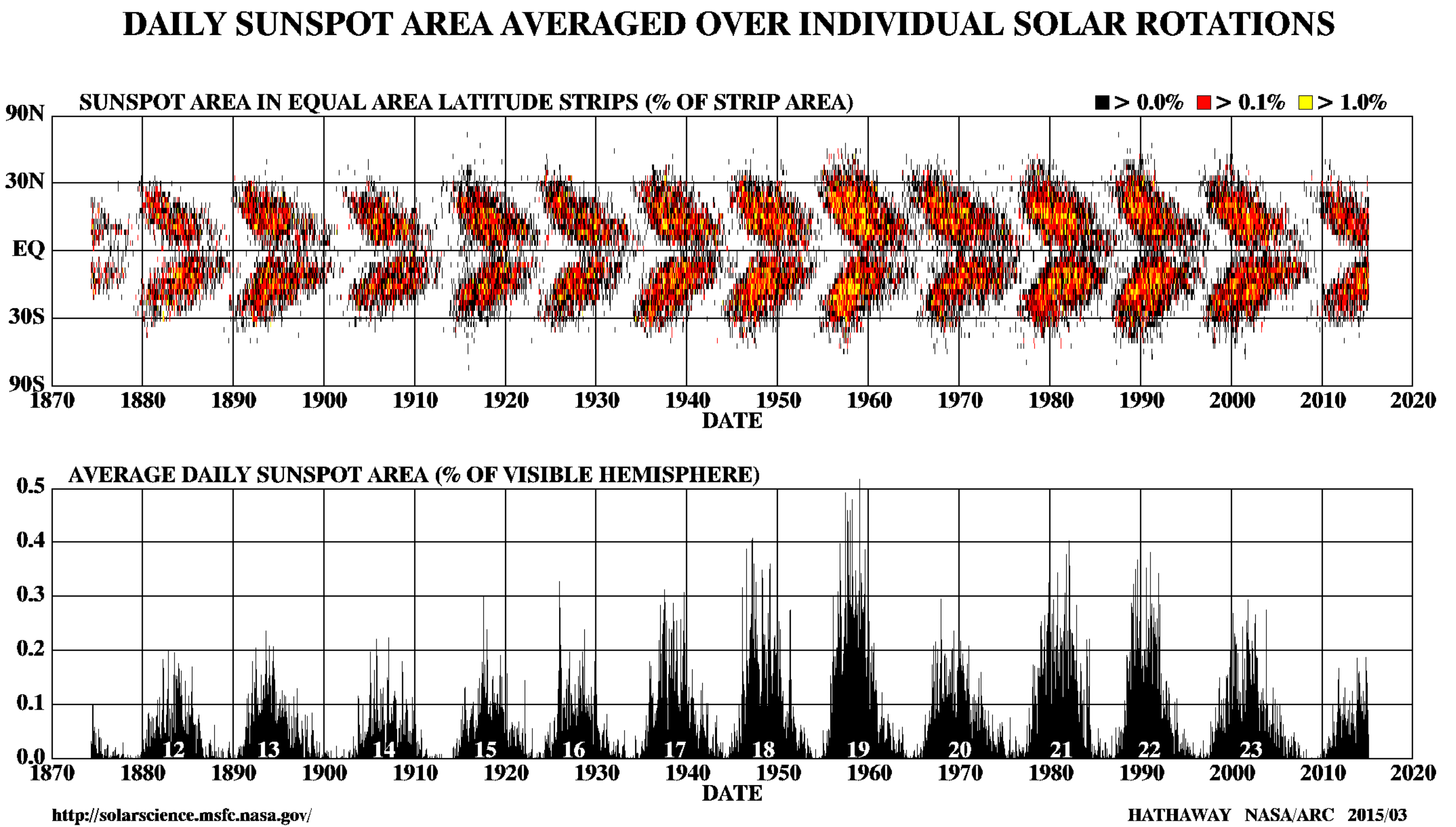
S= number of sunspots

SOLAR ACTIVITY

- Solar activity is a measure of the changing atmosphere of the Sun.
- The solar cycle (22 years in length) marks the evolution of the Sun’s magnetic field from a quiet dipolar configuration to a complicated multi-polar configuration.
  - https://www.youtube.com/watch?v=sASbVkK-p0w
- As the magnetic field becomes more complex in the photosphere and atmosphere, features on the photosphere and in the chromosphere evolve and become more numerous.

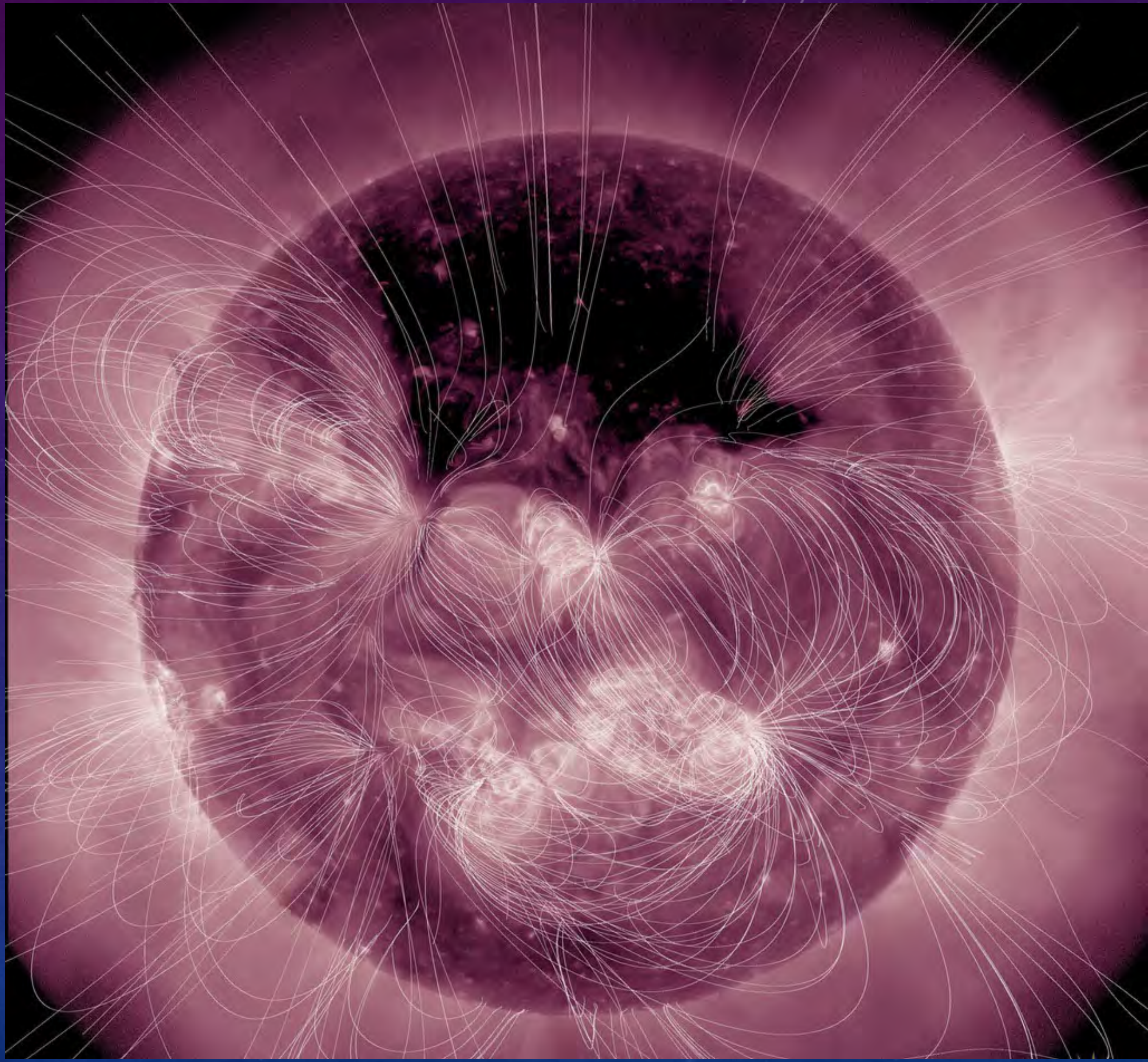


SOLAR ACTIVITY



CORONAL FEATURES

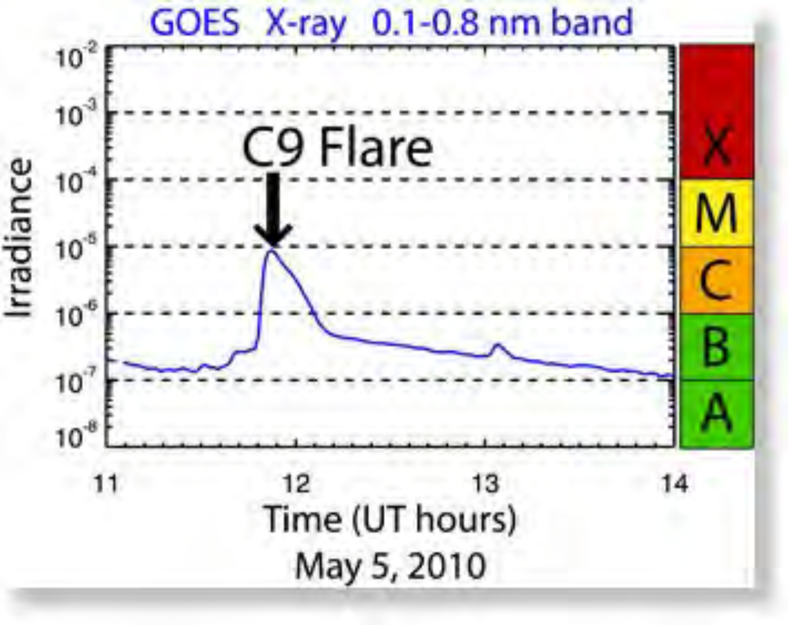
- Coronal holes: dark, cooler (~800,000K), less dense regions in the corona. Open fields stretch from the coronal holes out to the edges of the heliosphere and carry the solar wind.
- Active Regions: Bright, hotter (>2MK) regions in the low corona that map down the strong magnetic fields around sunspots. Large closed coronal loops can be traced within them.
- Quiet Sun: coronal loops, helmet streamers (T~1MK)

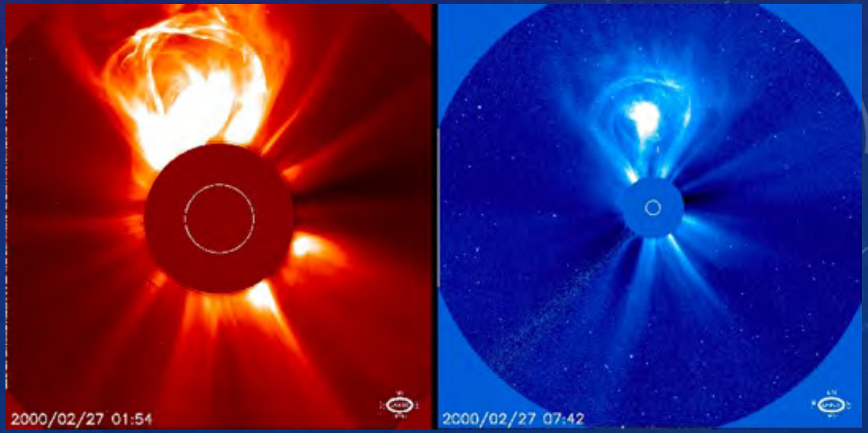


Coronal Holes and Active Regions

TRANSIENT EVENTS:

- During solar activity maximum, coronal magnetic fields can catastrophically change their connectivity in a solar flare
  - Sudden bright areas on the Sun occur as particle get accelerated and radiate vast quantities of energy out from the Sun (up to X-ray and gamma-ray energies)
  - Radiation can get to Earth in 10s of minutes
  - https://www.youtube.com/watch?v=dNnZTGMnXS8
- Sometimes the reconnection is so strong, it opens the overlying field holding it in the Sun’s atmosphere and it then powers a vast amount of plasma and magnetic field out of the Sun’s gravitational and magnetic potential—This is a Coronal Mass Ejection (or CME)
  - https://www.youtube.com/watch?v=TWjtYSRlOUI





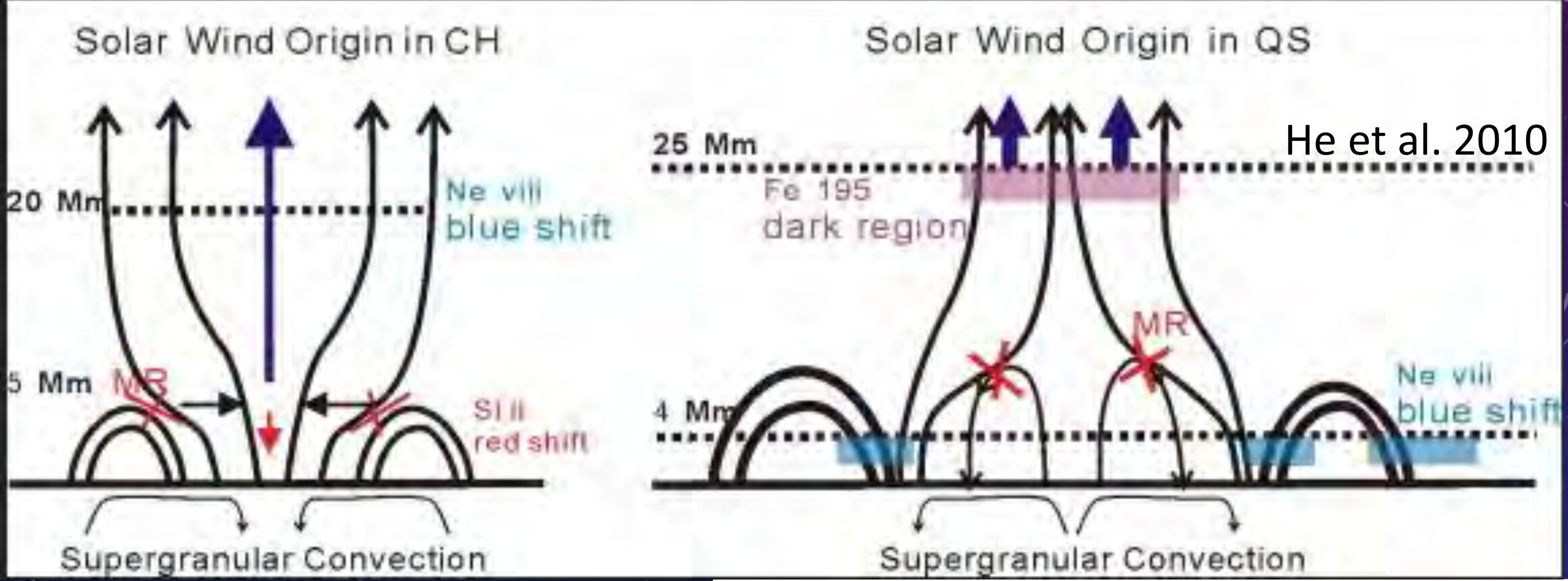
CORONAL MASS EJECTIONS

- CMEs involve large scale restructuring of magnetic fields via reconnection, but unlike flares, they involve the massive release of plasma out of the confines of the closed magnetic fields in the corona into the heliosphere.
- When they erupt, they carry large high-pressure pulses of plasma and magnetic field out into interplanetary space.
- These can drive disruptive space weather events and harm satellites, humans, and ground infrastructure.
- CMEs can have flares associated with them
- Plasma is carried out into the heliosphere, and if directed at Earth, reaches it in 2- 4 days depending on the CME speed.

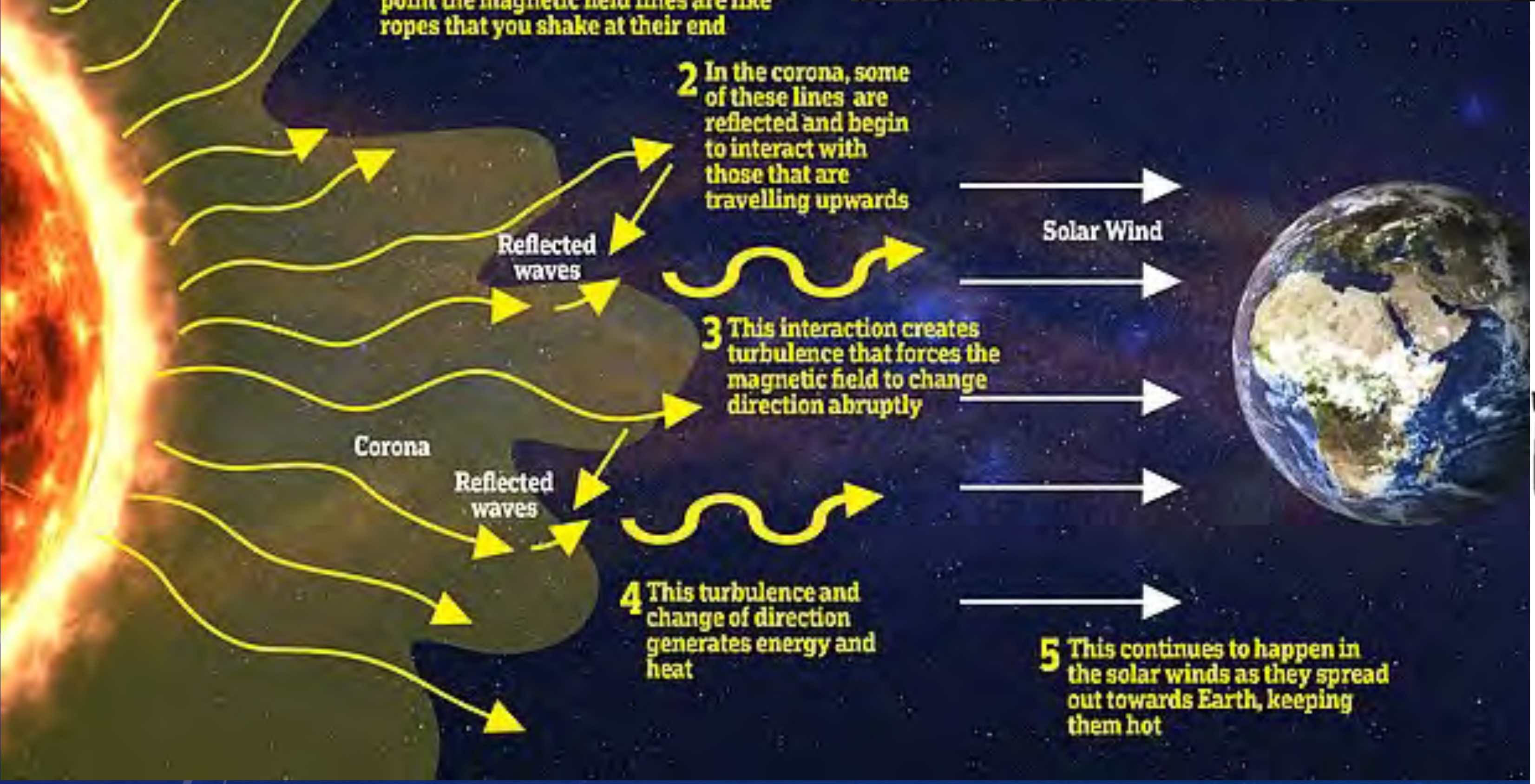
- https://www.youtube.com/watch?v=Zk09bTCY3Mw
- https://www.youtube.com/watch?v=6L3ms9jpyK4

WHERE DOES THE SOLAR WIND COME FROM

THE SOLAR WIND



He et al. 2010



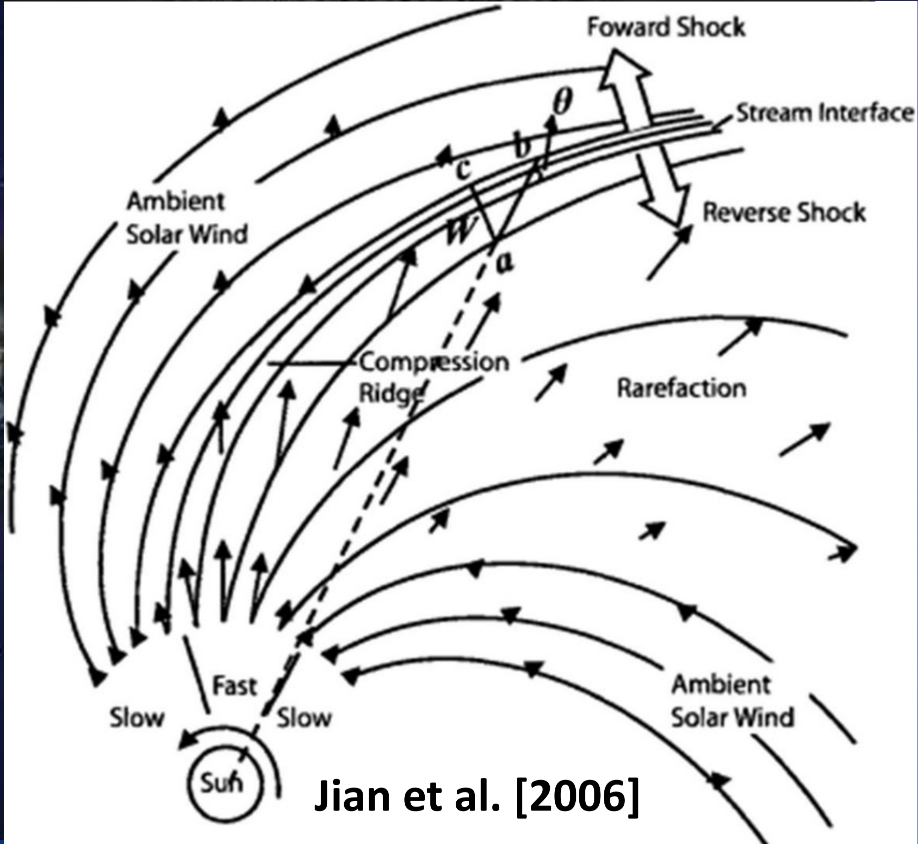
1 The surface of the sun shakes its own magnetic field, launching waves into the million degree Celsius corona. At this point the magnetic field lines are like ropes that you shake at their end

2 In the corona, some of these lines are reflected and begin to interact with those that are travelling upwards

3 This interaction creates turbulence that forces the magnetic field to change direction abruptly

4 This turbulence and change of direction generates energy and heat

5 This continues to happen in the solar winds as they spread out towards Earth, keeping them hot



Jian et al. [2006]

TRADITIONAL VIEWS OF THE SOLAR WIND: TWO TYPES

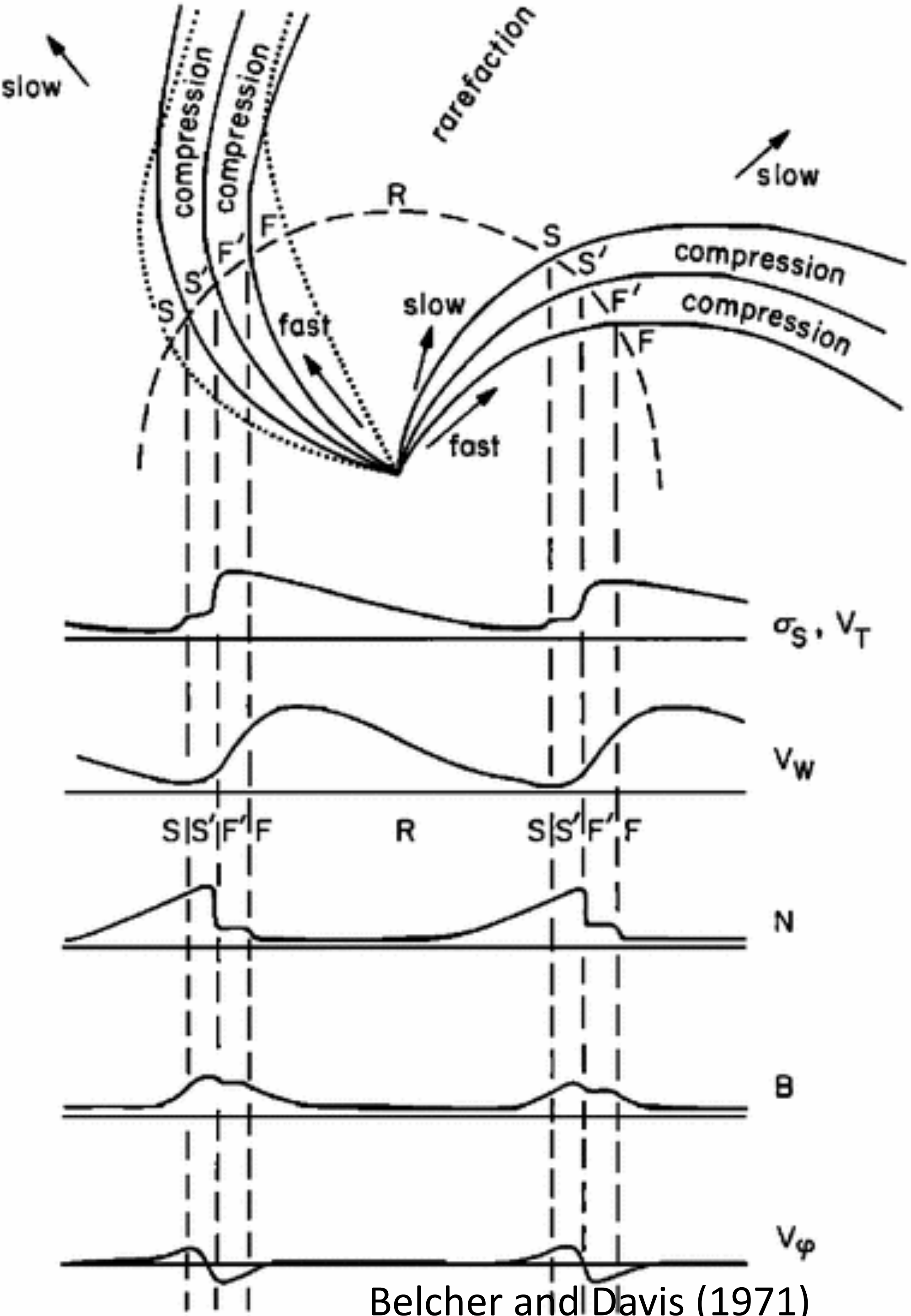
<u>Fast Solar Wind (v>500 km/s)</u>: Originating in coronal holes

- Steady, yet Alfvenic
- Lower bias in first ionization potential (FIP) elemental abundances
- Lower charge state ratios

<u>Slow Solar Wind (v<500km/s)</u>: Originating nearer to the heliospheric current sheet (HCS), up to 30° away

- Higher proton density, lower proton temperature, larger temporal variability,
- Higher bias in first ionization potential (FIP) elemental abundances
- Higher charge state ratios

Elemental and ion composition are some of the best indicators of different solar wind source region



Belcher and Davis (1971)

CHECK YOUR UNDERSTANDING

- Does the solar wind flow away from the Sun follow a…
  a) Spiral Pattern
  b) Radial Pattern

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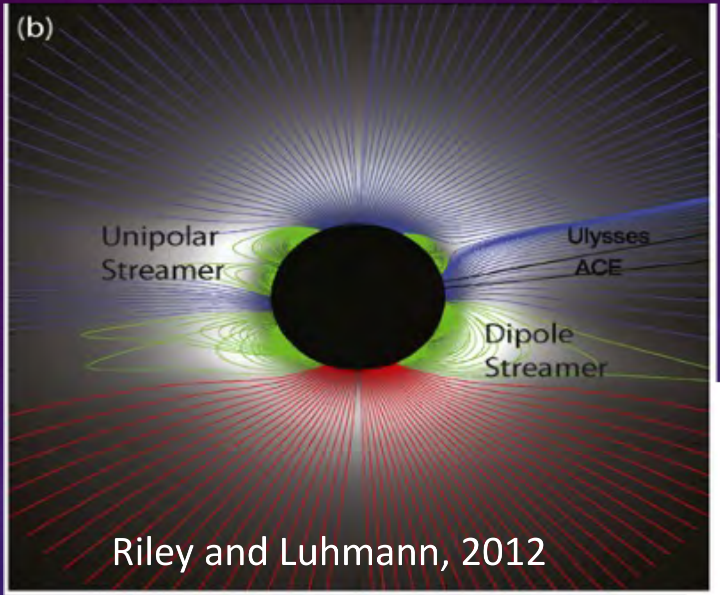
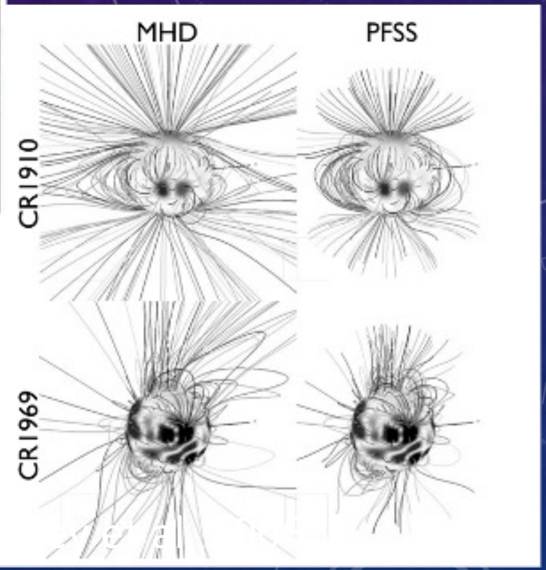
SOURCES OF SOLAR WIND

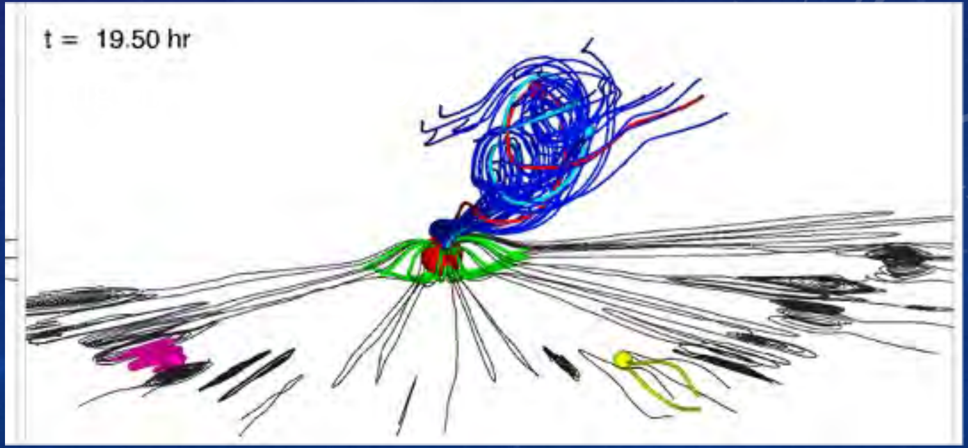
- Open fields in coronal holes create **fast wind**
- Dipolar Streamers centered at the heliospheric current sheet which separate coronal holes of opposite polarity and contribute to **slow wind**
- Pseudostreamers- originates in coronal holes and separates coronal holes of the same polarity. Observed in-situ, these have no embedded current sheet, and are associated with **slow wind**
- Transients-originate in **coronal mass ejections**, or other bursty releases of plasma and contribute to the **fastest wind**

Elemental and ion composition are some of the best indicators of different solar wind source regions



Riley and Luhmann, 2012





2012

CHECK YOUR UNDERSTANDING

- Which of these is associated with slow solar wind?
  a) Dipolar Streamers/Coronal Helmet Streamers
  b) Unipolar Streamers/Pseudostreamers
  c) Open fields
  d) Transients

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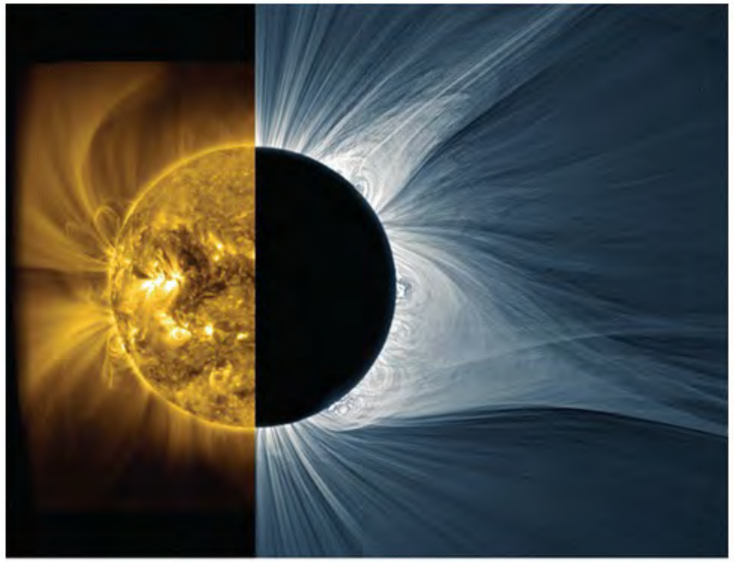
SOURCES OF THE SOLAR WIND



Cranmer SR, Winebarger AR. 2019.
Annu. Rev. Astron. Astrophys. 57:157–87

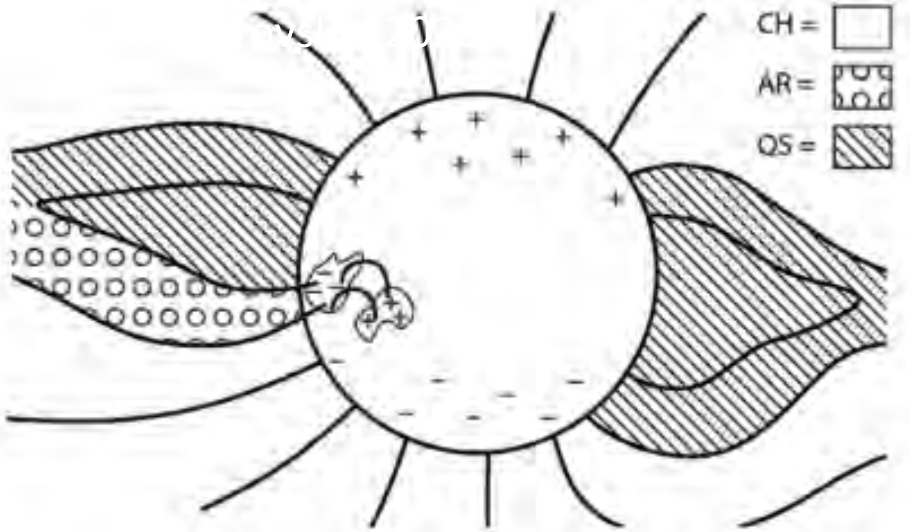


Figure 4. Cartoon of different source locations on the Sun, with black lines representing magnetic fields. An active region is present under the left streamer. The streamer on the left has plasma from the active region and plasma from the quiet Sun in it. The streamer on the right only has quiet Sun plasma.

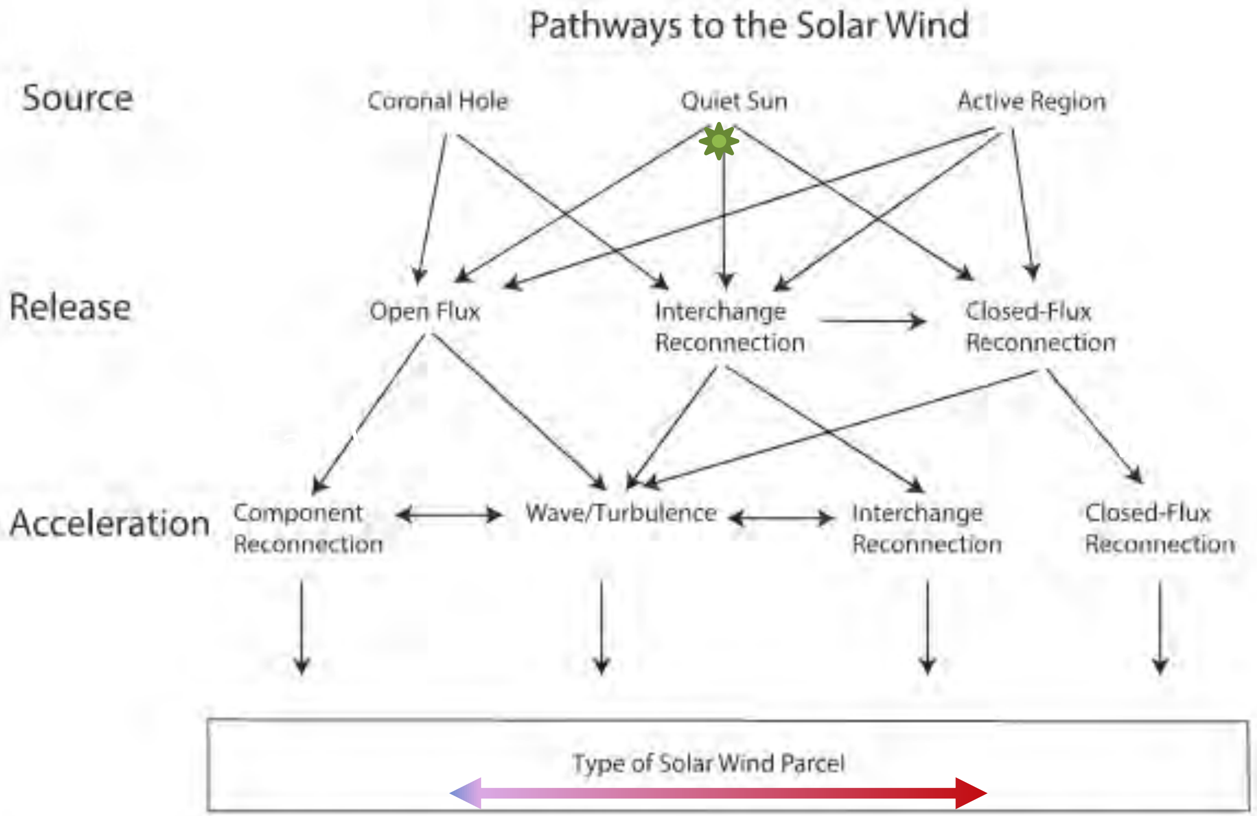


Figure 3. Pathways to the solar wind. Q1, source is the top line; there are three general options. Q2 is how the plasma parcel is released. Q3 is how the plasma is accelerated. The type of solar wind parcel that results will depend on which path it followed.

SOURCE OF THE SLOW SOLAR WIND IN THE QUIET CORONA

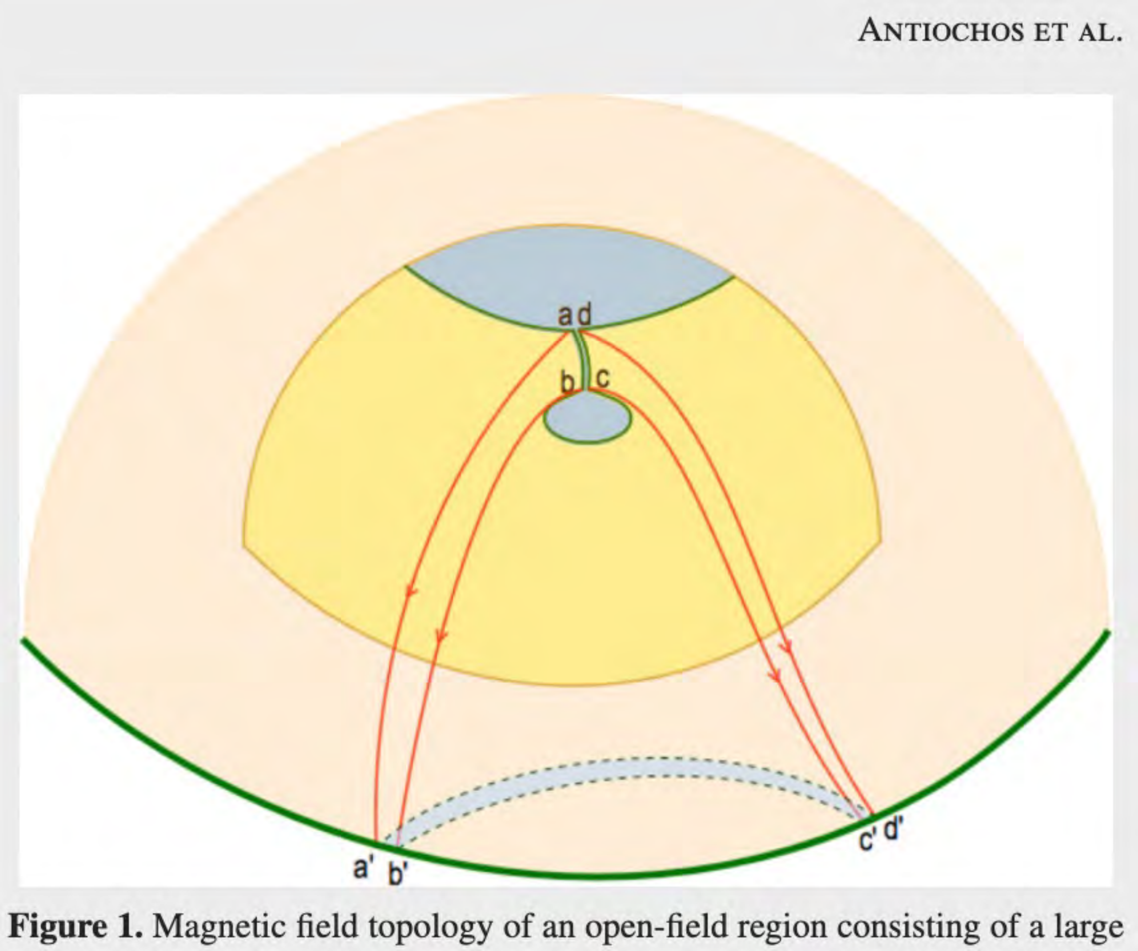
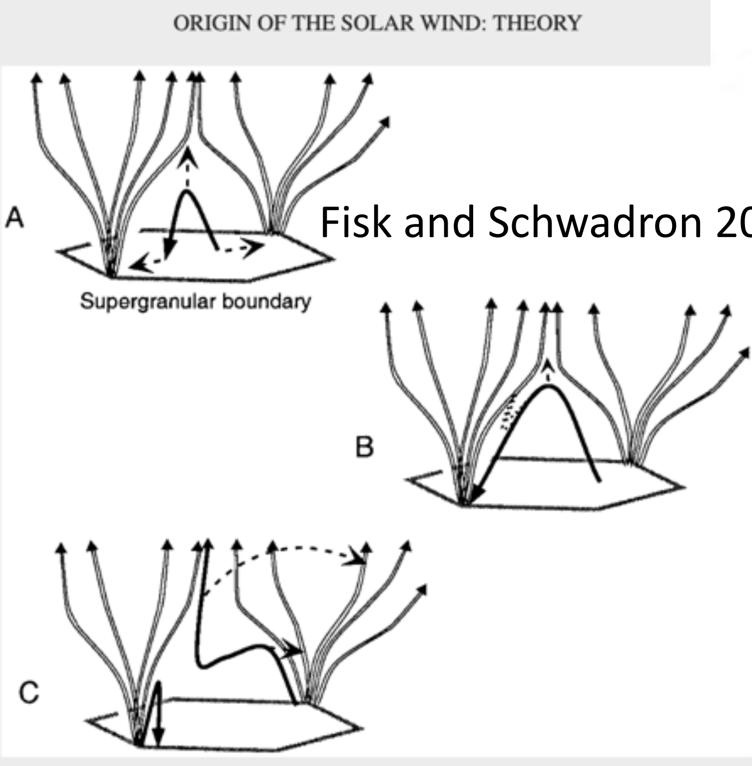
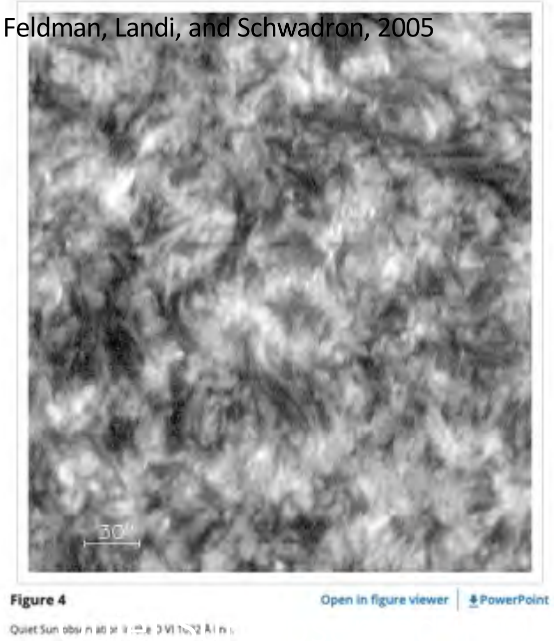
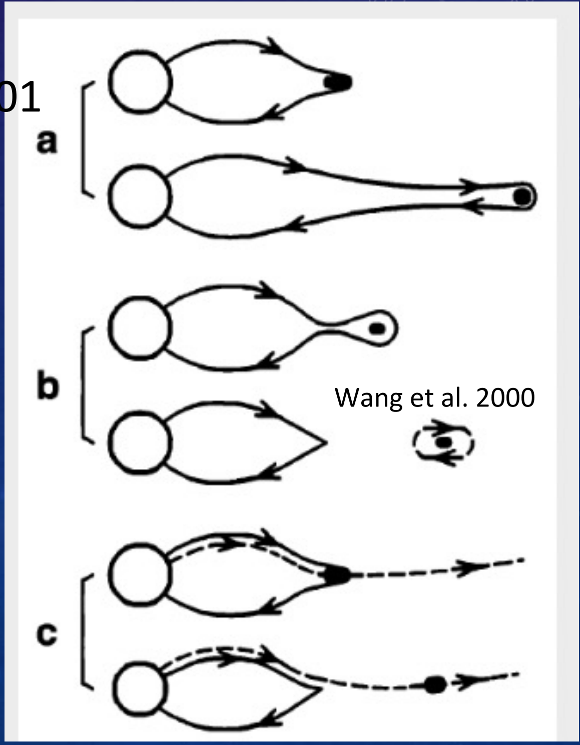

ANTIOCHOS ET AL.

Figure 1. Magnetic field topology of an open-field region consisting of a large


ORIGIN OF THE SOLAR WIND: THEORY

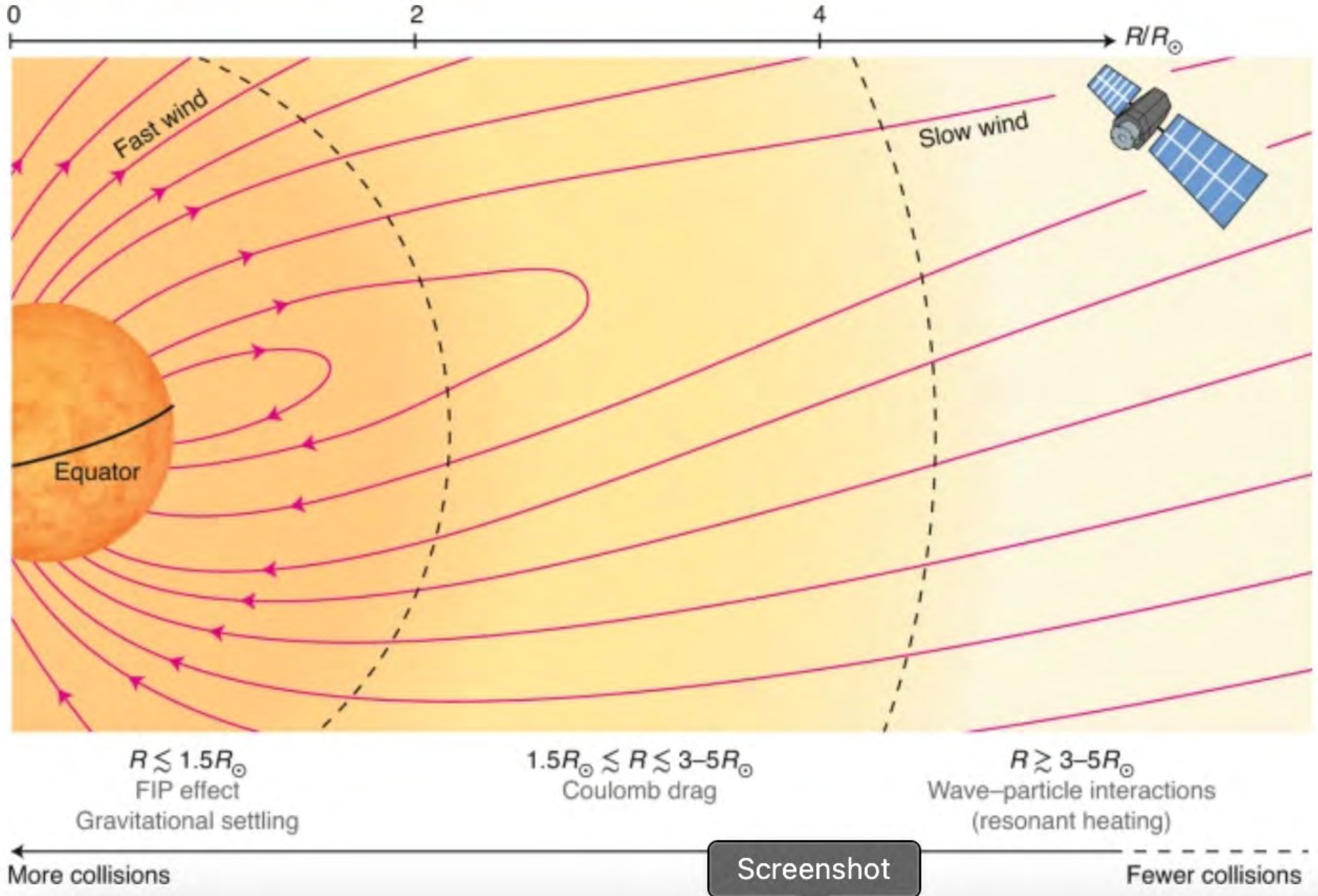
Fisk and Schwadron 2001


Feldman, Landi, and Schwadron, 2005



Wang et al. 2000

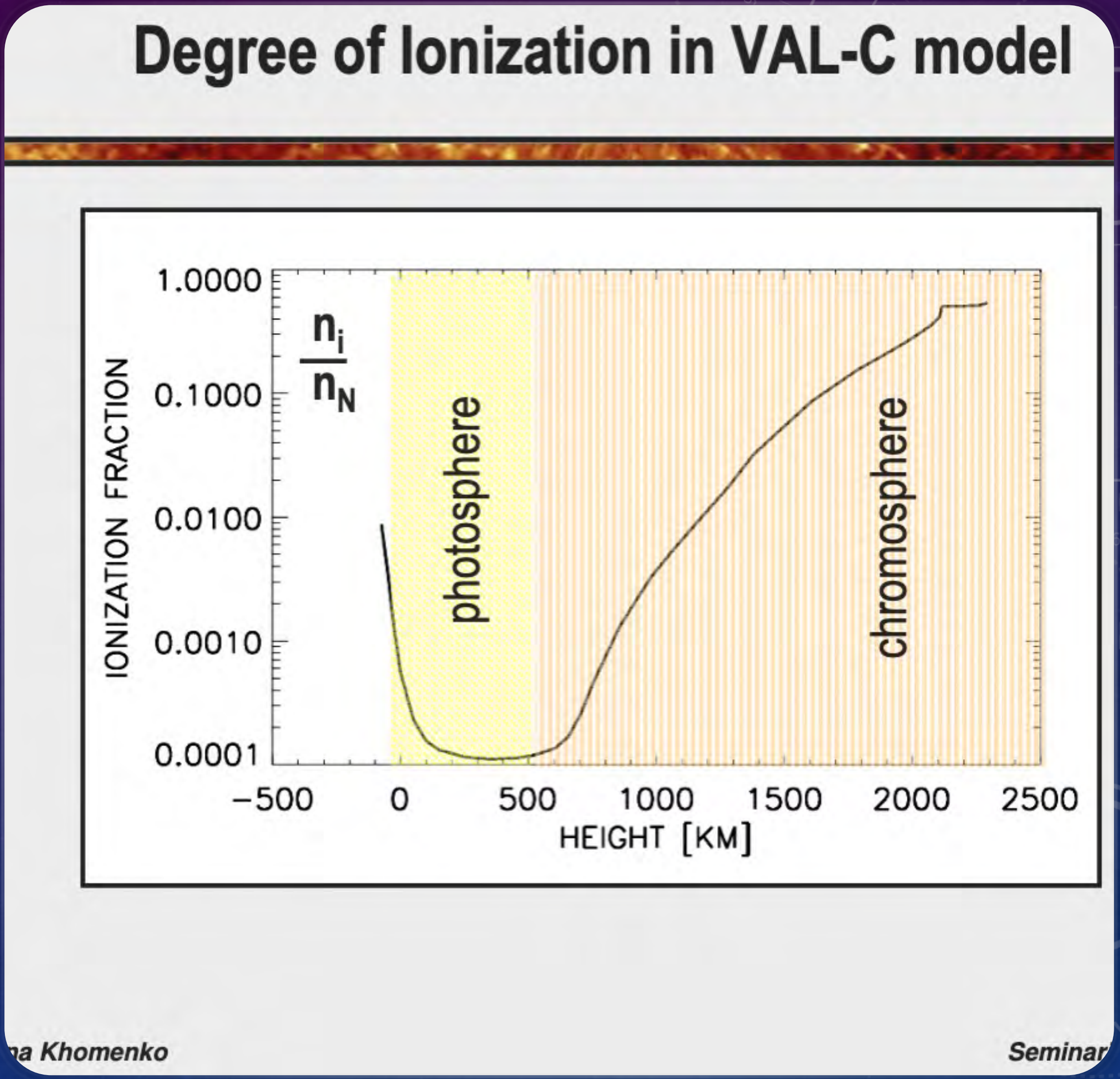
Fig. 1: Schematic of the solar corona and the various processes that change elemental abundances.



WHAT IS THE SOLAR WIND MADE UP OF

IONS IN THE SOLAR WIND

- The transition between neutral and ionized atmosphere on Earth starts around 300km (1% ionized), and by GEO it is 100% ionized, depends on the density and temperature of atmosphere.
- On the Sun, neutral plasma transitions to ionized plasma in the Photosphere/Chromosphere
- Plasma in the solar wind contains protons, electrons, helium, and heavy ions



Degree of Ionization in VAL-C model

a Khomenko

Seminar

HEAVY IONS IN THE SOLAR WIND

- Focus on thermal solar wind, with energies between about 1-20 keV/e
- Hydrogen (H^+, protons) and Helium (He^{2+}, alphas) constitute 99.9% (in number) of the solar wind
- Plasma processes governing the solar wind are mediated by those two species
- All other ions (C, O, Fe, Mg, Si) behave like test particles in the flow, and are commonly known as “minor ions” or “heavy ions”
- Heavy ion do not affect the physical phenomena (waves, instabilities, etc.), but are affected by them

Heavy ion ionization states and elemental fractionation tell us about the local environment in which they are heated and accelerated

ION COMPOSITION

In the solar corona, particles undergo ionization and recombination by

- Collisional ionization by electron impact

  $X^i + e \rightarrow X^{i+1} + e + e$

- Excitation-autoionization:

  X^i+e -> $(X^i)^{**}$ -> X^i+1 + e +e

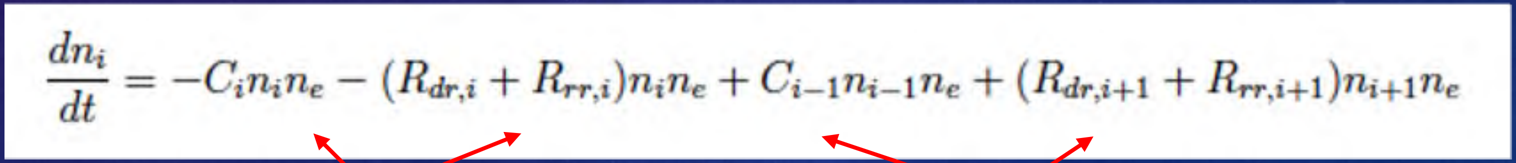
- Dielectronic and Radiative recombination

  $X^i + e \rightarrow X^{i-1**} \rightarrow X^{i-1} + \nu$

  $X^i + e \rightarrow X^{i-1} + \nu$

dn_i/dt	Source term for X^i
C_i	Ionization rate
$R_{xr,i}$	Recombination rate
n_i	Density of X^i
n_e	Density of electrons

The source term for the creation and destruction of the ion, X^i, is



$$\frac{dn_i}{dt} = -C_i n_i n_e - (R_{dr,i} + R_{rr,i}) n_i n_e + C_{i-1} n_{i-1} n_e + (R_{dr,i+1} + R_{rr,i+1}) n_{i+1} n_e$$

Losses due to ionization and recombination

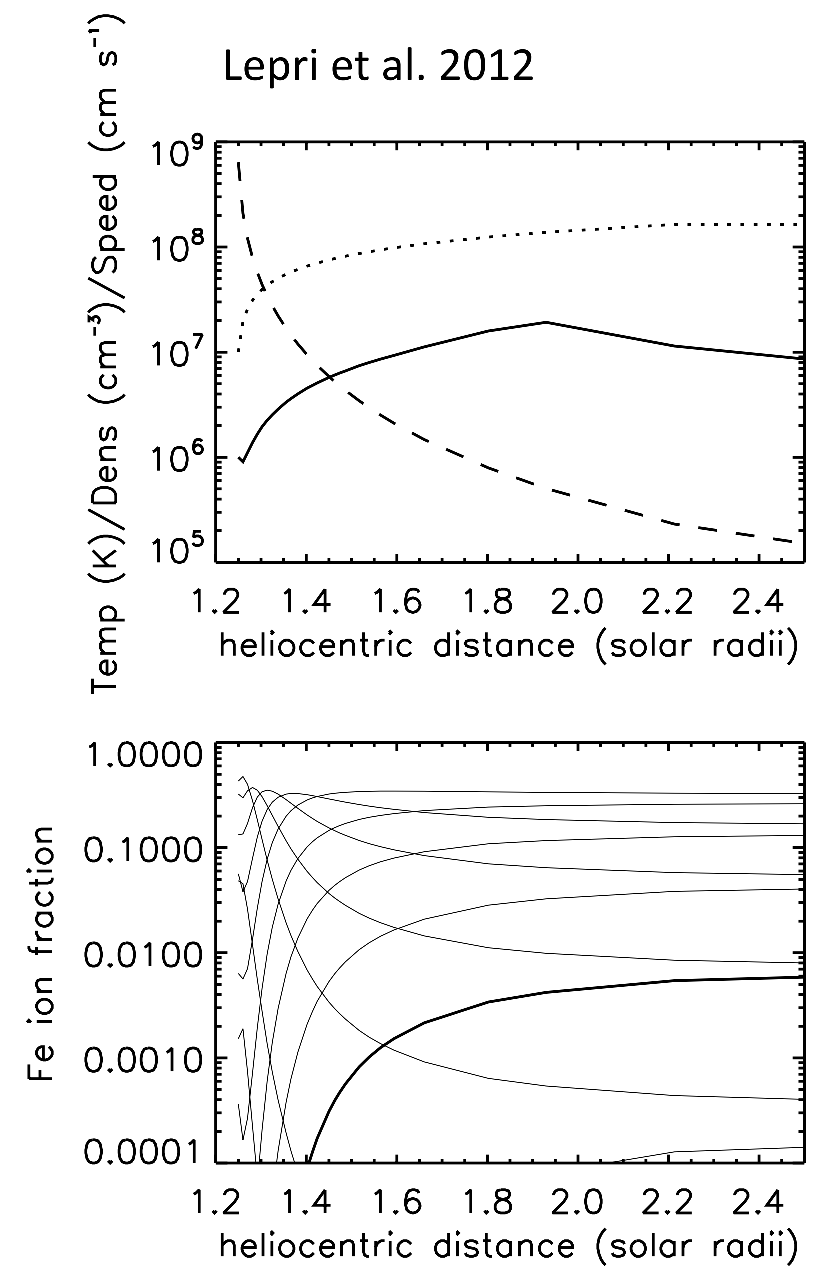
Creation due to ionization and recombination

C_i, $R_{xr,I}$ depend on T_e. The steady state solution depends on n_e, T_e, and time spent in the ionizing/recombination region

Ionization Freeze-in

- To determine the limiting case, examine the timescales involved
- τ_e is the expansion timescale and τ_a is the timescale for atomic processes
  - If $\tau_e >> \tau_a$, atomic processes take place quicker than expansion ⇒the charge states will continue to adjust
  - If $\tau_e << \tau_a$, atomic processes occur slower than expansion ⇒ **the charge states in the plasma become frozen-in**

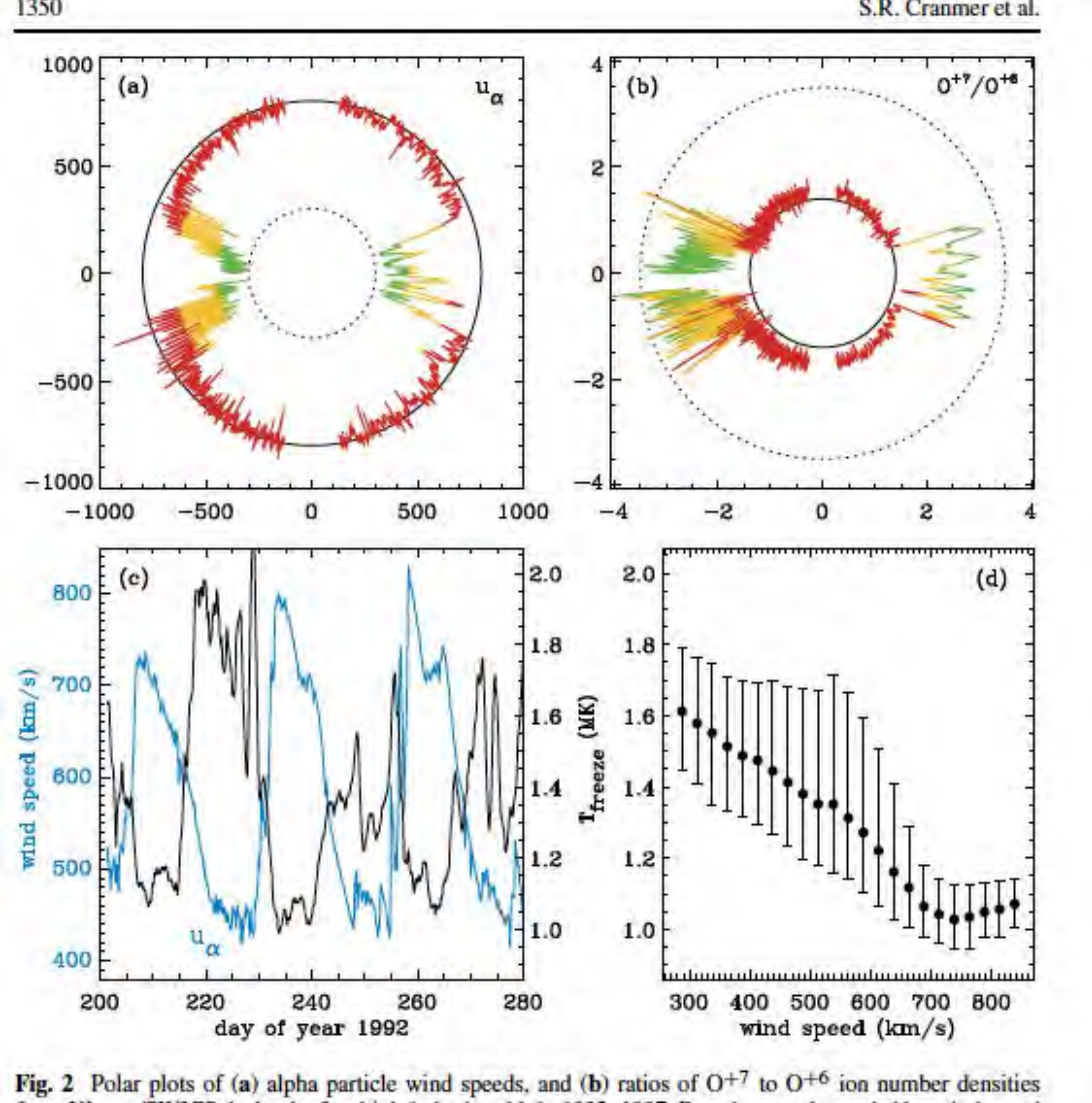
⇒ **The charge states observed in the solar wind represent the coronal electron temperature and density in the freeze-in region**



Lepri et al. 2012

ION COMPOSITION IN THE SOLAR WIND

- Freeze-in temperature is shown to anti-correlate with solar wind speed
- Higher ionization states of C and O are seen in the slow wind
- Lower ionization states are seen in the fast wind



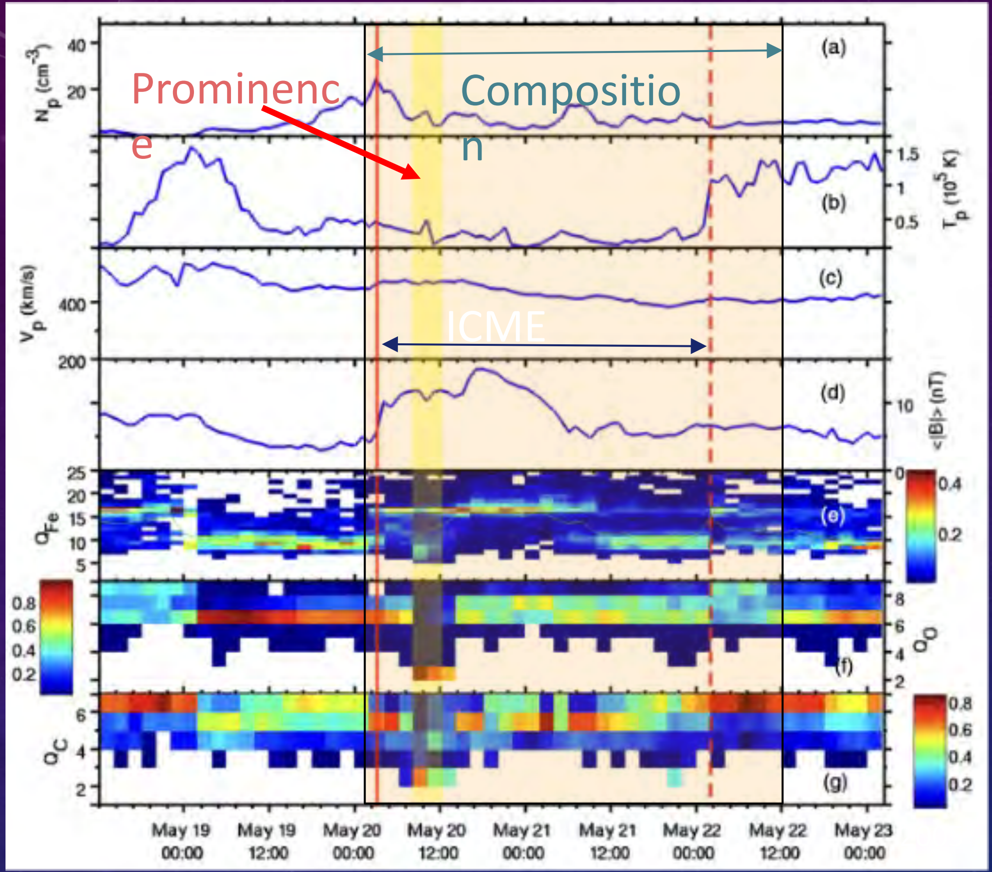
1350

S.R. Cranmer et al.

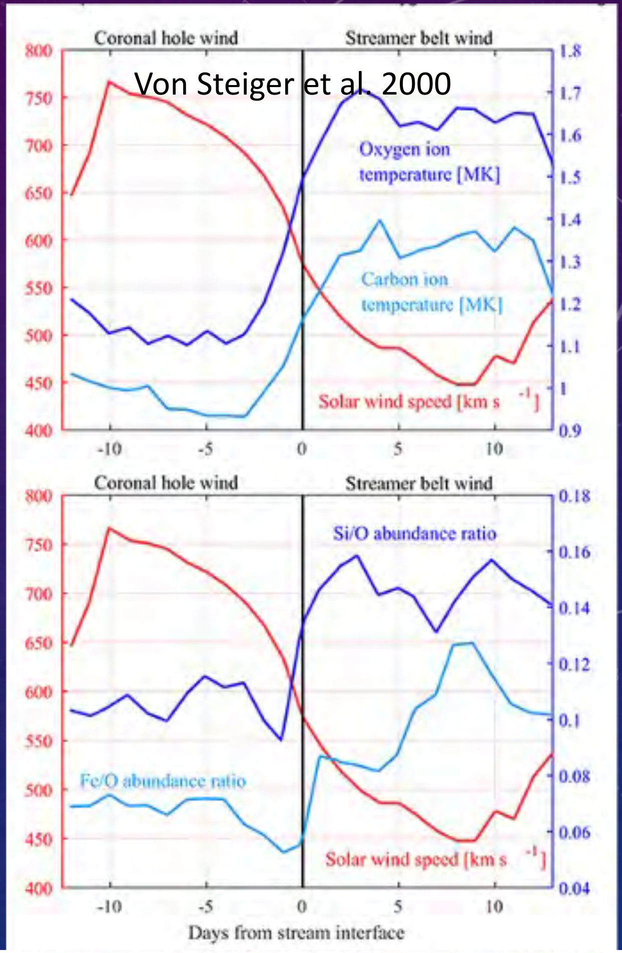
Fig. 2 Polar plots of (**a**) alpha particle wind speeds, and (**b**) ratios of O^{+7} to O^{+6} ion number densities

ION COMPOSITION

- The nature of the the solar corona and the sources of the solar wind can be revealed in in-situ observations.
- Ion composition in the solar wind gives information about the electron temperature, plasma density and residence time in the corona in the region it freezes-in.
- The fast, slow, and ICME wind all are characterized by distinct ion composition signatures.
- Remote sensing measurements can give temperatures and intensities of certain ions at varying altitudes in the solar atmosphere.

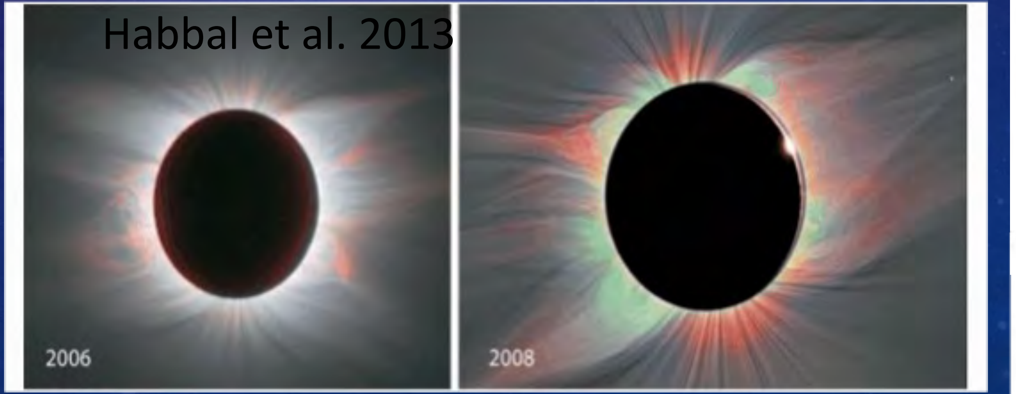


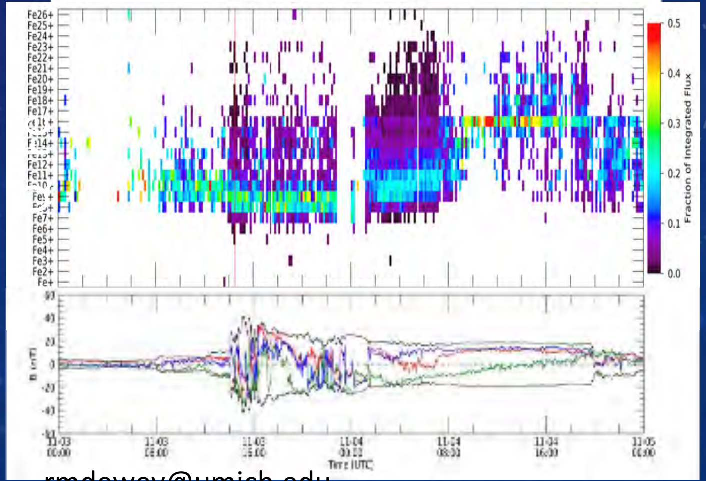
Lepri and Zurbuchen 2010



Von Steiger et al. 2000

Habbal et al. 2013





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MODELING CHARGE STATES

Simulation of a CME that undergoes rapid heating near the corona and rapid expansion of its volume.

Left: enhanced initial density.

Right: unenhanced initial density.

Gruesbeck et al. 2011

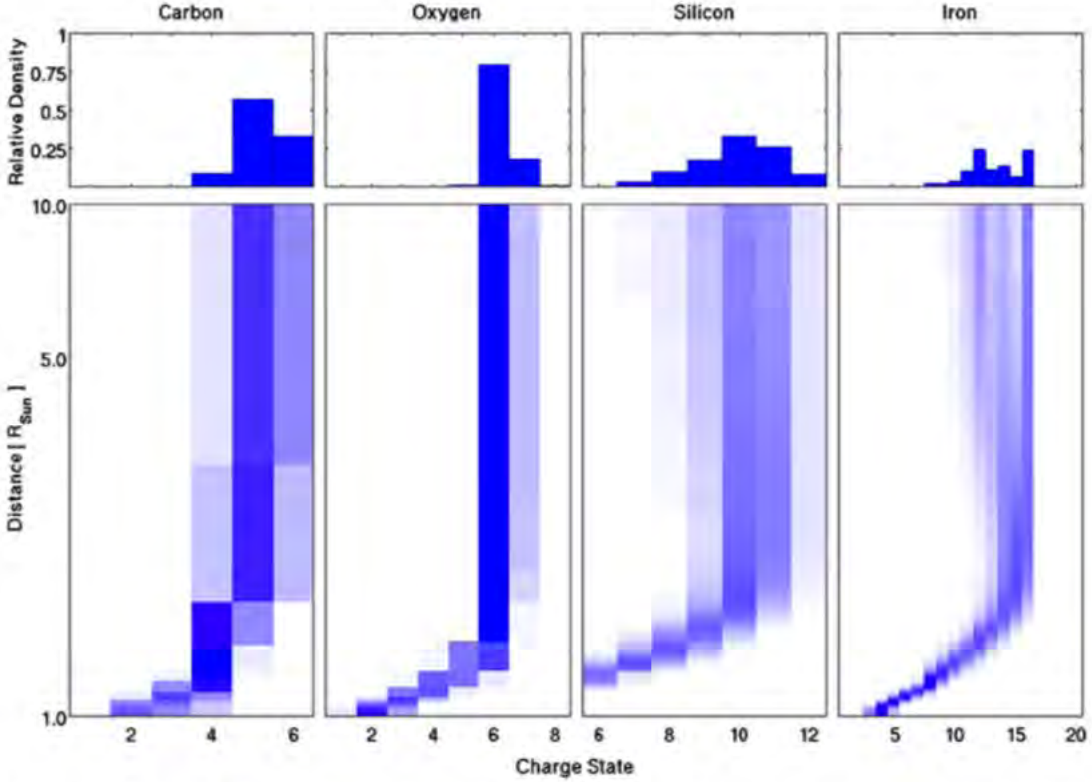


Figure 8. Results from the model for the case where the plasma is rapidly heated, experiences rapid expansion, and has a sufficiently high initial density. Format as in Figure 6.

(A color version of this figure is available in the online journal.)

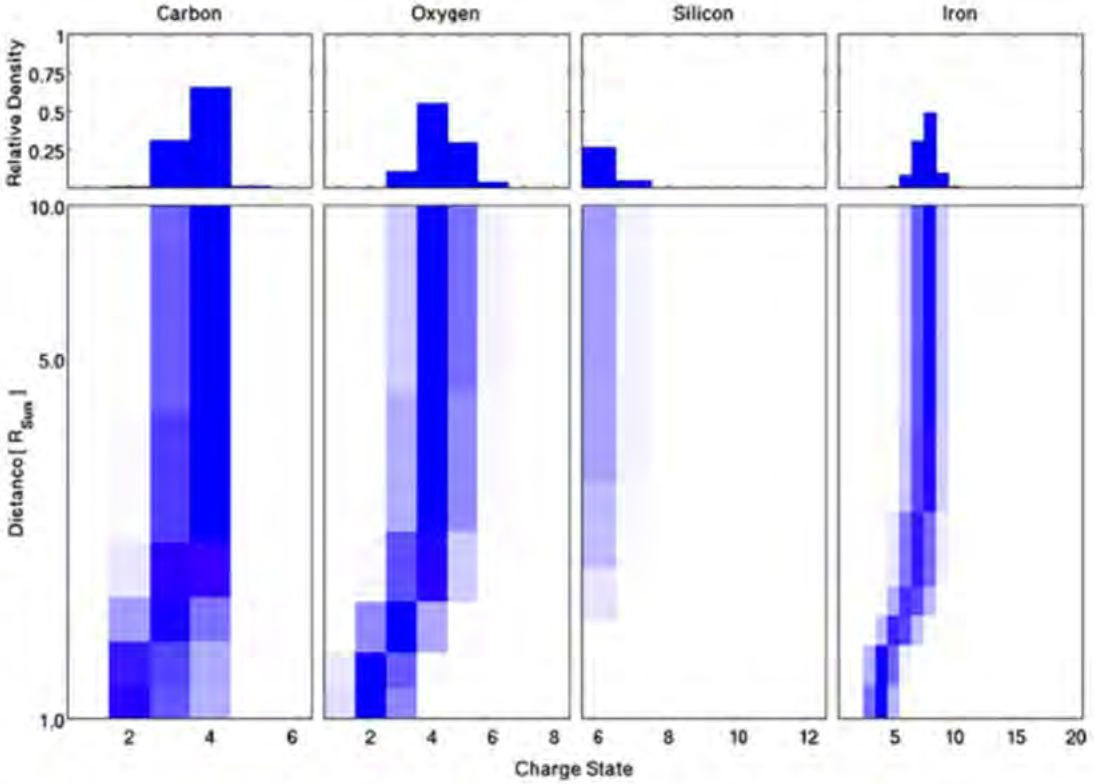
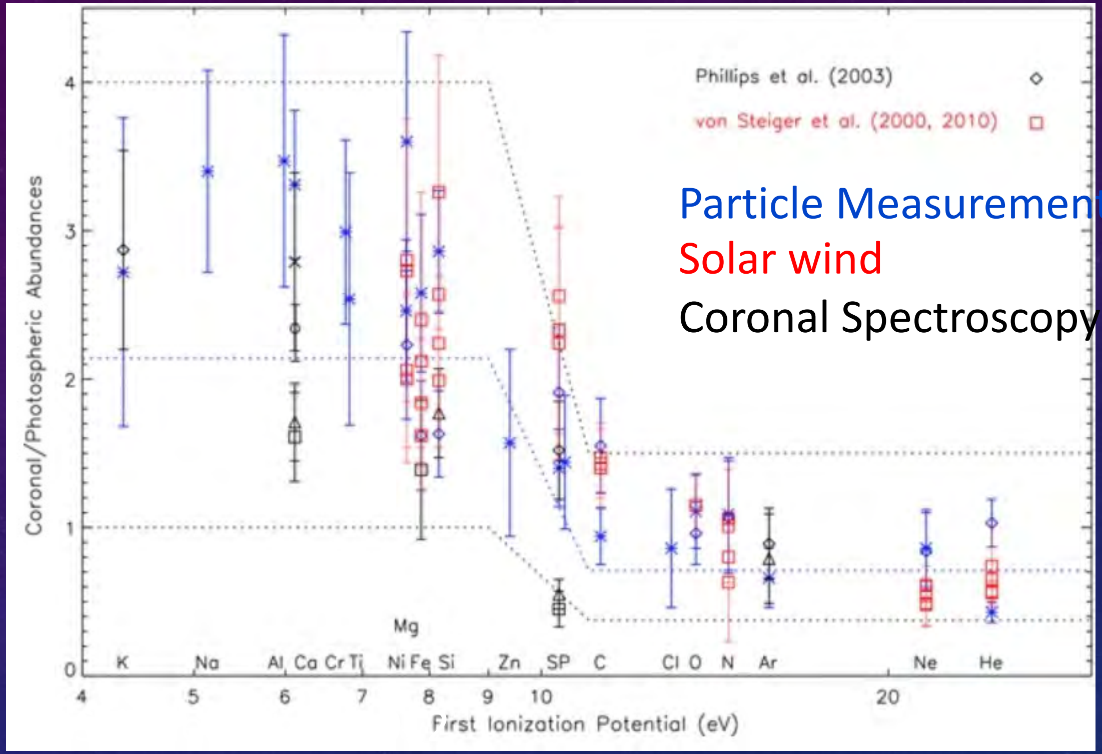


Figure 6. Results from the model which includes rapid heating and expansion, but with the omission of an enhanced initial density. The bottom set of panels shows the evolution of the charge states from the coronal surface to a distance of 10 $R_{\odot}$ away plotted for arbitrary instances during the expansion. For all four atomic species, it can be seen that freeze-in occurred around 3 $R_{\odot}$. The top panels show the frozen-in charge-state distribution observed at 1 AU.

ELEMENTAL FRACTIONATION

- Coronal elemental abundances were observed to not match those of the photosphere in early spectroscopic observations (e.g. Pottasch (1963, 1964), Meyer (1985).
- This effect was also seen in solar wind and energetic particle measurements.
- Elements with low first ionization potential (<10eV) tended to be enhanced above their photospheric levels by factors of 2-4.
- This fractionation may take 2-3 days to develop on coronal loops (Feldman and Widing 2003)



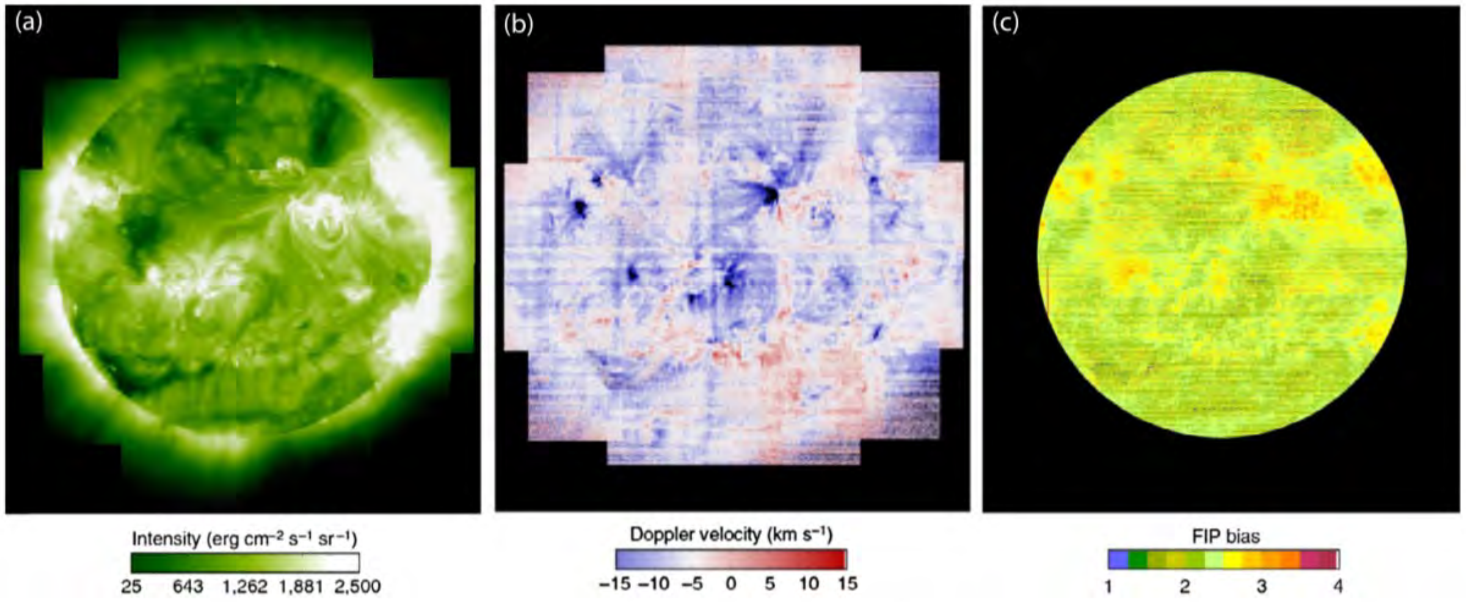
Particle Measurements
Solar wind
Coronal Spectroscopy

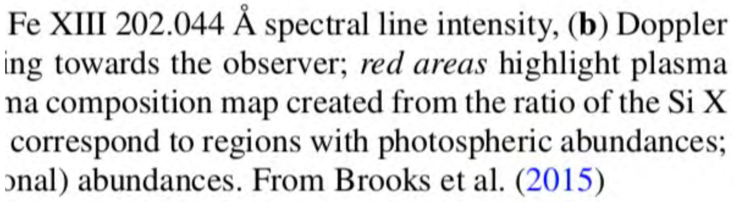
- The differences between the photospheric and coronal abundances implied that some sort of ion-neutral separation must be occurring in the chromosphere.

FRACTIONATION OF ELEMENTAL ABUNDANCES

- Fractionation processes in the low corona (R<2Rs) determine the elemental abundances.
- Fractionation processes enhance or deplete different elements in different regions of the Sun.
- Remote observations show that heavy elements become enhanced in long lived hot loops and active regions (Brooks and Warren 2011)
- Remote observations reveal that heavy elements are depleted in the core region of coronal streamers (Raymond et al. 1998)
- Fractionation varies across solar wind sources, and varies across different magnetic topologies that are more or less favorable to fractionation processes

Abbo et al. 2016





Fe XIII 202.044 Å spectral line intensity, (**b**) Doppler
ing towards the observer; *red areas* highlight plasma
na composition map created from the ratio of the Si X
correspond to regions with photospheric abundances;
onal) abundances. From Brooks et al. (2015)

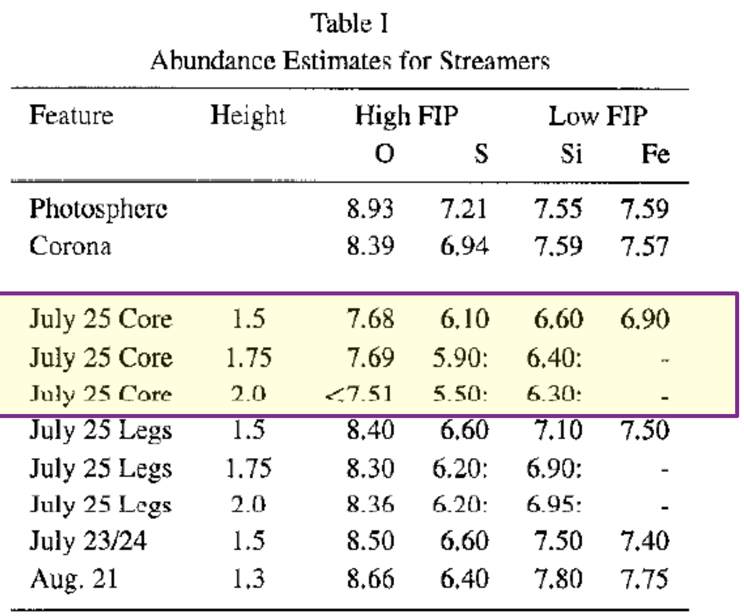


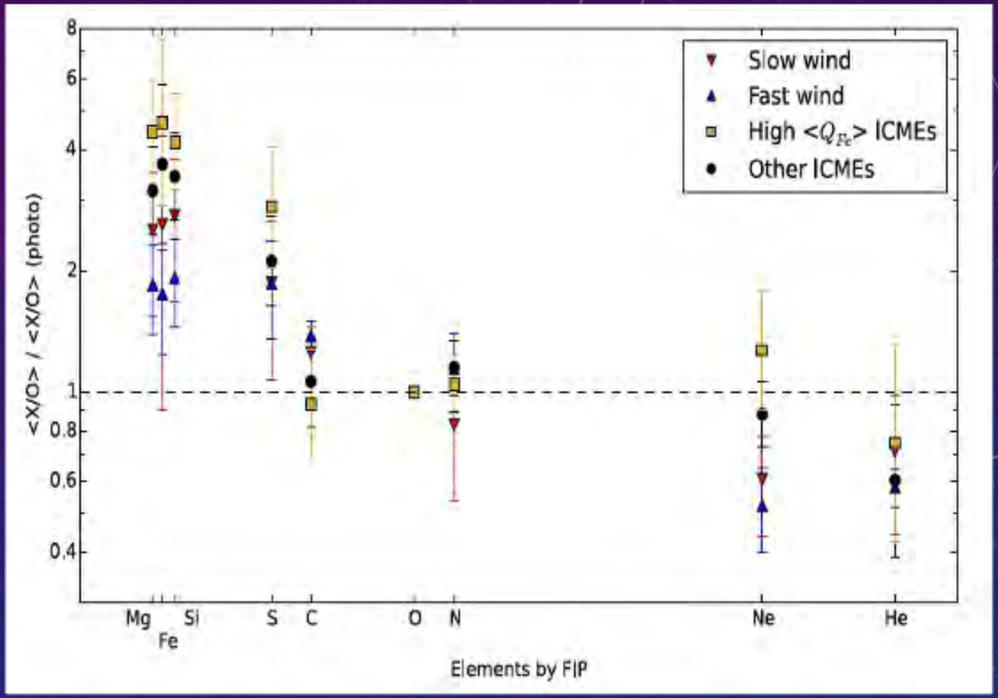
Table I
Abundance Estimates for Streamers

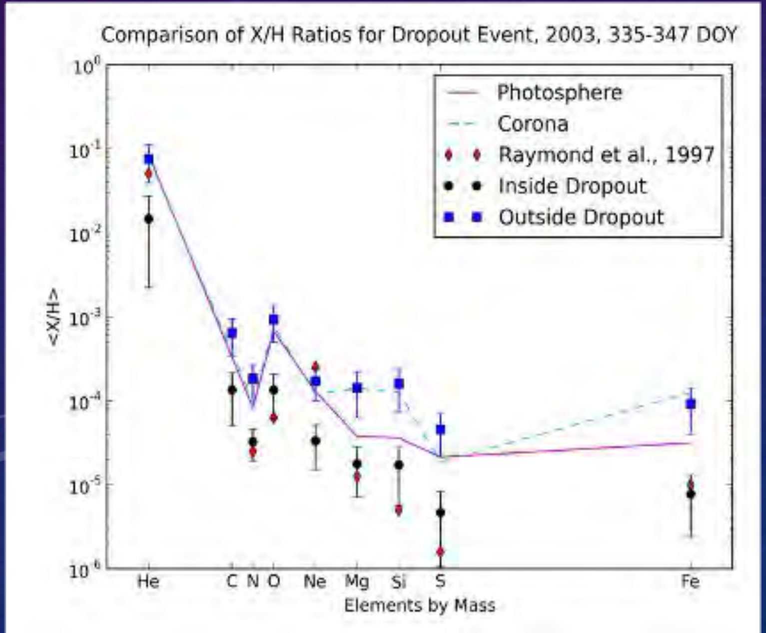
Feature	Height	High FIP		Low FIP	
		O	S	Si	Fe
Photosphere		8.93	7.21	7.55	7.59
Corona		8.39	6.94	7.59	7.57
July 25 Core	1.5	7.68	6.10	6.60	6.90
July 25 Core	1.75	7.69	5.90:	6.40:	-
July 25 Core	2.0	<7.51	5.50:	6.30:	-
July 25 Legs	1.5	8.40	6.60	7.10	7.50
July 25 Legs	1.75	8.30	6.20:	6.90:	-
July 25 Legs	2.0	8.36	6.20:	6.95:	-
July 23/24	1.5	8.50	6.60	7.50	7.40
Aug. 21	1.3	8.66	6.40	7.80	7.75

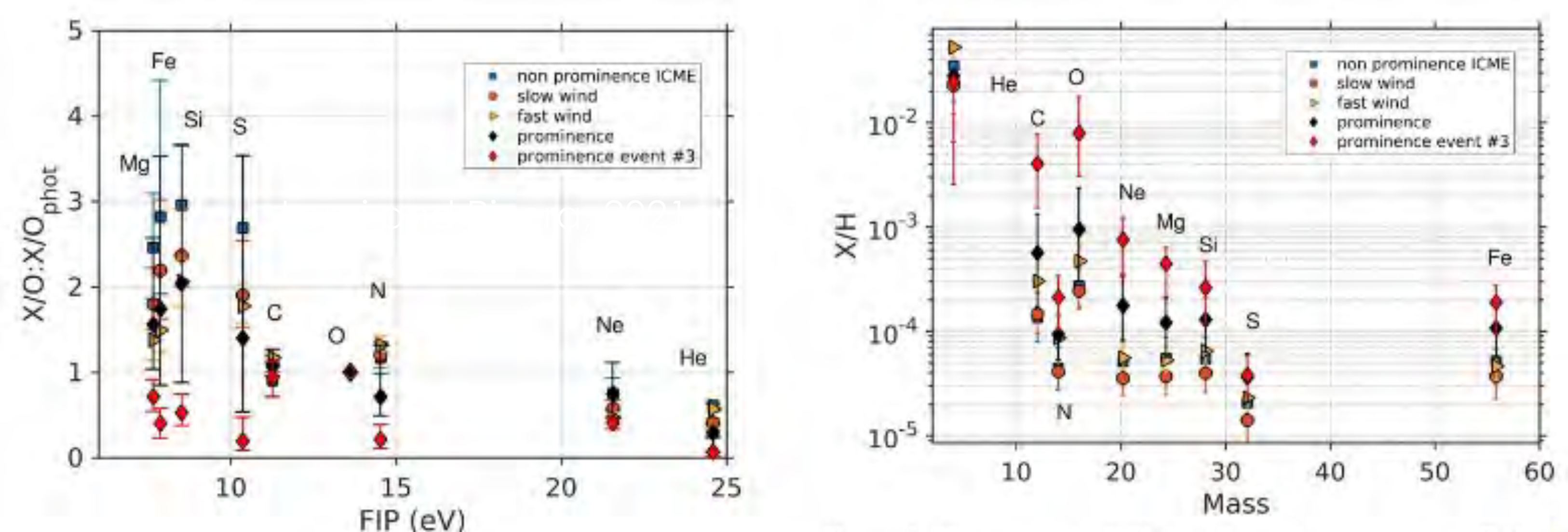
Raymond et al. 1998

IN SITU OBSERVATIONS OF FRACTIONATION

- Slow solar wind tends to be enhanced in low FIP elements, but exhibits a large spread in Fe/O values.
- Fast solar wind from coronal holes reflects values closer to photospheric abundances
- Hot ICMEs tend to have the highest FIP bias
- Cold Prominence material tends to appear more photospheric
- Gravitational settled material is observed in some slow wind, select ICMEs, and some prominence material.
- The FIP bias tends to be preserved in the slow wind over the solar cycle.







CHECK YOUR UNDERSTANDING

- Charge states and elemental abundances of the solar wind can be alterned by propagation effects like stream interactions and shocks?

a) T

b) F

CHECK YOUR UNDERSTANDING

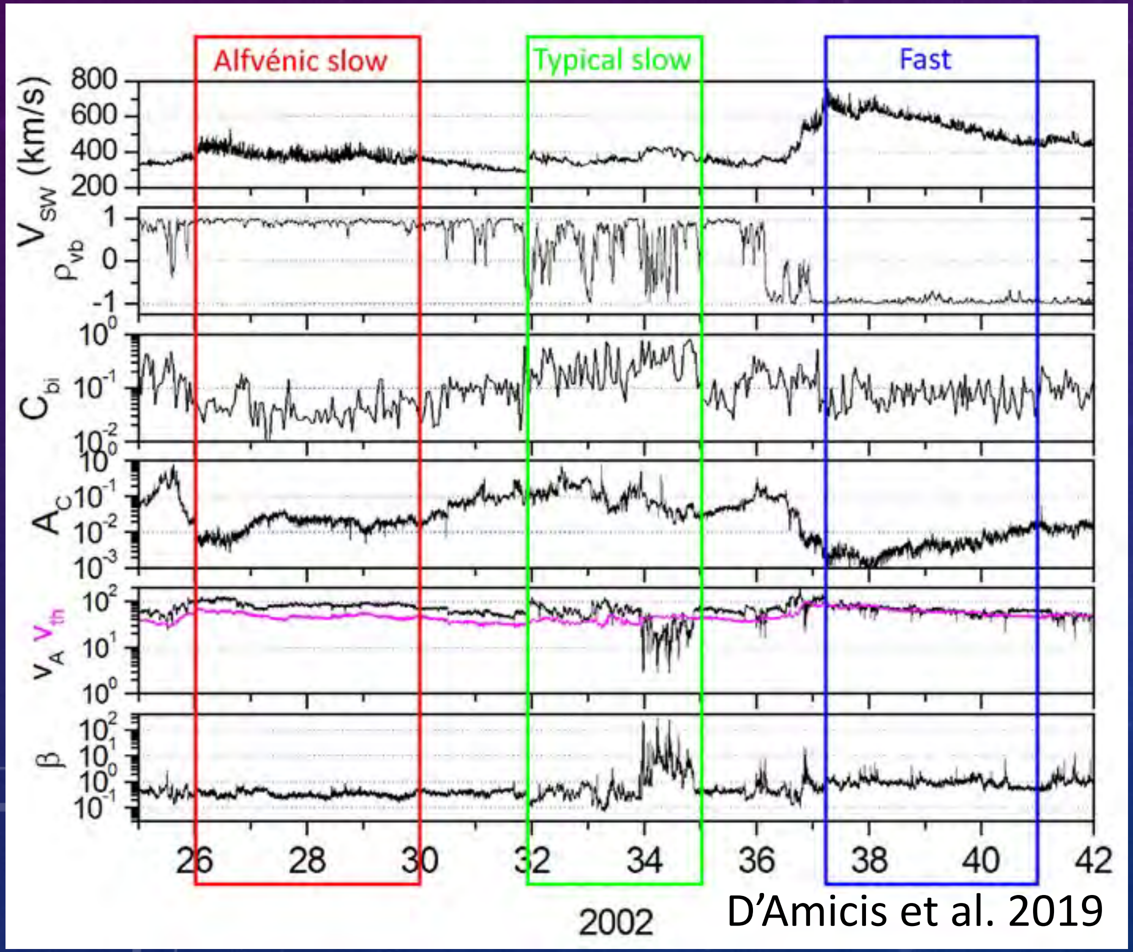
- Charge states and elemental abundances of the solar wind can be altered by propagation effects like stream interactions and shocks?

a) T

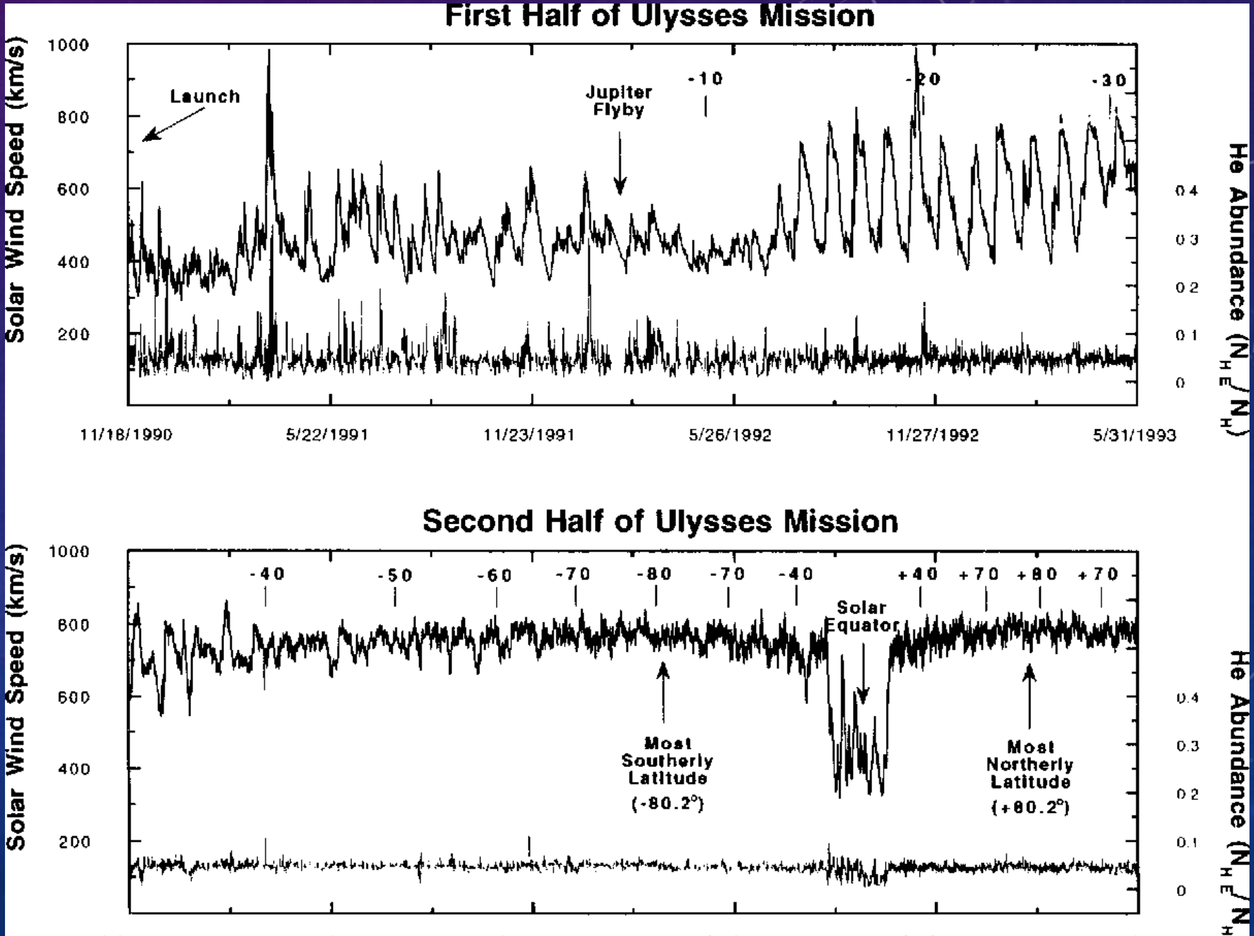
b) F

KINETIC PROPERTIES OF THE SOLAR WIND

- As plasma flows away from the Sun, it expands and cools, yet can be observed to vary a lot in the heliosphere.

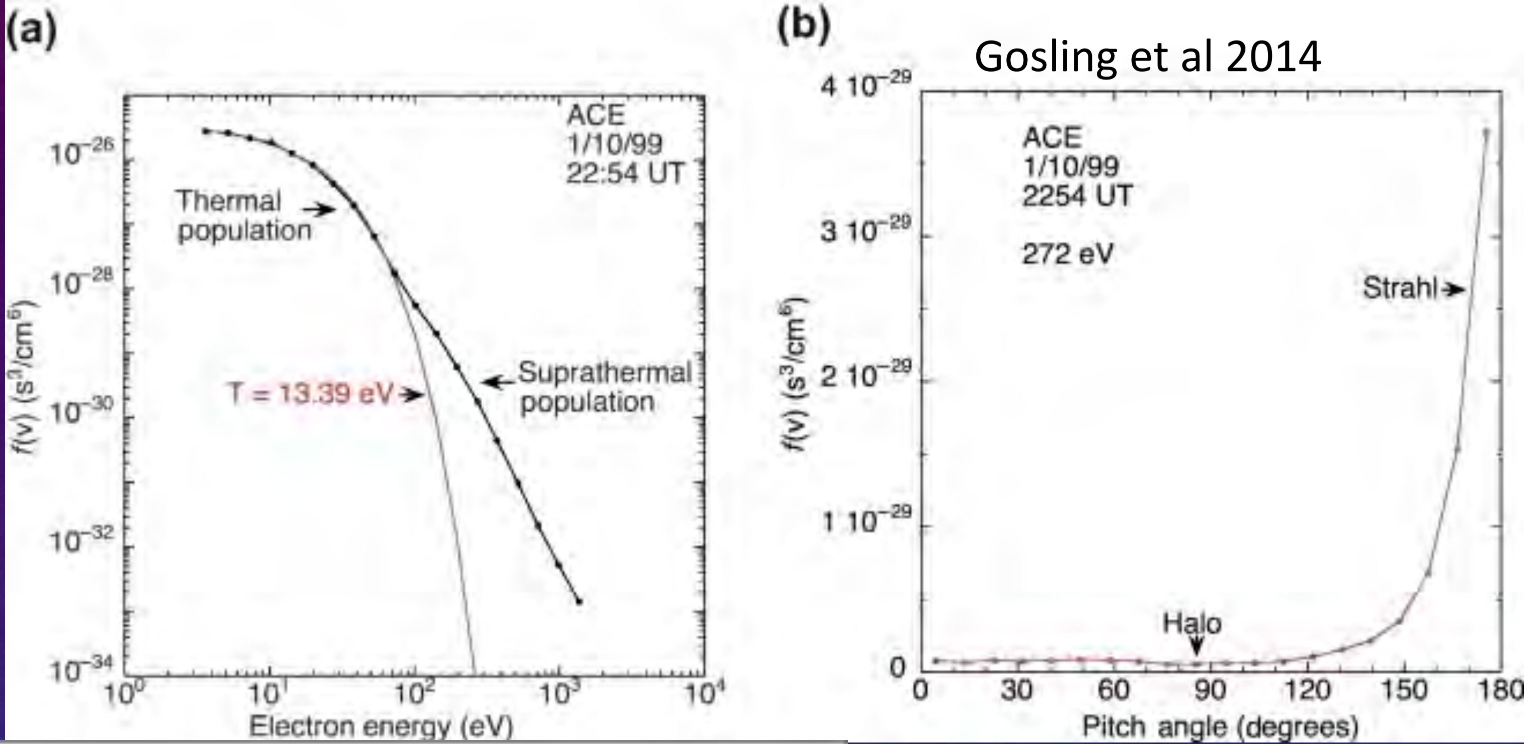


D'Amicis et al. 2019

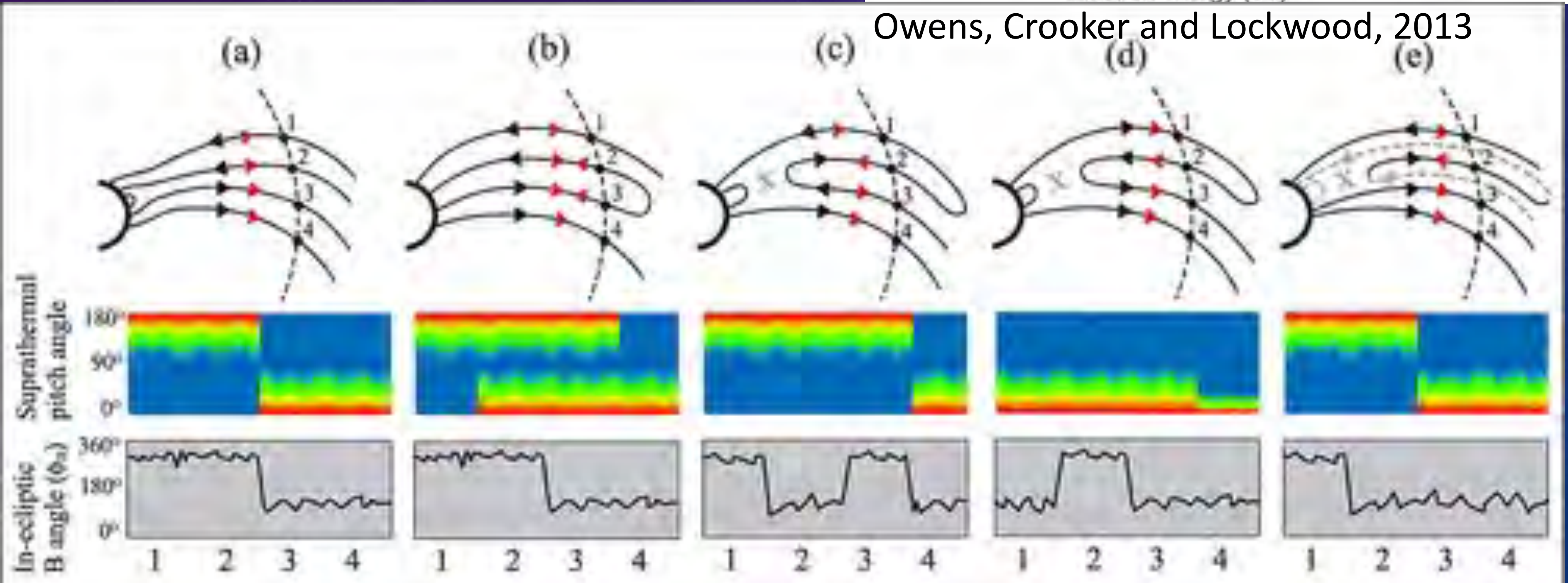


MAGNETIC TOPOLOGY OF THE SOLAR WIND

- Suprathermal electron measurements can help reveal magnetic connectivity and topology of the solar wind.

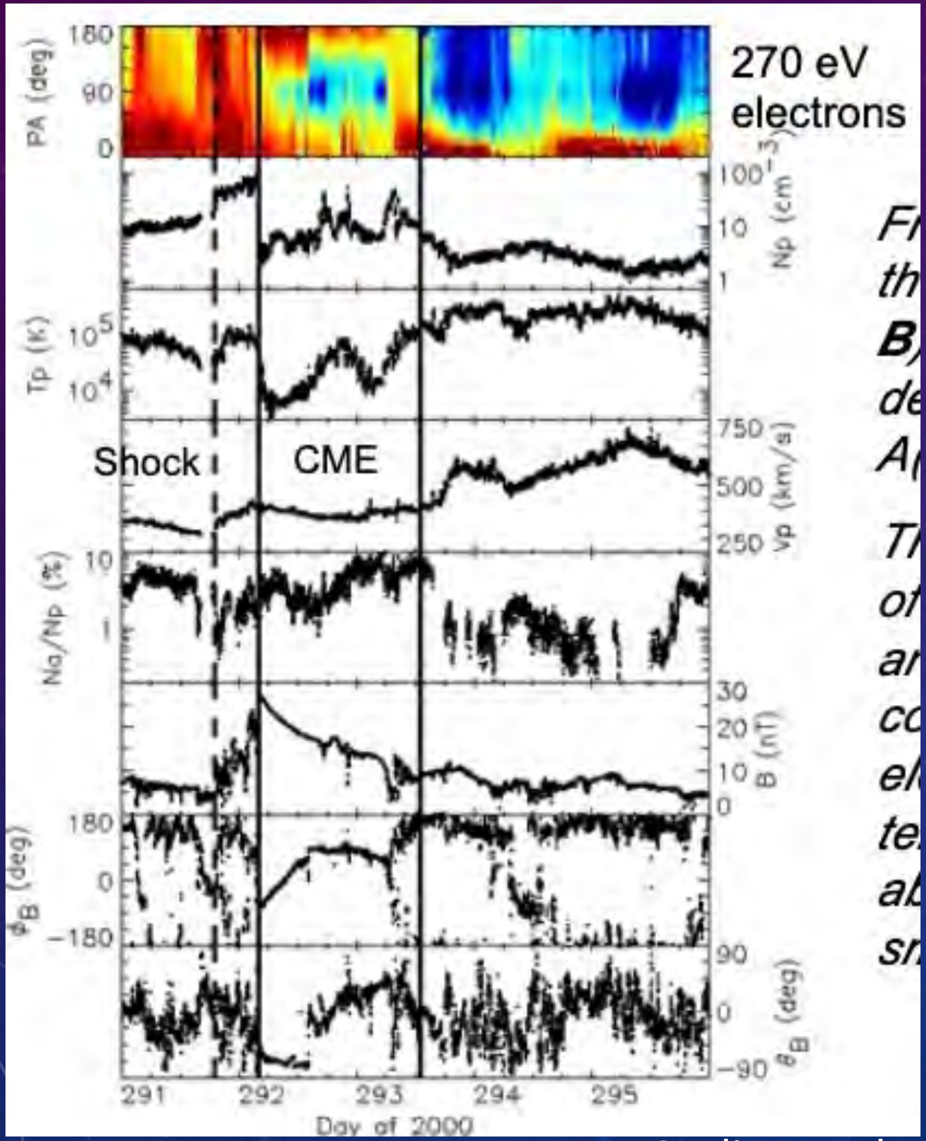


Gosling et al 2014

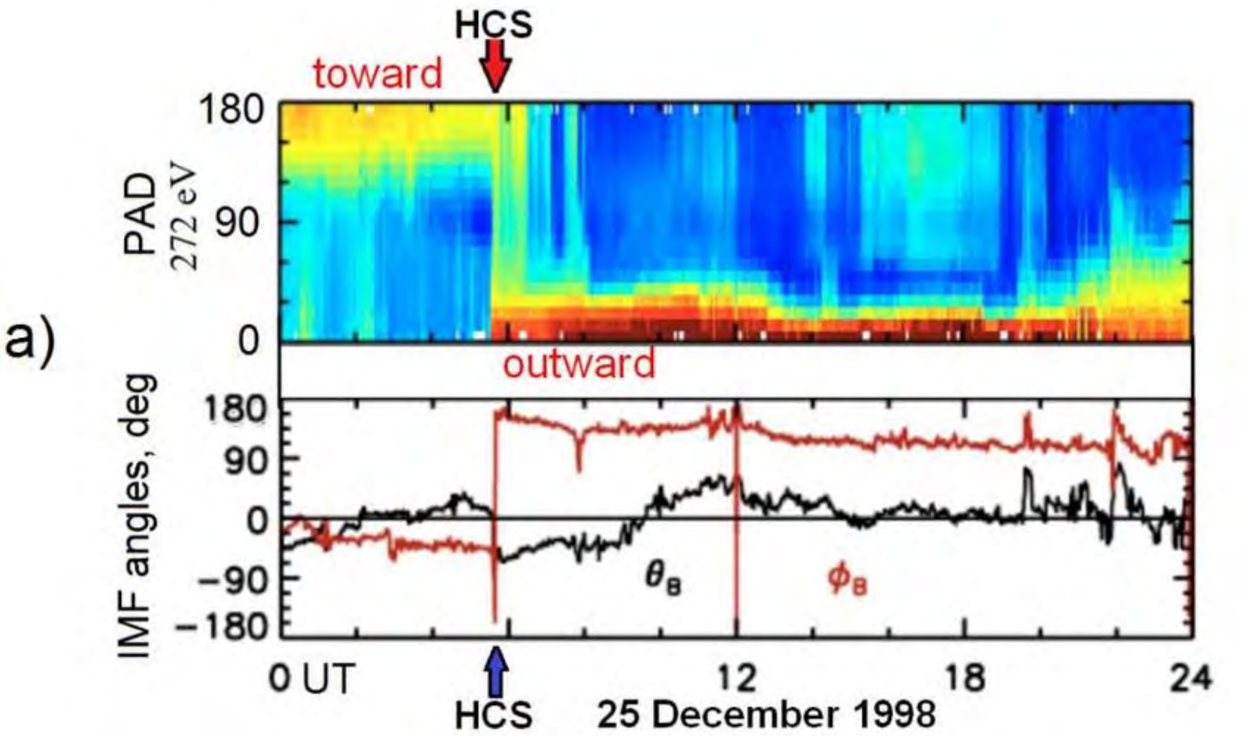


Owens, Crooker and Lockwood, 2013

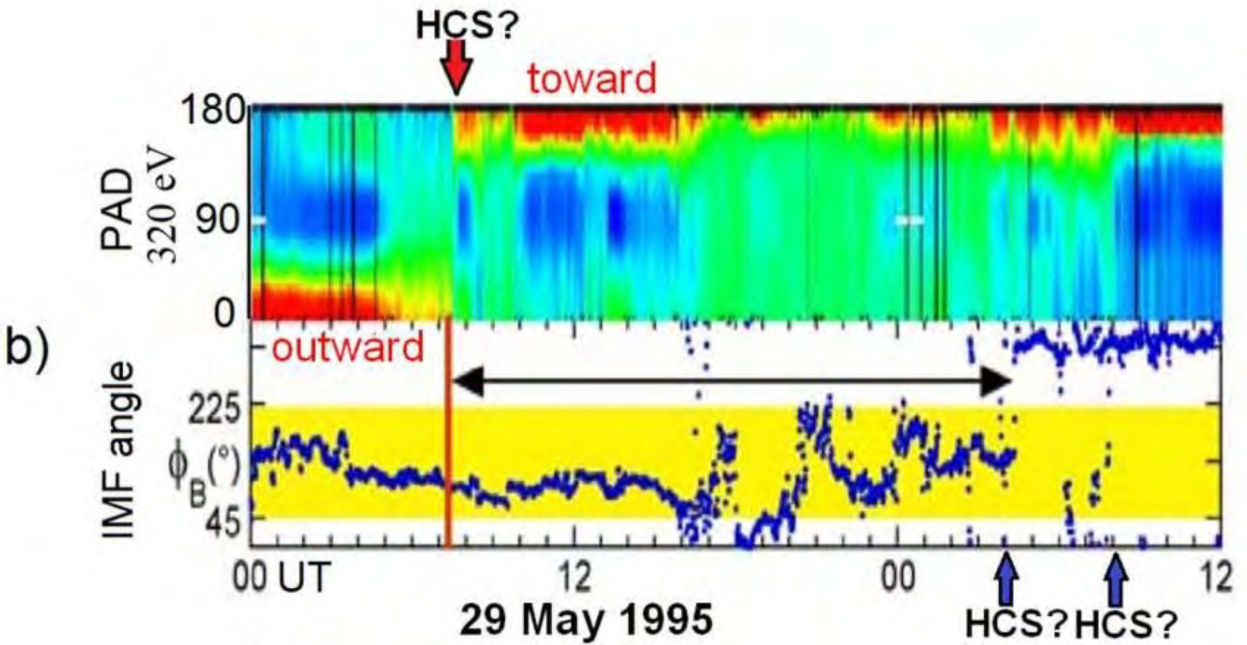
MAGNETIC TOPOLOGY



Gosling et al.



Khabarova O. Malandraki H. V. Malova V. D. Kuznetsov



CHECK YOUR UNDERSTANDING

- Which type of wind is NOT enhanced in elements with low First Ionization Potential (FIP)
  - a) Slow solar wind
  - b) Fast solar wind
  - c) ICMEs

CHECK YOUR UNDERSTANDING

- Which type of wind is NOT enhanced in elements with low First Ionization Potential (FIP)
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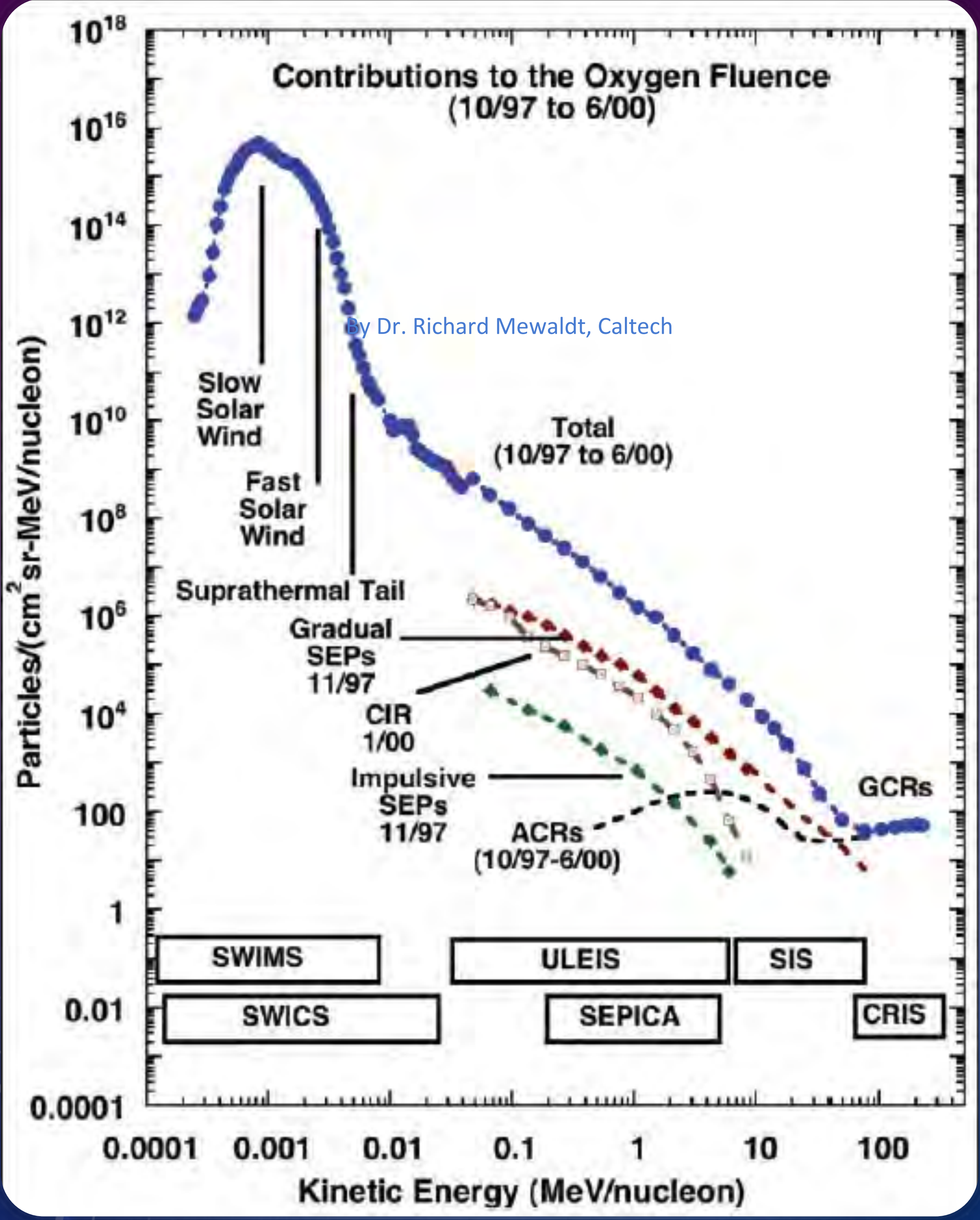
SOLAR WIND DATA

- What kind of data?
  - Data recorded in situ
  - Could be sample collection
  - Could be in-situ collection
  - Could be remote sensing
- What parameters
  - Density
  - Temperature
  - Velocity
  - Magnetic connectivity
  - Magnetic field strength
  - Magnetic field direction
  - Composition

TYPES OF ANALYSES

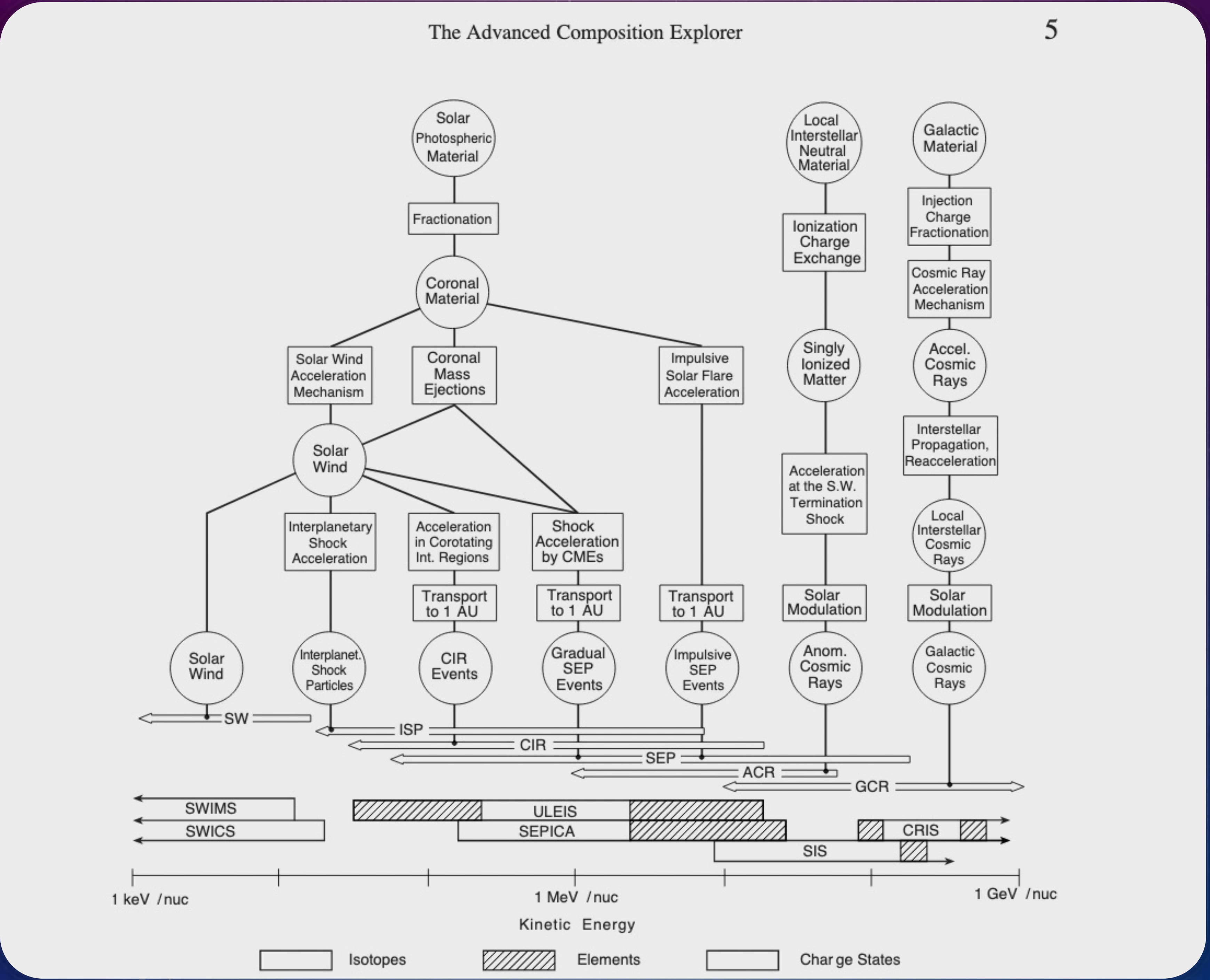
- Time series
- Statistical
- Correlation
- Event studies
- Superposed epoch analysis

ADVANCED COMPOSITION EXPLORER



By Dr. Richard Mewaldt, Caltech

SCIENCE OF ACE



The Advanced Composition Explorer 5

SOLAR WIND SIGNATURES

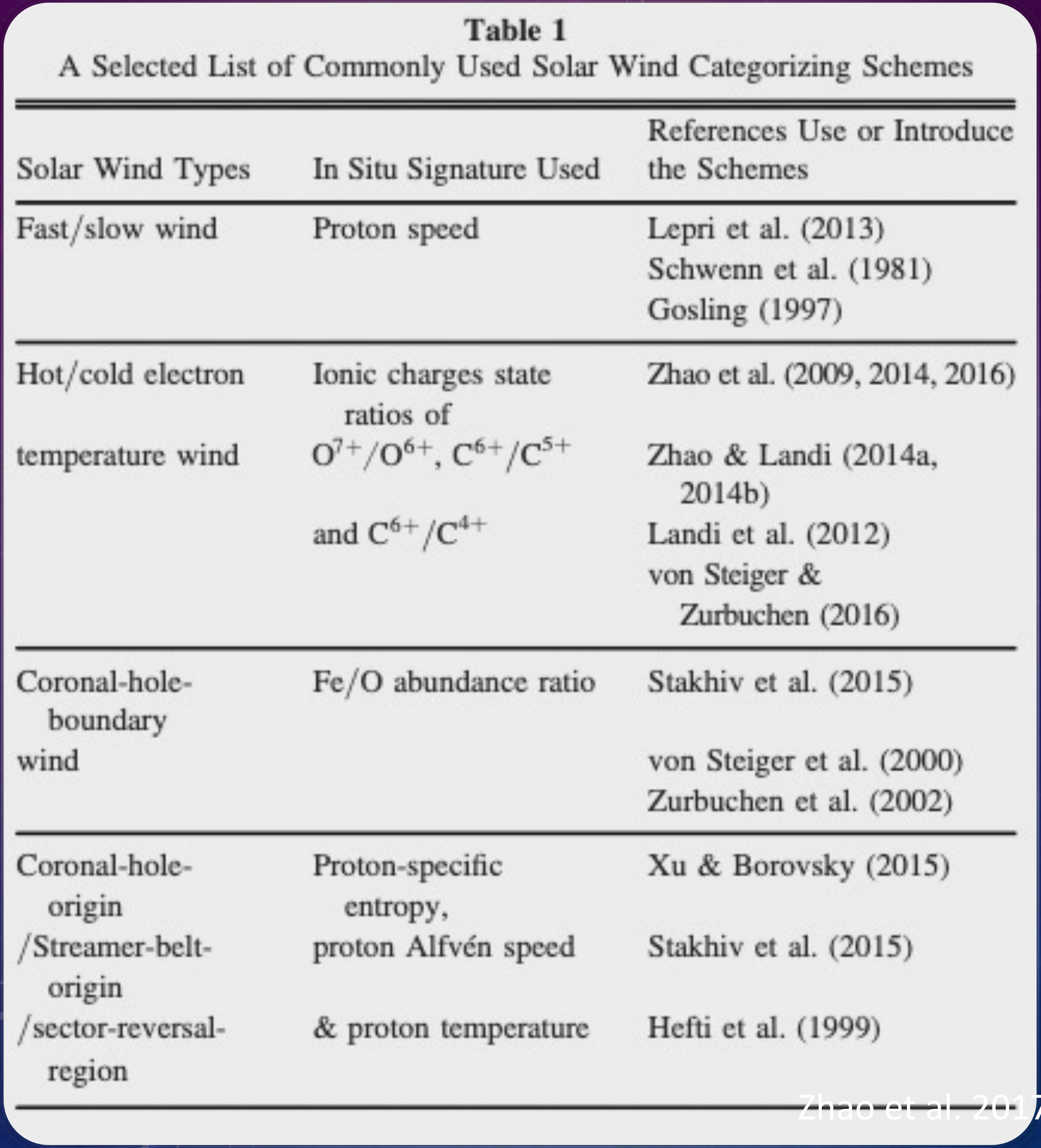


Table 1

A Selected List of Commonly Used Solar Wind Categorizing Schemes

Solar Wind Types	In Situ Signature Used	References Use or Introduce the Schemes
Fast/slow wind	Proton speed	Lepri et al. (2013) Schwenn et al. (1981) Gosling (1997)
Hot/cold electron temperature wind	Ionic charges state ratios of O^{7+}/O^{6+}, C^{6+}/C^{5+} and C^{6+}/C^{4+}	Zhao et al. (2009, 2014, 2016) Zhao & Landi (2014a, 2014b) Landi et al. (2012) von Steiger & Zurbuchen (2016)
Coronal-hole-boundary wind	Fe/O abundance ratio	Stakhiv et al. (2015) von Steiger et al. (2000) Zurbuchen et al. (2002)
Coronal-hole-origin /Streamer-belt-origin /sector-reversal-region	Proton-specific entropy, proton Alfvén speed & proton temperature	Xu & Borovsky (2015) Stakhiv et al. (2015) Hefti et al. (1999)

Zhao et al. 2017

THINK-PAIR-SHARE

- Go into your groups and discuss what parameters you would like to observe or collect for the following question (5 minutes in breakout room)
- Imagine you wanted to study the following phenomena, what solar wind data would you want to collect, and why?
  a) Interplanetary Coronal Mass Ejections
  b) Stream Interaction Regions
  c) Heliospheric current sheet
  d) Fast solar wind
  e) Interplanetary Shock
  f) Other?
- Share what your group talked about!

THINK-PAIR-SHARE

- Back to the breakout rooms:
  - Go into your groups make plots of an event or phenomena that you just selected.
  - Create a google slide with screenshots of your plots
- Return from the breakout room to discuss what you observed.

- Links:
  - https://izw1.caltech.edu/ACE/ASC/level2/lvl2DATA_MULTI.html
  - https://izw1.caltech.edu/ACE/ASC/level2/index.html
  - https://izw1.caltech.edu/ACE/ASC/DATA/level3/swepam/index.html
  - https://cdaweb.gsfc.nasa.gov/
  - http://ufa.esac.esa.int/ufa/#plots

EXTRA SPACE