#### Solar Wind : Understanding Sun's Breath

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#### Outlines

#### Introduction

- Sun (Composition and Structure)
- Solar Wind
- Solar wind (Origin and Features)
- Distance and temperature scale
- Historical Milestones in Solar corona
- Magnetic Reconnection
- Interaction with solar system
- Solar wind consequences Aurora Borealis Artificial orbits damage Power grid damage

# Introduction

## Layers of the Sun



## Solar Corona

- Definition: the outermost layer of hot plasma that surrounds the sun.
- Composition: electrons,
   protons, Helium, heavy
   elements.
- Temperature:  $1-3 \times 10^6$  K.



## **Solar wind**



- What is the Solar Wind?
- Continuous flow of  $\bullet$ some coronal plasma (charged particles) expands into interplanetary space. Composed of electrons, protons, and alpha particles. Key characteristics at • 1 Au: velocity (300-800 km/s) and density (1 - 10)narticles/cm<sup>3</sup>)



#### **Temperature Profile**



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- 1869: Young discovered a 530 nm emission line from corona emissions → 'Coronium" element
- 1943: Elden used QMT→emission line due to unusual high ionized iron (1 × 10<sup>6</sup> K)
- Spectroscopy revealed that the corona is so hot.



## Evidences for Solar Wind #1

- Late 1800s → early 1900s: evidence kept accumulating for *something* out there that connects the Sun and the Earth together.
- I'll summarize 3 pieces of circumstantial evidence that Parker (1958) had in-hand...
- First, after the "Carrington event" (Sept. 1, 1859), there was increased awareness that there's some kind of cause-and-effect between events on the Sun & events on Earth.





#### A. STORM, OF ELECTRICITY

TELEGRAPH WIRES USELESS FOR SEVERAL HOURS.

ONE OF THE MOST SEVERE DISTURBANCES FOR MANY YEARS, EXTENDING EVEN TO EUROPE-TELEPHONE WIRES ALSO OB-STRUCTED-BUSINESS DELAYED & GOOD PART OF THE DAY.

## Evidences for Solar Wind #2

- Second piece of evidence: many comets have dust tails (whose ejecta fall back along ballistic orbits) and ion tails (always oriented away from the Sun).
- Biermann (1951) also analyzed the kinematics of ion-tail inhomogeneities, which can be tracked to flow away from the Sun at speeds of a few × 100 km/s.

#### Kometenschweife und solare Korpuskularstrahlung

(Comet tails and solar corpuscular radiation)





## Evidences for Solar Wind #3

- Third piece of evidence: the existence of the hot (10<sup>6</sup> K) corona was well known, but if the corona was assumed to exist in a state of hydrostatic equilibrium, it gives a nonsensical answer for the gas pressure.
- For Chapman's (1957) heat conduction model,

$$T(r) = T_0 \left(\frac{r_0}{r}\right)^{2/7} \quad \text{and as } r \to \infty, \quad P \to P_0 \exp\left[-\left(\frac{V_{\text{esc},0}}{c_{s,0}}\right)^2\right] \approx 10^{-5} \text{ dynes/cm}^2$$

- However, by the 1950s, astronomers already knew typical gas pressures in the local interstellar medium were only 10<sup>-14</sup> to 10<sup>-12</sup> dynes/cm<sup>2</sup>.
- If such a huge pressure difference were to exist, the pressure-gradient force would cause the corona to expand (explosively?) out to huge distances (parsecs?) before coming into equilibrium with the interstellar medium.
- If a new hydrostatic equilibrium was established, the near-Sun corona wouldn't look anything like it does now...
  - Something about this doesn't make sense.

## Existence for Solar Wind #1

 Parker (1958) showed that if the corona is hot it must expand.



## Existence for Solar Wind #2

Parker (1958) showed that if the corona is hot it must expand.

After 4 years of controversy, Neugebauer et al. (1962) used in-situ space probe data to confirm the



 It's observable with a coronagraph (i.e., telescope with an occulter to generate "artificial eclipses") –



# Large-scale coronal structure Sunsposts (dark in visible)





# Large-scale coronal structure Active regions (brightest in UV&X-ray)



#### Large-scale coronal structure

Active regions (brightest in UV & X-ray) tend to coincide with sunspots (dark in visible):



Some isolated **coronal loops** aren't associated with active regions...



When active regions get ready to flare, the underlying B-field twist is observable as "sigmoid" X-ray loops:









#### Large-scale coronal structure

Coronal holes have low density (dark in UV/X-ray) & coincide with solar wind footpoints



Fuzzy regions with intermediate intensity are often called Quiet Sun



Some "pseudostreamers" are associated with more complex polarities & dark prominence cavities...



## **Open vs closed magnetic field**

B large enough to restrict plasma motion: only along field lines



Different coronae from different magnetic topology: open vs. closed

outflow



heat in

## **Magnetic Reconnection**



# Interaction with solar system

#### Solar wind interaction with Earth



#### Solar wind interaction with Earth



#### SW interaction with Venus



#### SW interaction with



### Interaction between SW and ionospheres

Wave (soliton, IAWs, rogue,...)

Ionic escape

#### **Interaction between SW and ionospheres**

# lonic escape





### **Wake potential**

#### • Test charge particles





# Northern lights (Aurora borealis)



# Northern lights (Aurora borealis)



## Solar wind vs. satellite



## Solar wind vs. Power grid





