

Sailing the Seas of the Solar Wind

Kevin Urban



Part I: The importance of experimentation and observation

- * No doubt theory and mathematics are powerful, insightful tools

- * Unconstrained, however, math-driven physics has often gotten us into trouble

- a few too many approximations and the mathematics is too beautiful to resist, too simple to be true

- * The irreplaceable role of observations, in-situ measurements, and experimentation is to motivate the math and to constrain it.



Possible Solar-Terrestrial Connection?

A STORM OF ELECTRICITY

*TELEGRAPH WIRES USELESS FOR
SEVERAL HOURS.*

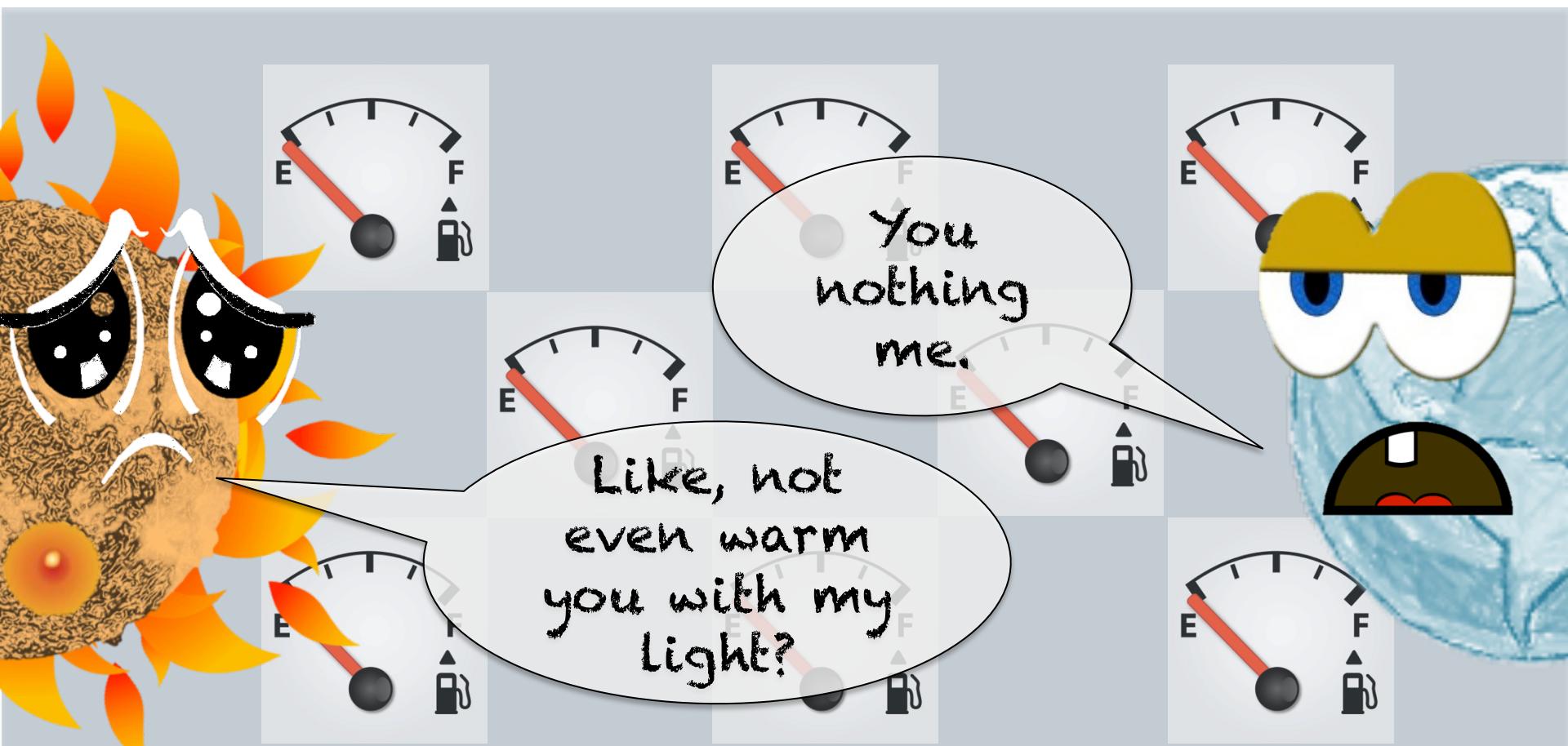
ONE OF THE MOST SEVERE DISTURBANCES
FOR MANY YEARS, EXTENDING EVEN TO
EUROPE—TELEPHONE WIRES ALSO OB-
STRUCTED—BUSINESS DELAYED A GOOD
PART OF THE DAY.

Yesterday's storm was accompanied by a
more serious electrical disturbance than has been
known for years. It very seriously affected the
workings of the telegraph lines both on the land
and in the sea, and for three hours—from 9 A. M.
until noon—telegraph business east of the Missis-
sippi and north of Washington was at a stand-still.

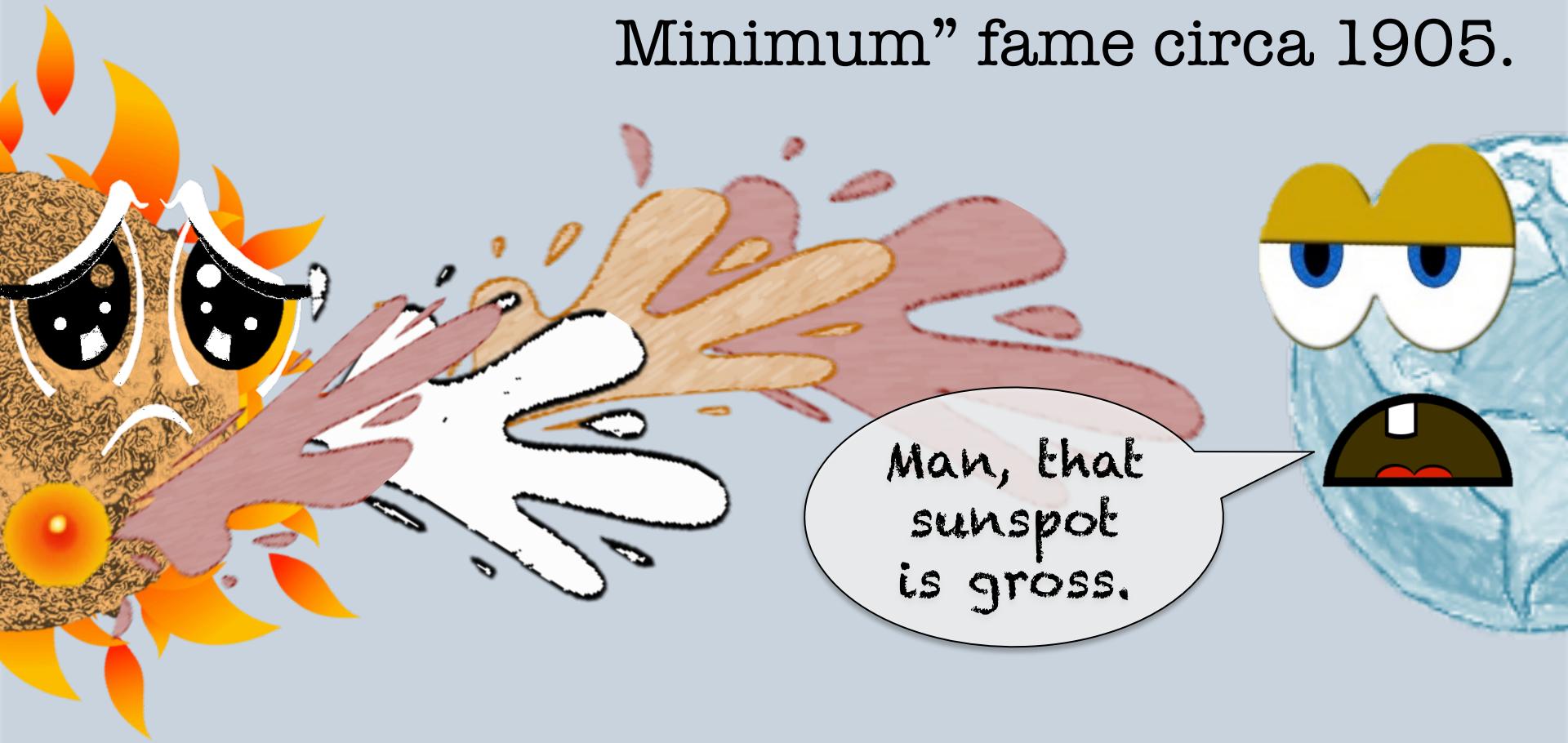
The Carrington Event, 1859

“It seems as if we may also be forced to conclude that the supposed connection between magnetic storms and sunspots is unreal, and that the seeming agreement between the periods has been mere coincidence.”

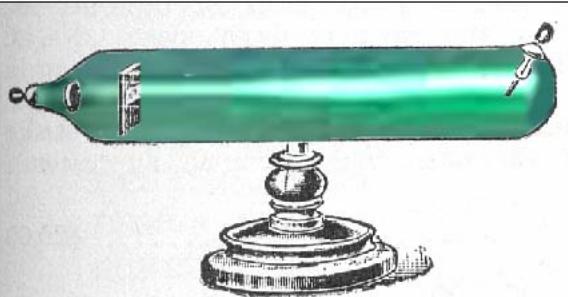
-- Lord Kelvin, 1892



“But, wait a sec...,” said Maunder of “Maunder Minimum” fame circa 1905.



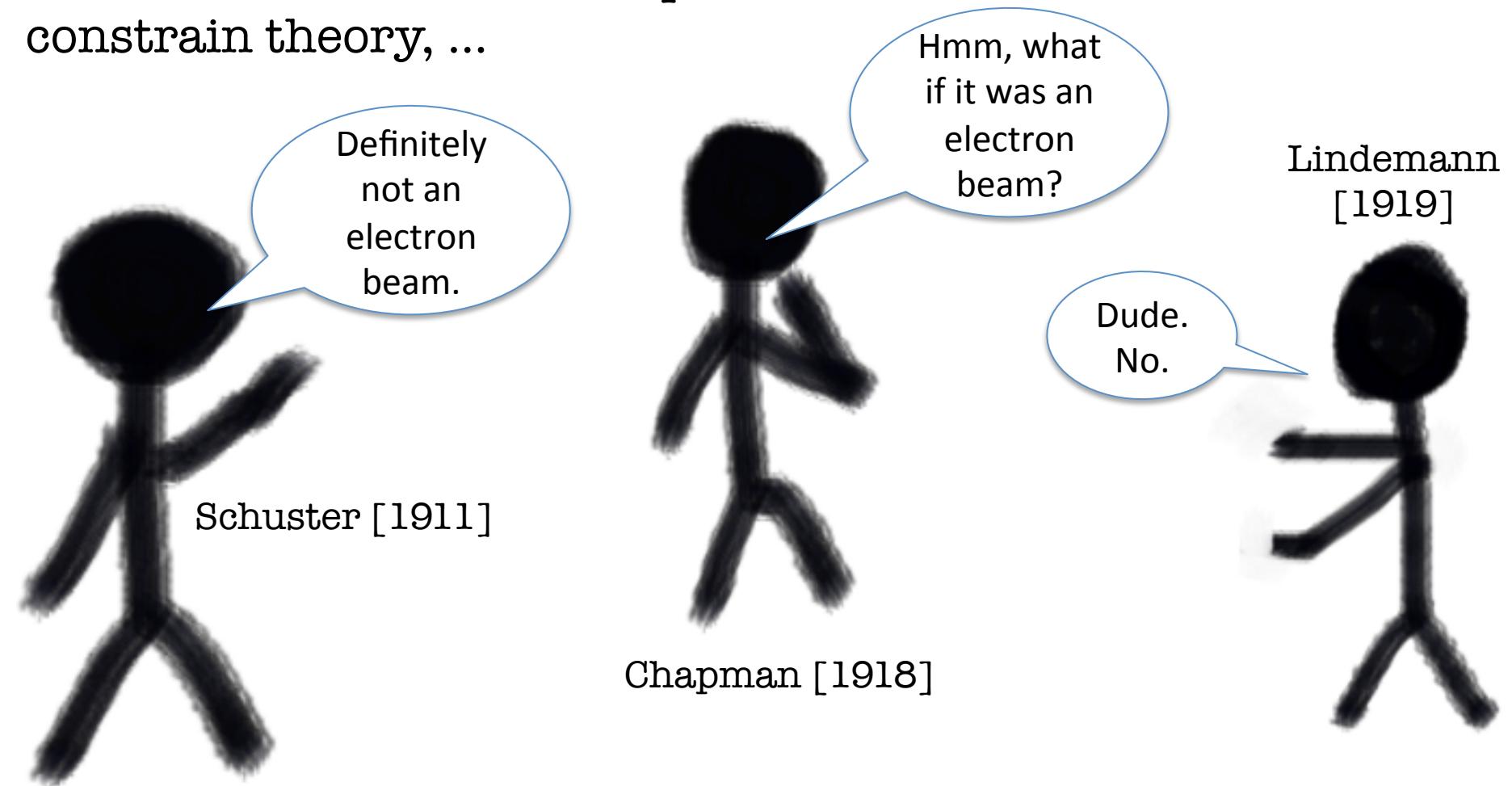
Cathode rays were pretty hot in the late 1800s, early 1900s.



“...the magnetic action being supposed to be due to a swarm of electrified corpuscles ejected by the Sun.” (Schuster [1911] on Maunder’s suggestion.)

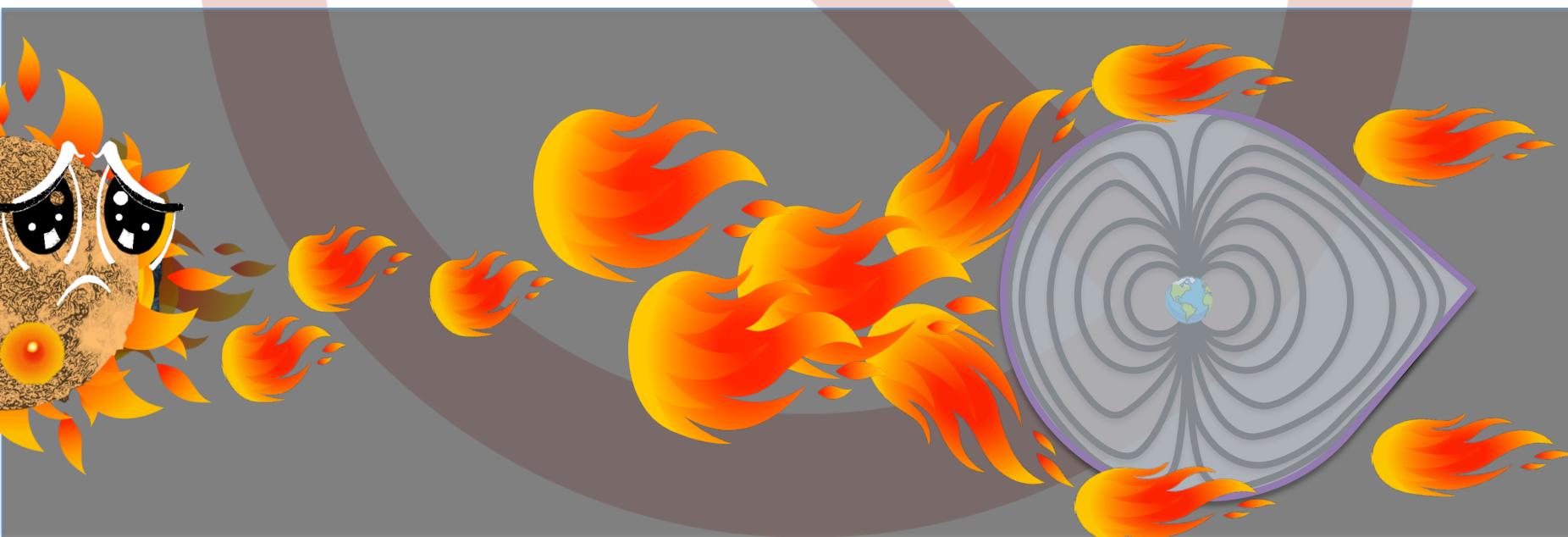
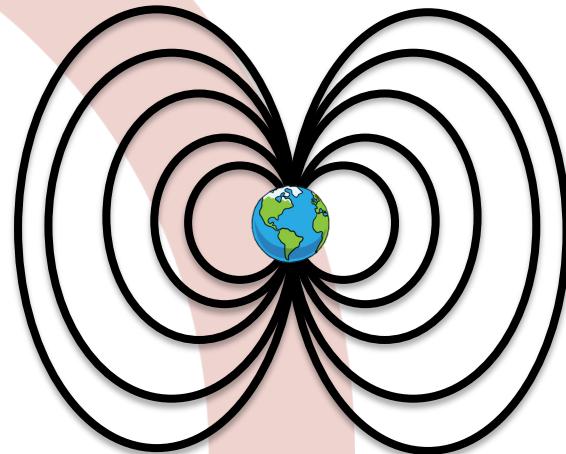
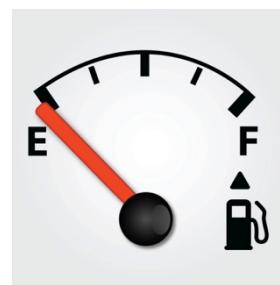
Mathematics to the rescue, ruin, and rescue!

Just as observation and experiment constrain theory, ...

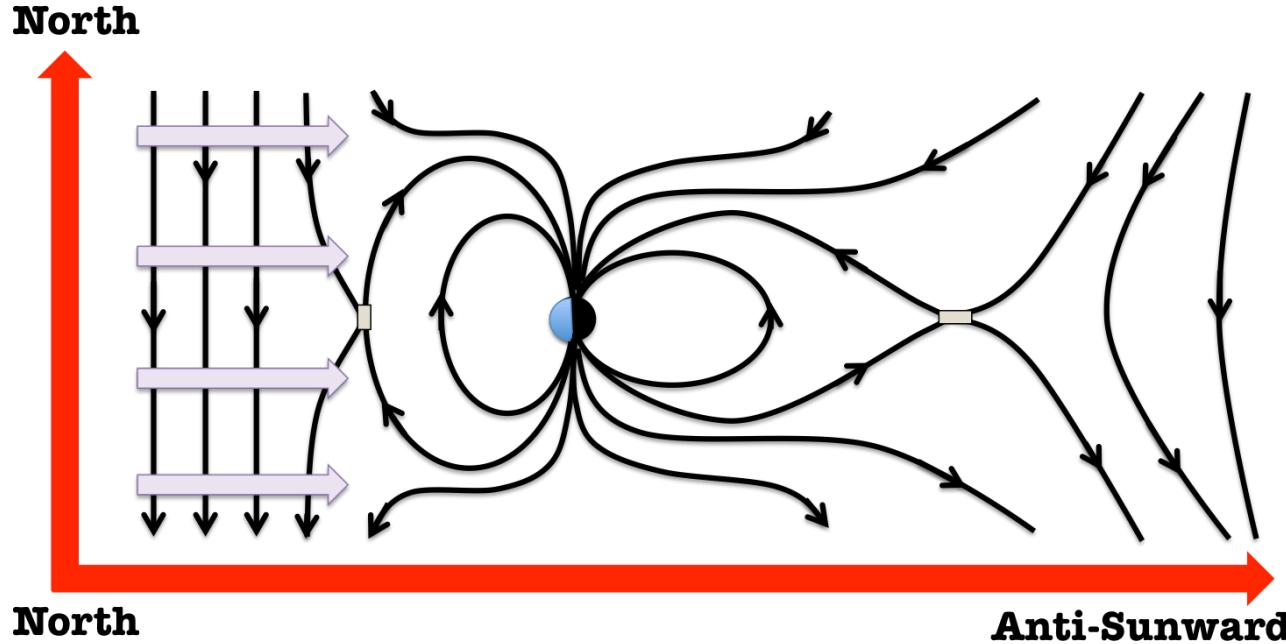


...a precise mathematical formulation of a physical problem from first principles rules out silly and misguided interpretations of observations.

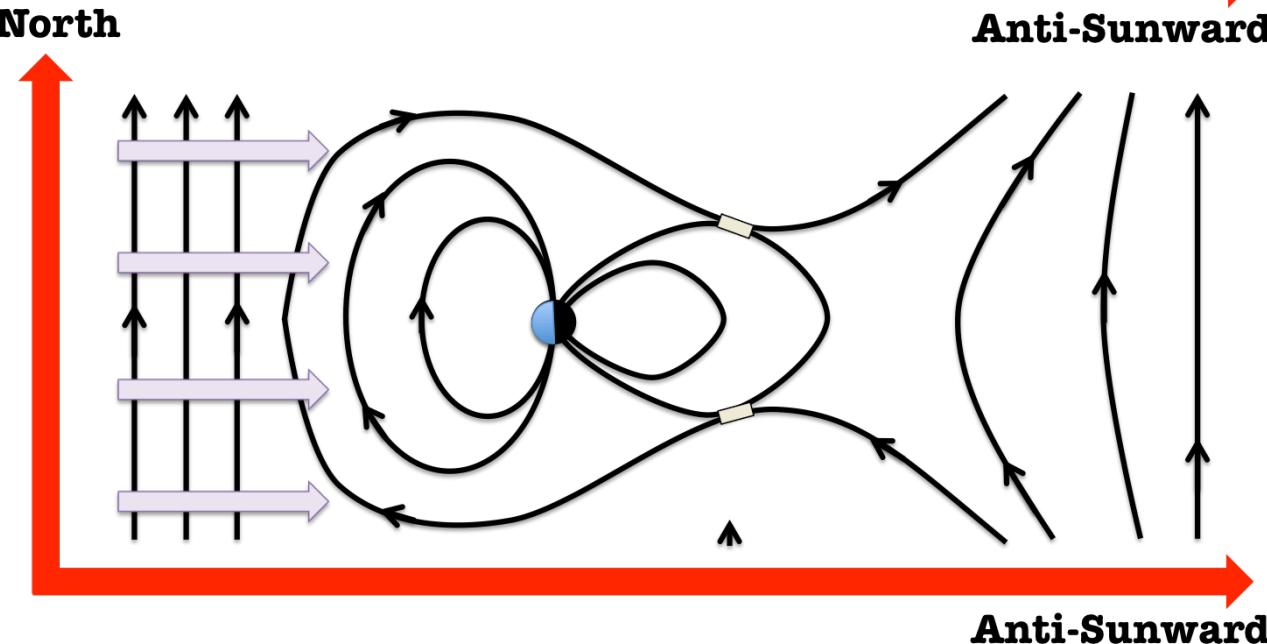
Chapman-Ferraro Theory



Dungey's Open Magnesphere



IT WORKS

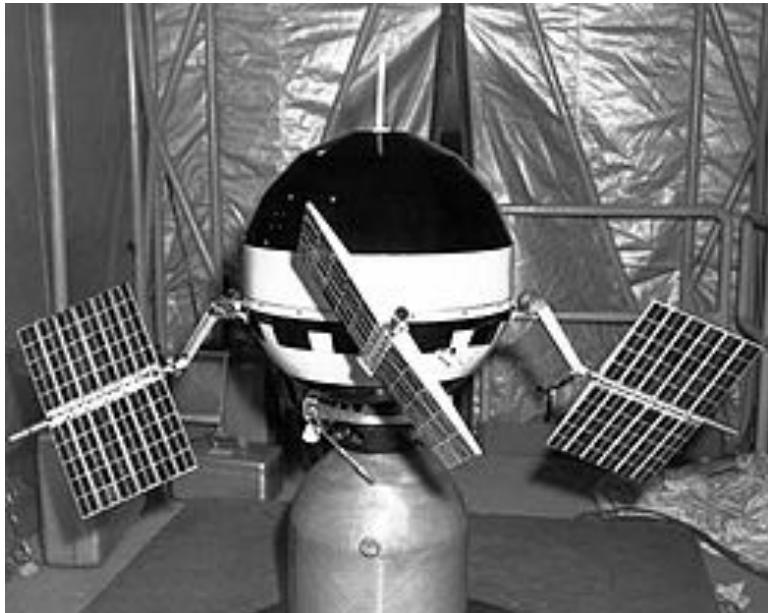


BUT...

NOT EXACTLY

Circa 1962

Pioneer V

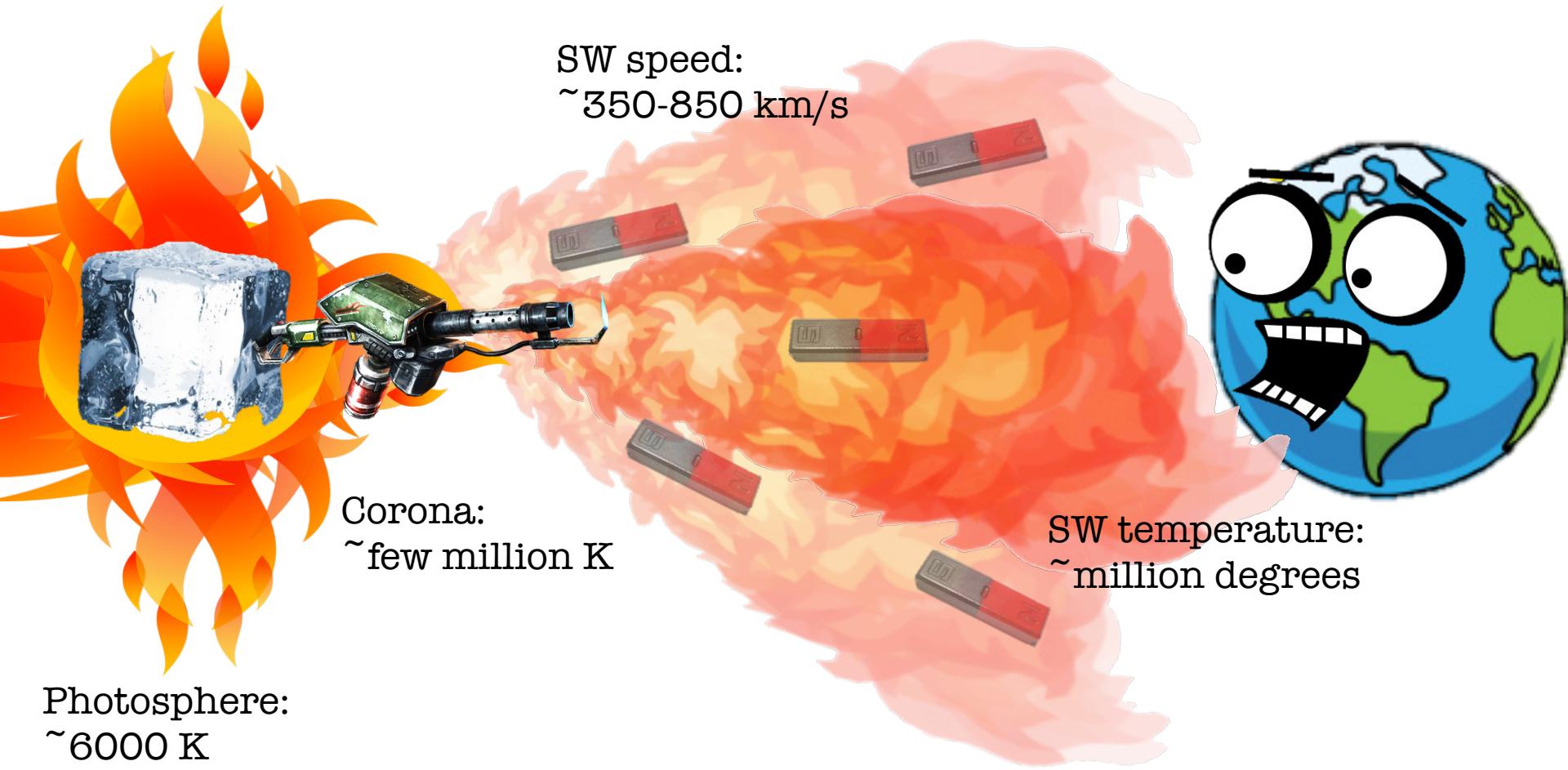


Mariner II



Measurements were made.

The Sun is like a fiery ice cube torching the solar system with a magnetized plasma flame thrower.



The solar wind has about 7000 particles per liter. Call it 10^4 and compare this to the air in an empty liter bottle of soda: $\sim 10^{22}$ particles.

How does a fiery ice cube shoot flames?

Parker's Solution



So nice, so inspiring...

So WRONG!

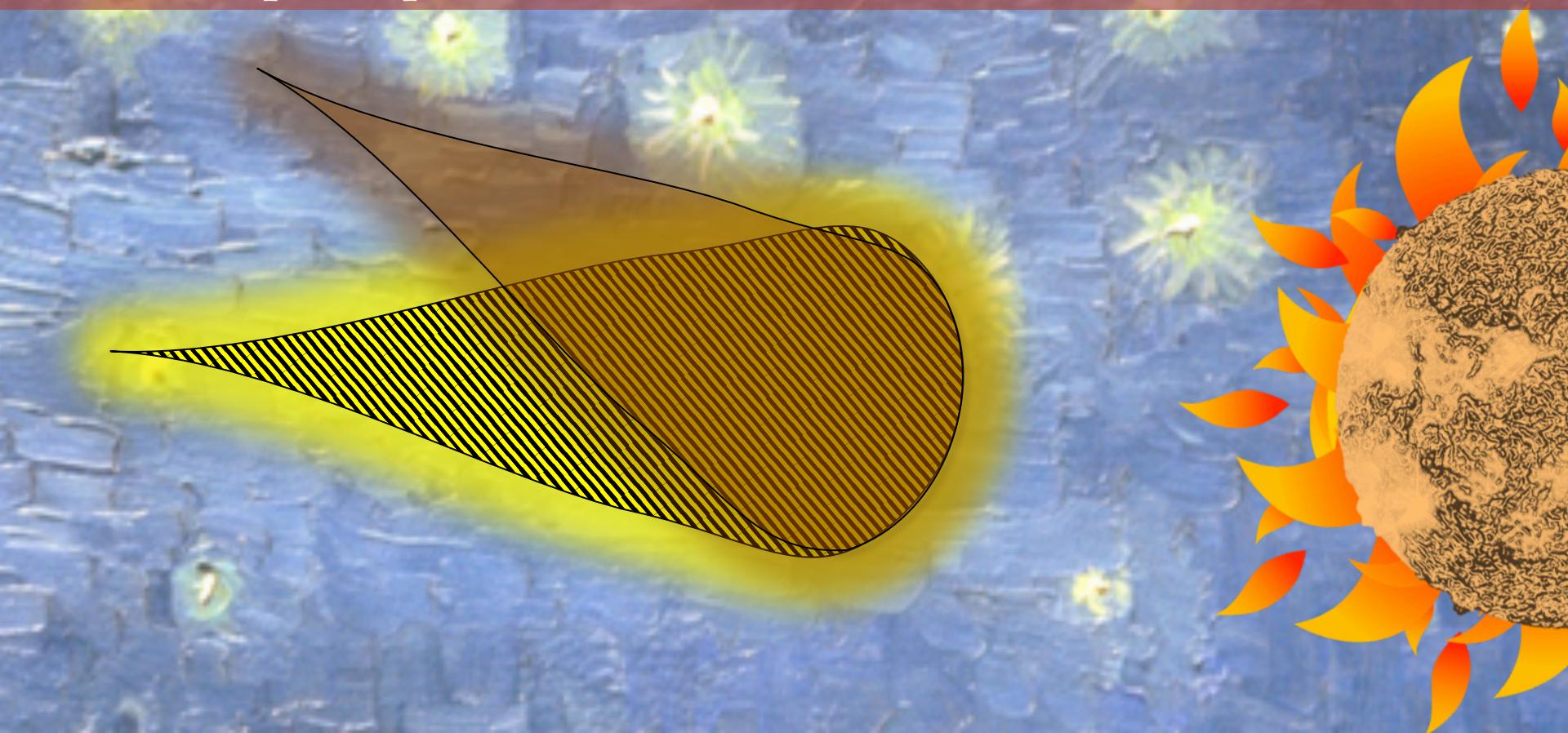
However, on the right track, so...



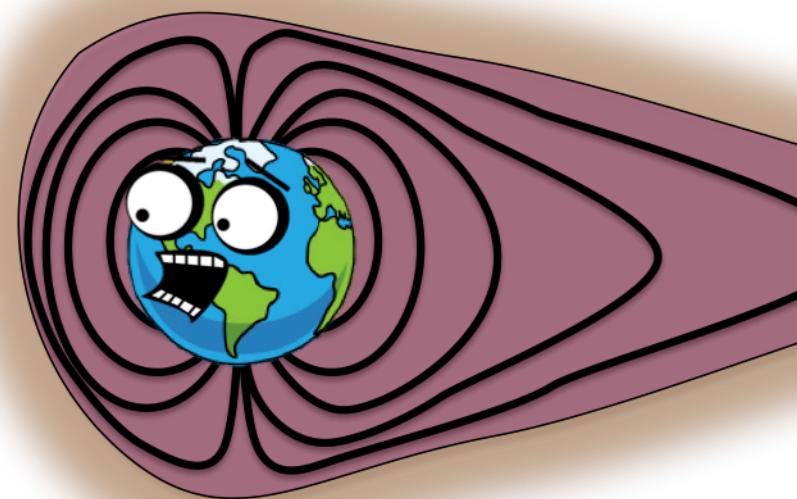
“Of all the theories of interplanetary space which were proposed before space measurements could be made, there is only one that has survived the encounter with observational facts.”

-- Hannes Alfvén, 1967

Bierman [1951]: Prediction of the Solar Korpuskularstrahlung



Theorists suggested that there should be a magnetotail well before it was observed.



Magnetotail

Part II: Solar Wind-Polar Cap Interactions

This is the part where
I ~~sell you~~ tell you
about my own
research.



“Electromagnetism is difficult, hydrodynamics is very difficult, but magnetohydrodynamics is damned difficult”

--1948 Nobel Laureate Lord Blackett

**Existence of
Electromagnetic-Hydrodynamic Waves**

If a conducting liquid is placed in a constant magnetic field, every motion of the liquid gives rise to an E.M.F. which produces electric currents. Owing to the magnetic field, these currents give mechanical forces which change the state of motion of the liquid. Thus a kind of combined electromagnetic-hydrodynamic wave is produced which, so far as I know, has as yet attracted no attention.

The phenomenon may be described by the electrodynamic equations

$$\text{rot } H = \frac{4\pi}{c} i$$

$$\text{rot } E = - \frac{1}{c} \frac{dB}{dt}$$

$$B = \mu H$$

$$i = \sigma(E + \frac{v}{c} \times B);$$

together with the hydrodynamic equation

$$\partial \frac{dv}{dt} = \frac{1}{\rho} (i \times B) - \text{grad } p,$$

where σ is the electric conductivity, μ the permeability, ρ the mass density of the liquid, i the electric current, v the velocity of the liquid, and p the pressure.

Consider the simple case when $\sigma = \infty$, $\mu = 1$ and the imposed constant magnetic field H_0 is homogeneous and parallel to the z -axis. In order to study a plane wave we assume that all variables depend upon the time t and z only. If the velocity v is parallel to the x -axis, the current i is parallel to the y -axis and produces variable magnetic field H' in the x -direction. By elementary calculation we obtain

$$\frac{d^2H'}{dz^2} = \frac{4\pi\delta}{H_0^2} \frac{d^2H'}{dt^2},$$

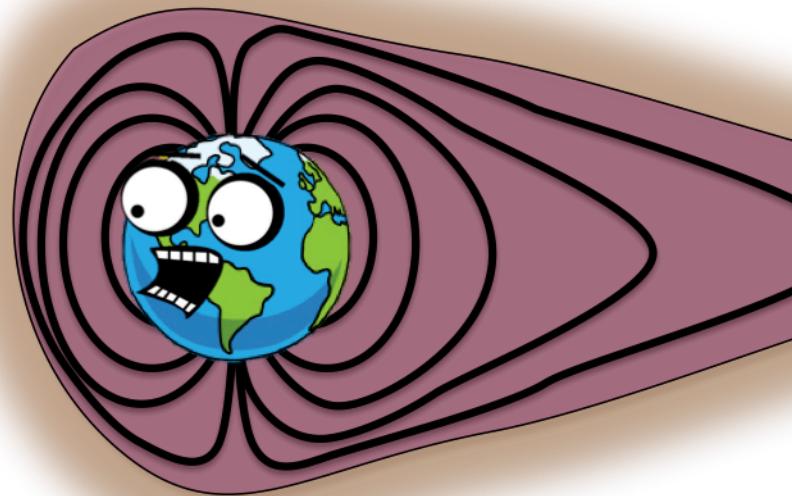
V ~ 60 cm. sec.⁻¹.

This is about the velocity with which the sunspot zone moves towards the equator during the sunspot cycle. The above values of H_0 and δ refer to a distance of about 10^{16} cm. below the solar surface where the original cause of the sunspots may be found. Thus it is possible that the sunspots are associated with a magnetic and mechanical disturbance proceeding as an electromagnetic-hydrodynamic wave.

The matter is further discussed in a paper which will appear in *Arkiv för matematik, astronomi och fysik*.
H. ALFVEN.

Eigl Tekniska Högskolan,
Stockholm.
Aug. 21.

Nature, vol 130, 400-406, 1942

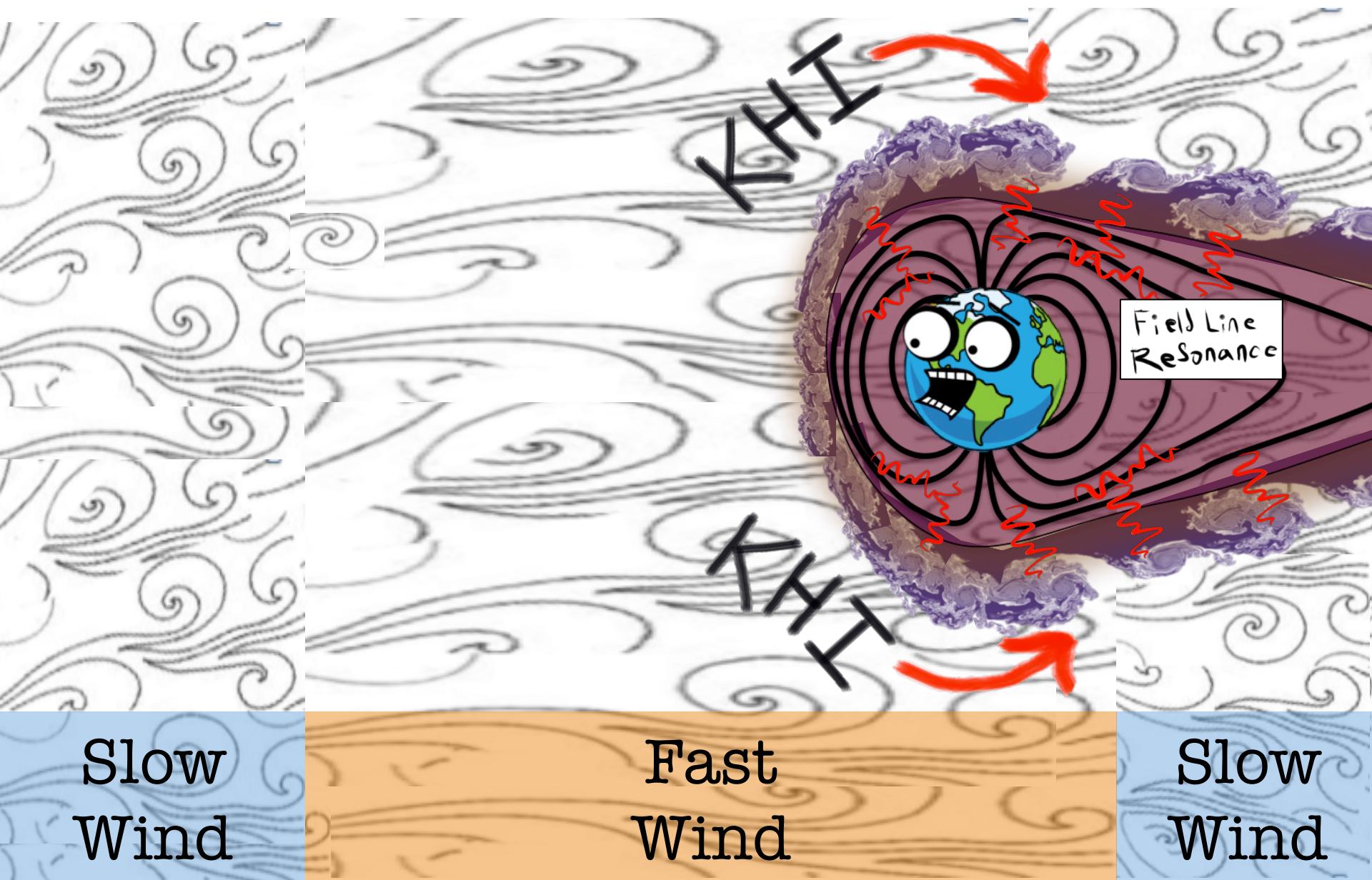


The magnetosphere is full of these things.

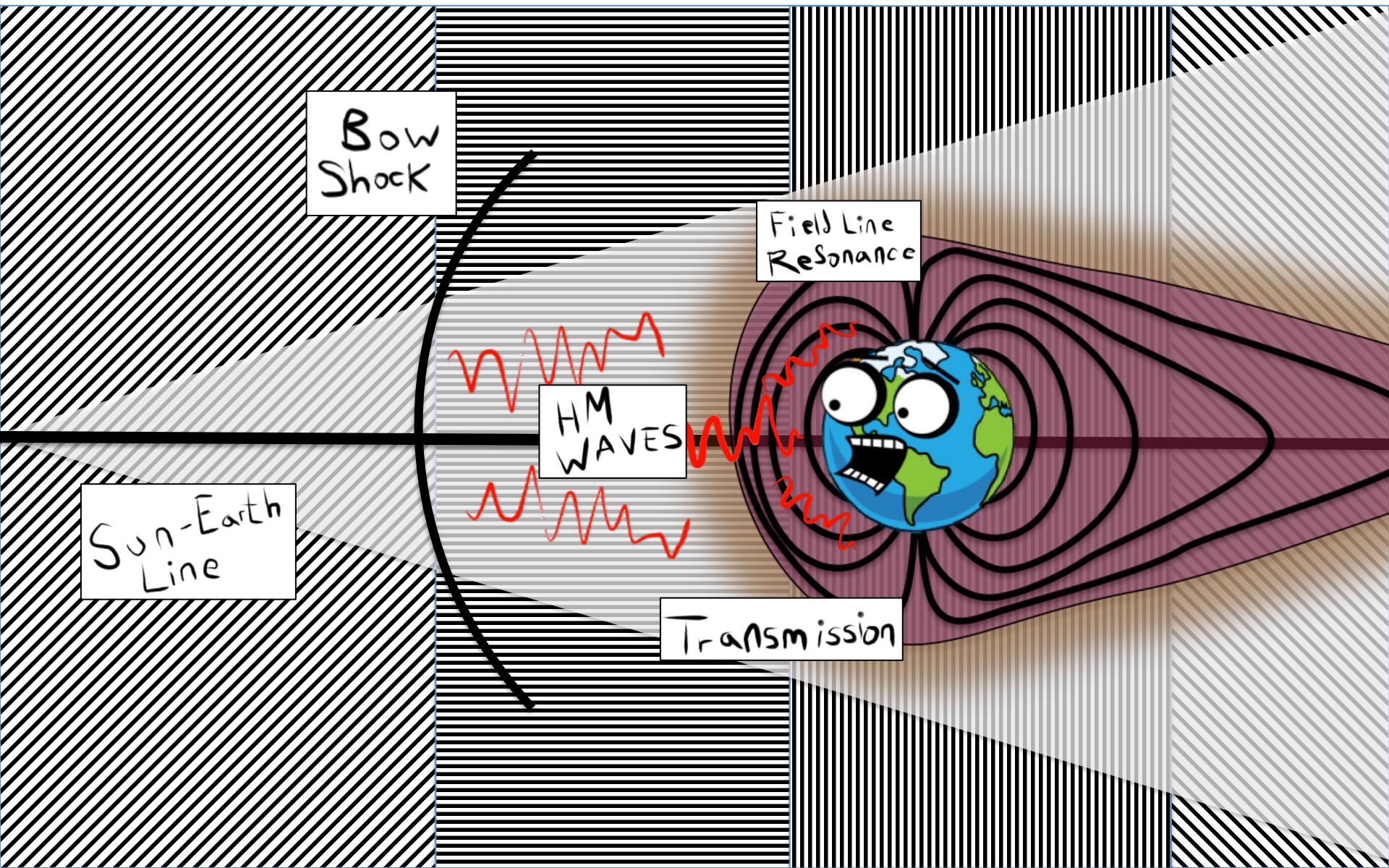
Cause?

Solar wind-driving.

Solar wind-driving: The Velocity Effect



Solar wind-driving: The Cone Angle Effect



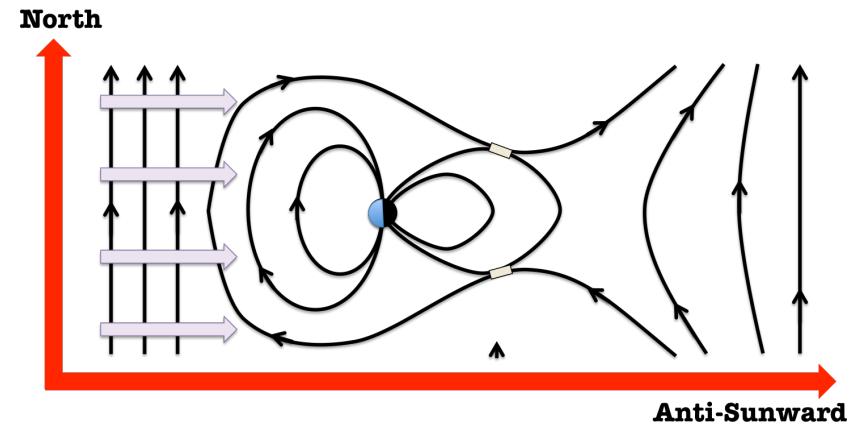
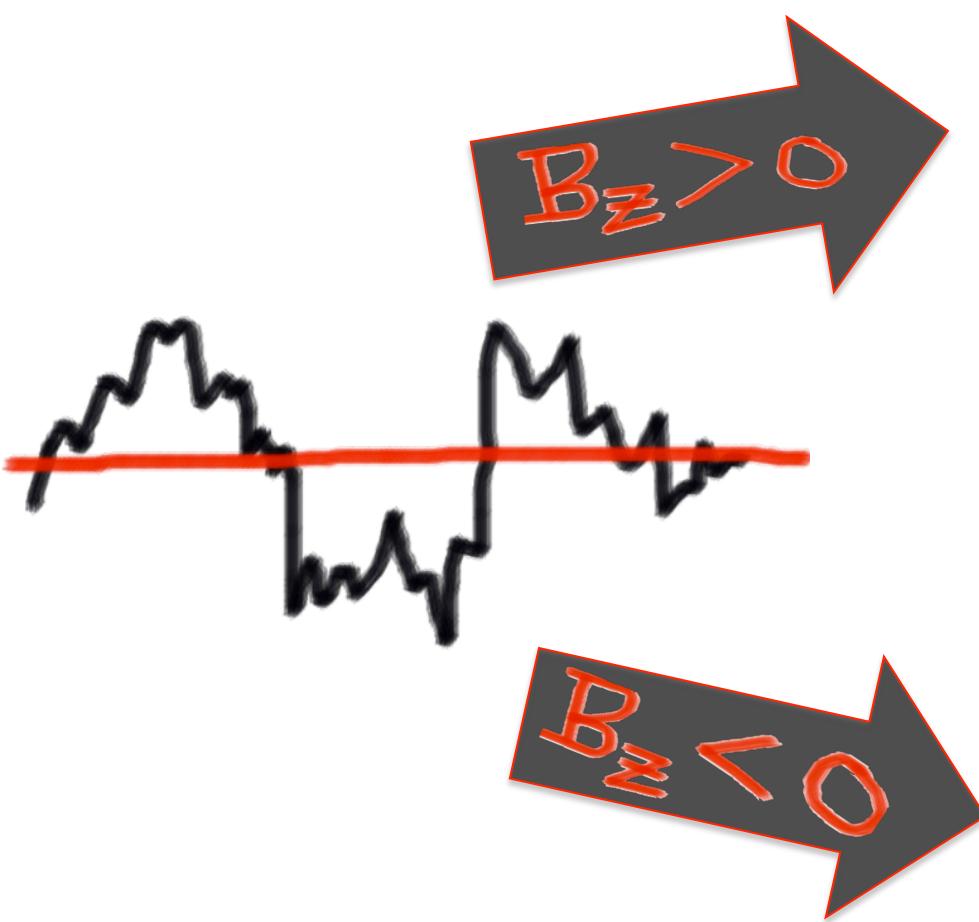
Lots of effects, really!

- e.g. The Field Strength Effect
- The Dynamic Pressure Effect
- The Clock Angle Effect
- The Density Effect

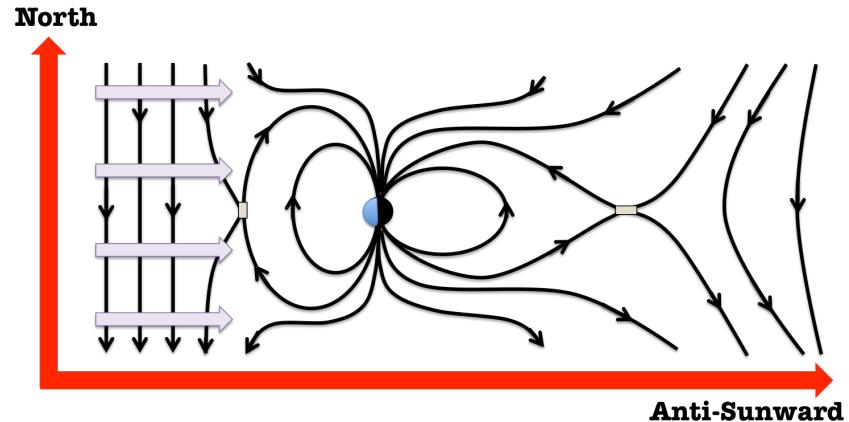
As space missions flourished and data sets grew, such “effects” can be even more specific:

- e.g.
- The CIR Effect
- The CMEEffect

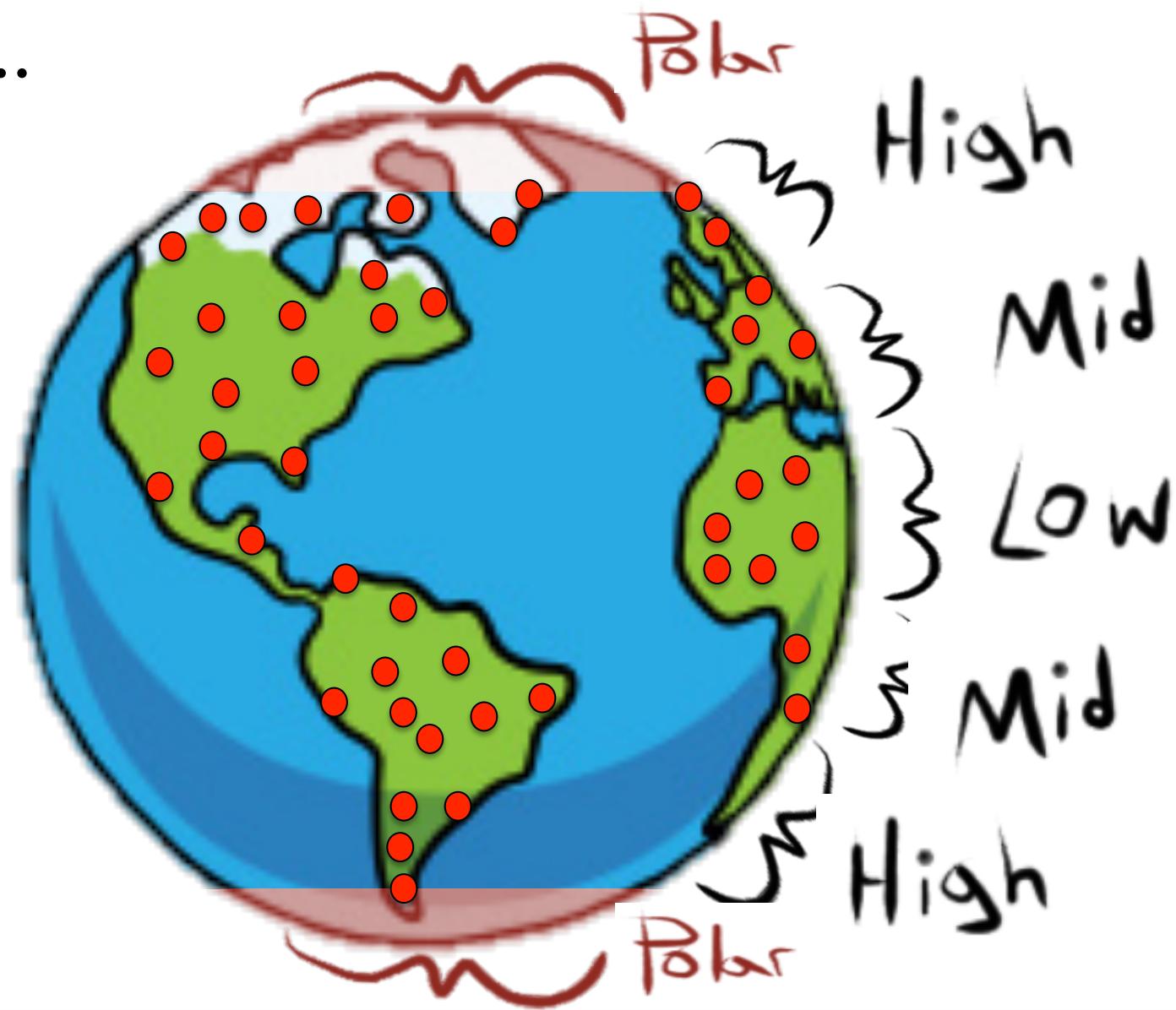
Due to the success and popularity of the Dungey model, **the sign of the interplanetary magnetic field Z-component** is often used to subset geomagnetic parameters of interest



Bz North or Bz South?



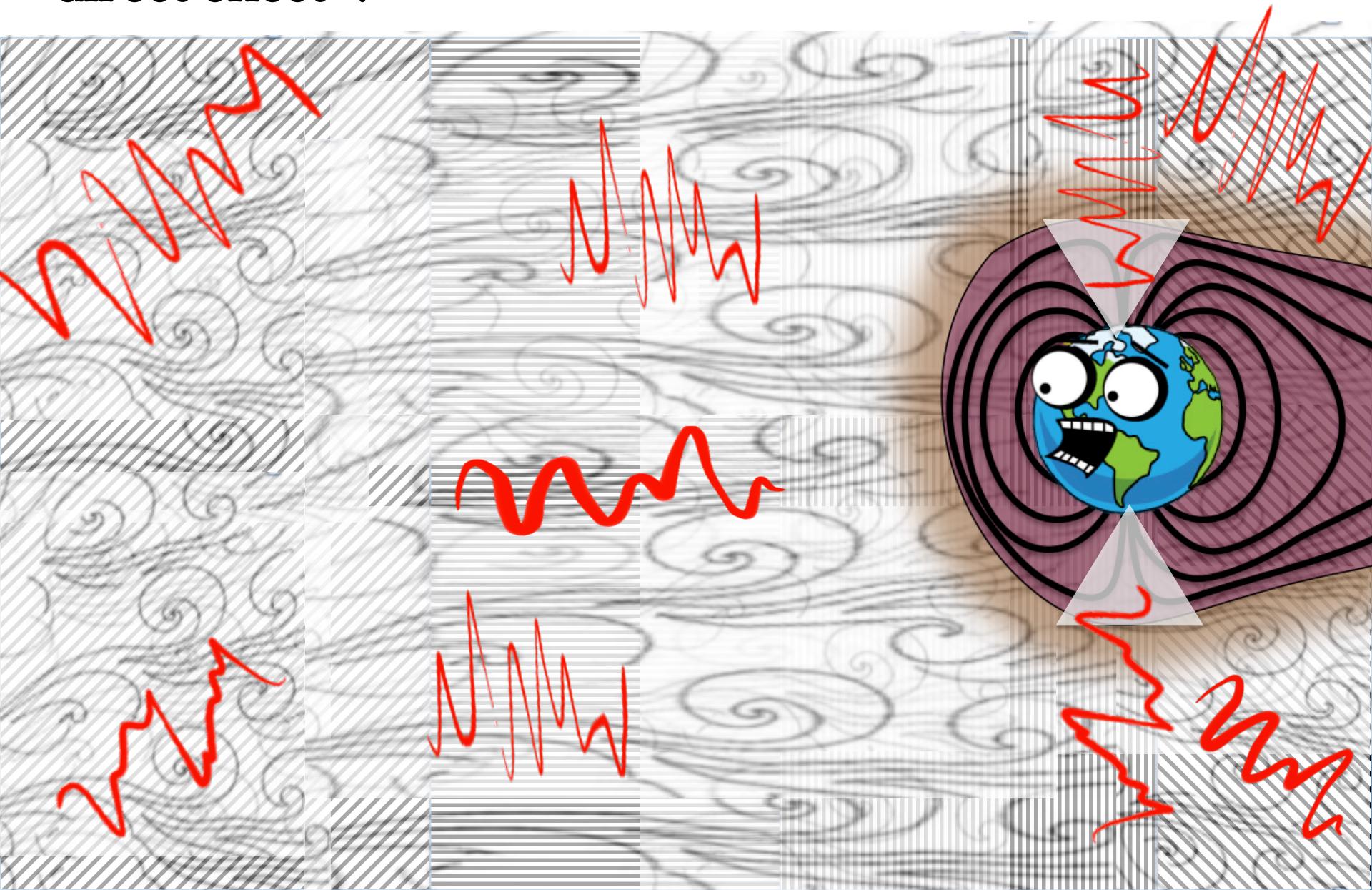
One issue...



“Well, this shouldn’t matter since the polar cap is likely hydromagnetically quiet anyway... At least we’ve got the auroral zone covered!”

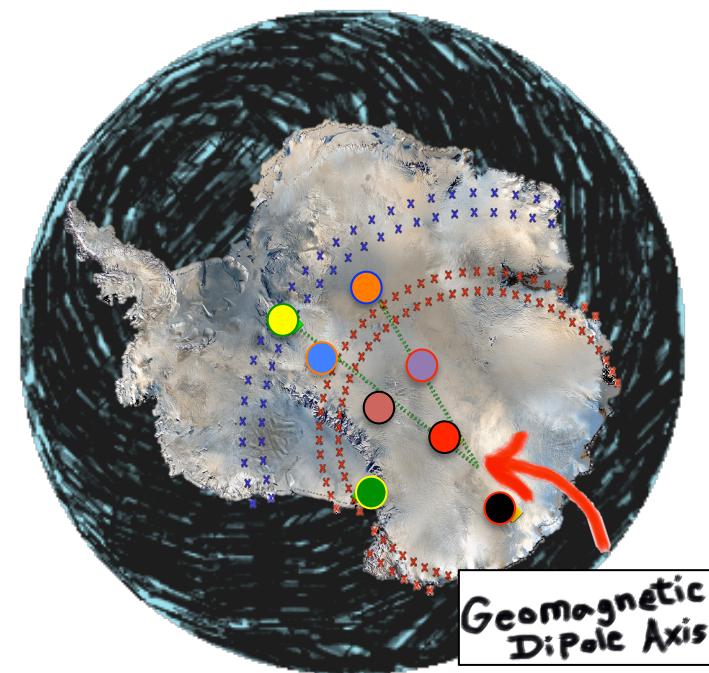
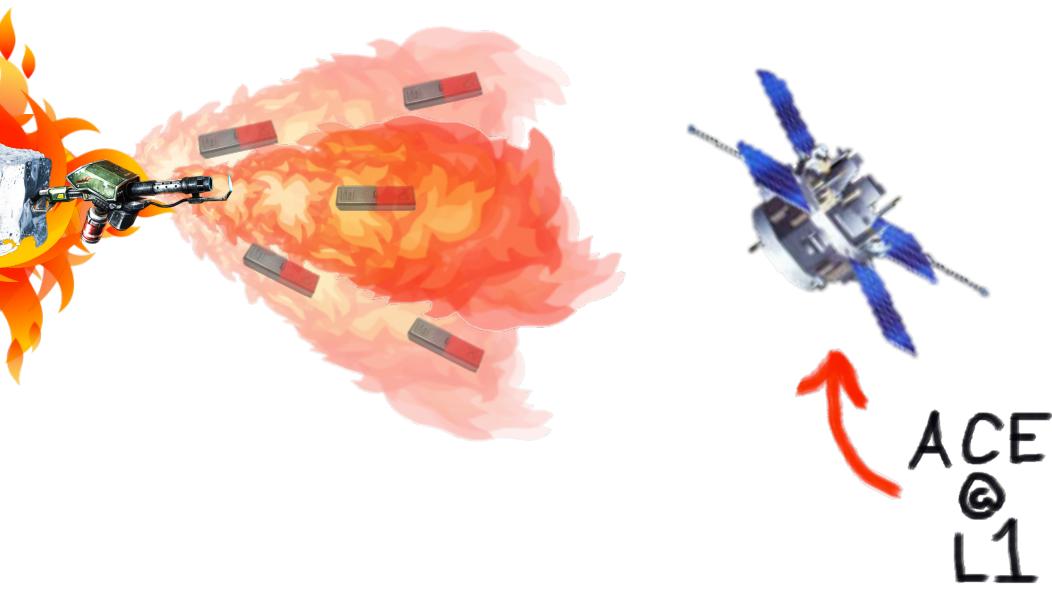
-- No One In Particular, early on

Question: Given an open polar cap, couldn't there be a “direct effect”?



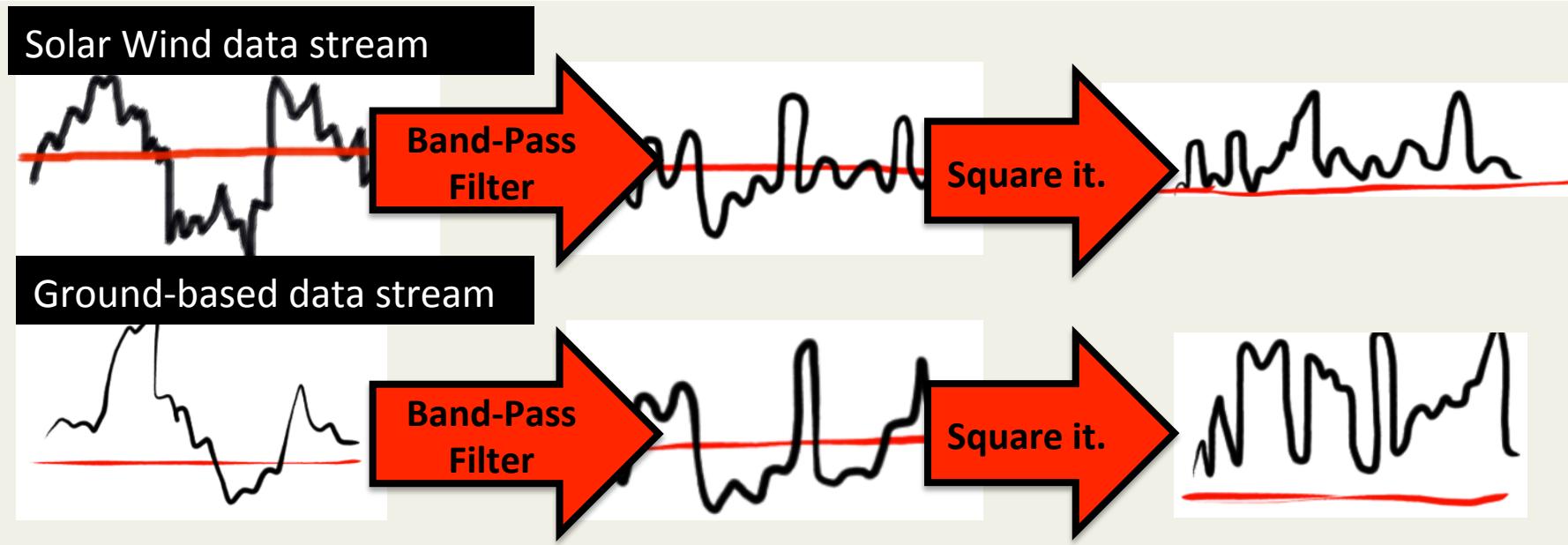
Let's test that...

Experimental Set-Up

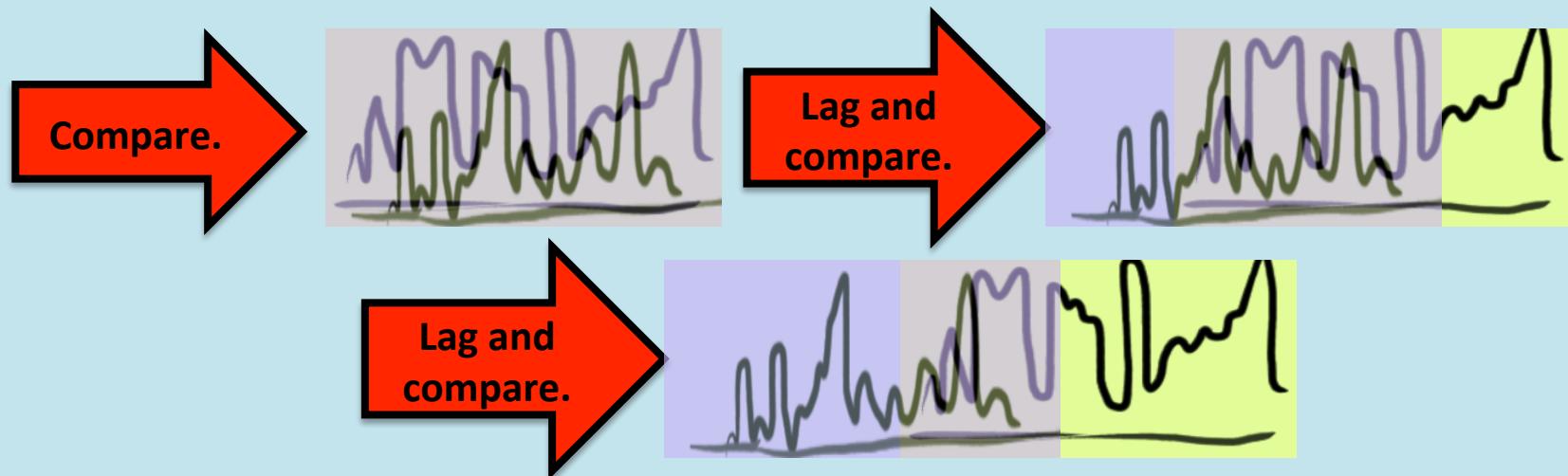


The U.S. Manned and
Automated Geophysical
Observatories in
Antarctica

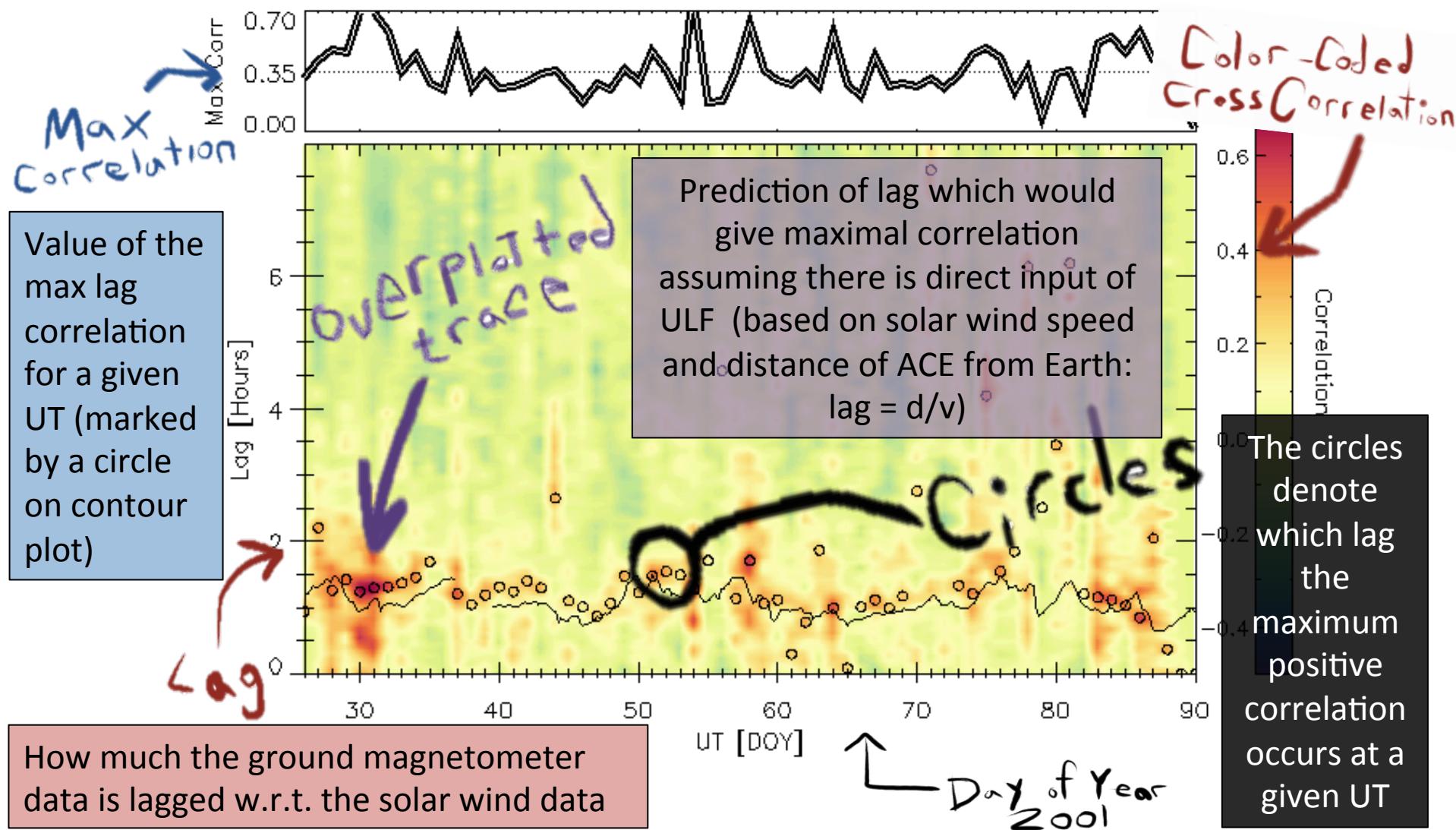
Dynamic Correlograms: We will look at sequences of lagged correlations between band-pass filtered solar wind and ground-based data sets.



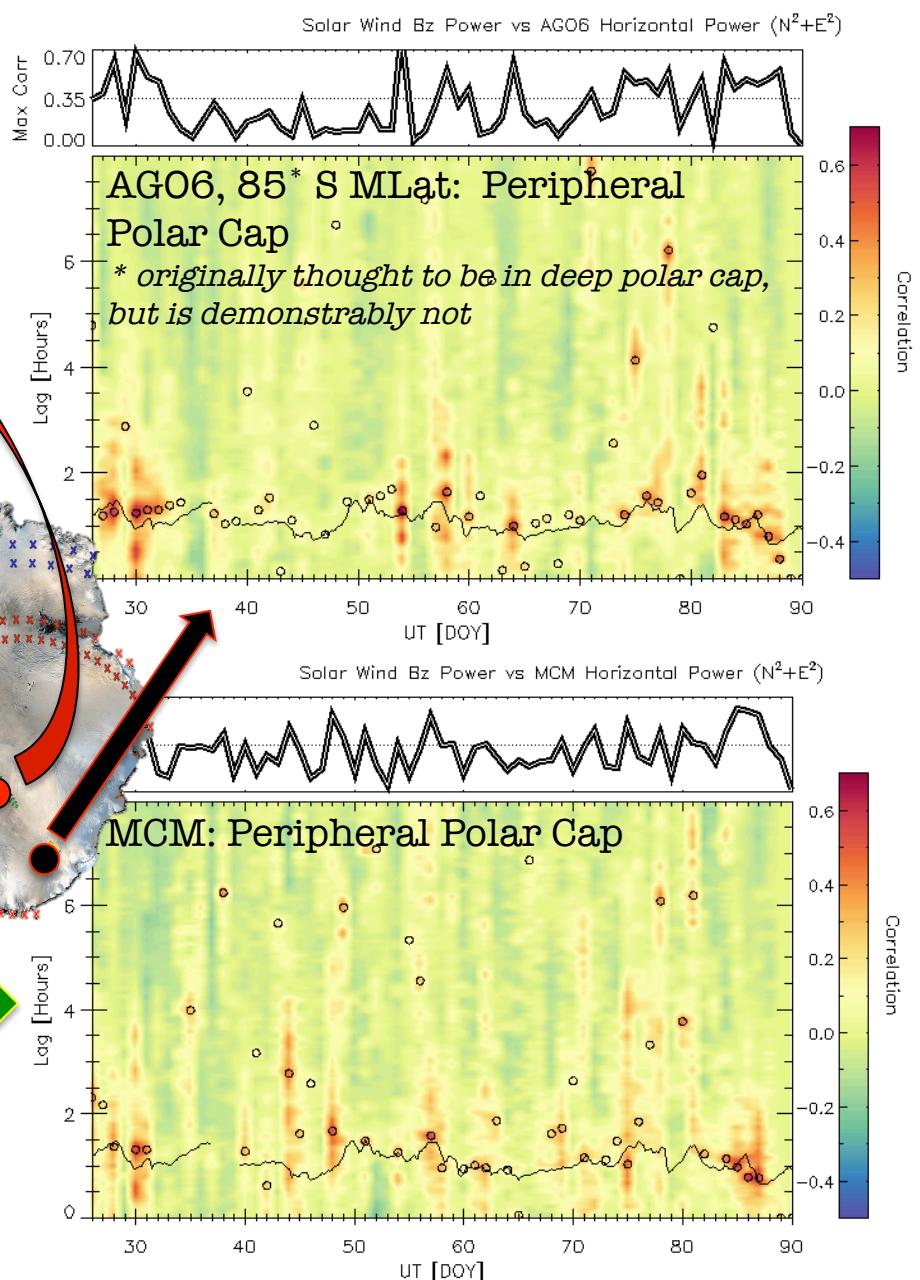
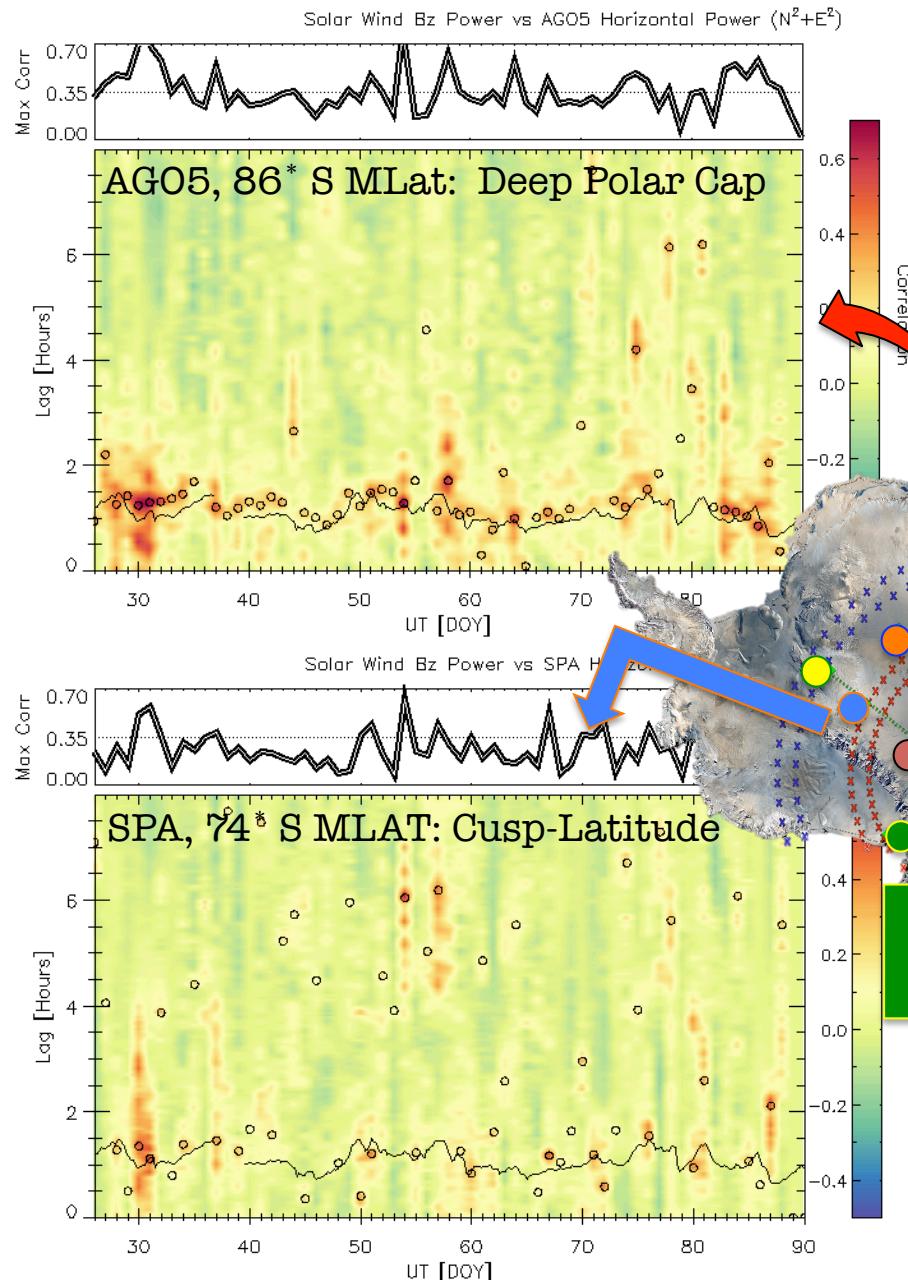
Correlate

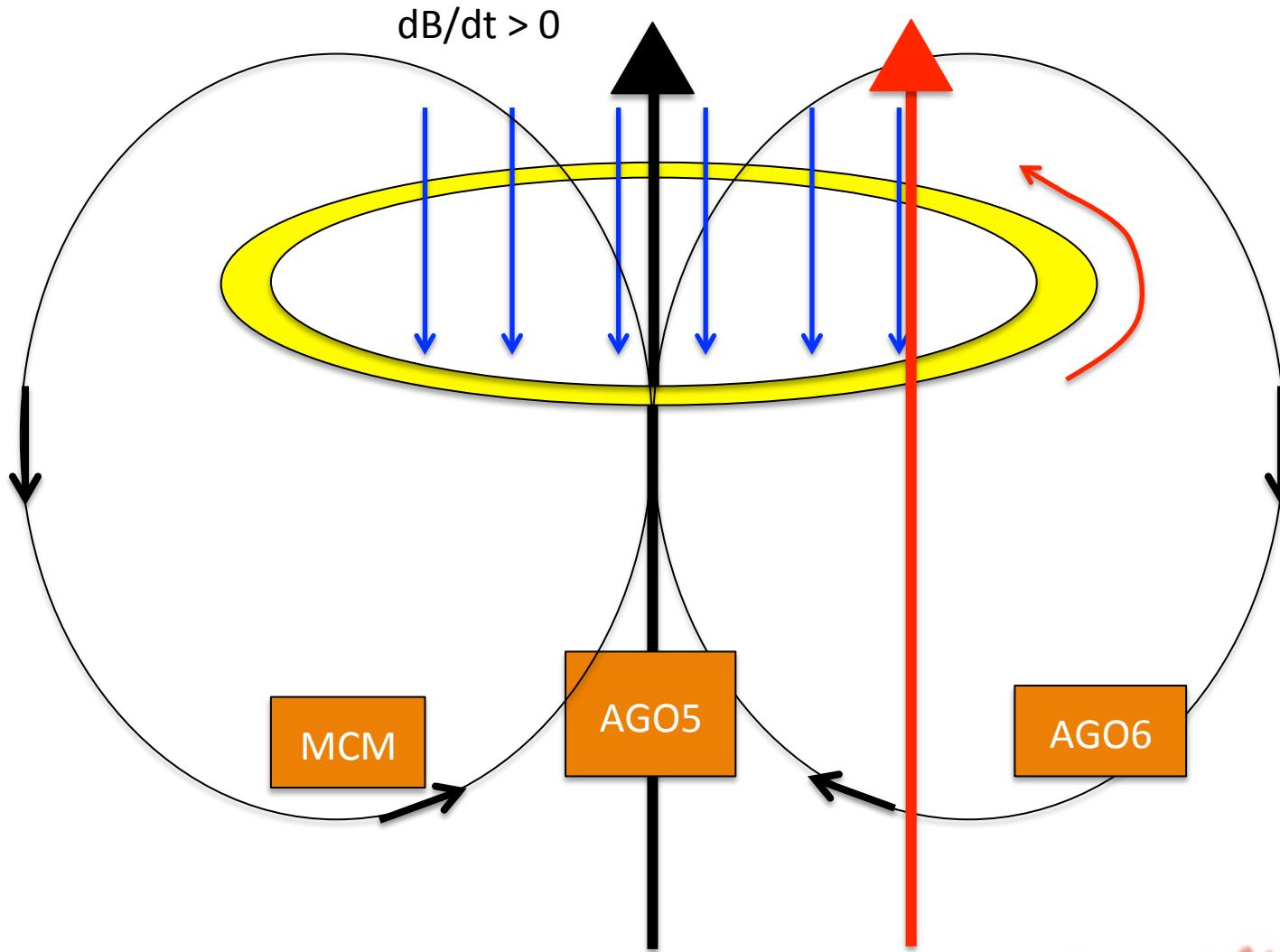


Dynamic Correlograms



Solar Wind Bz HM Wave Power vs Ground-based HM Power

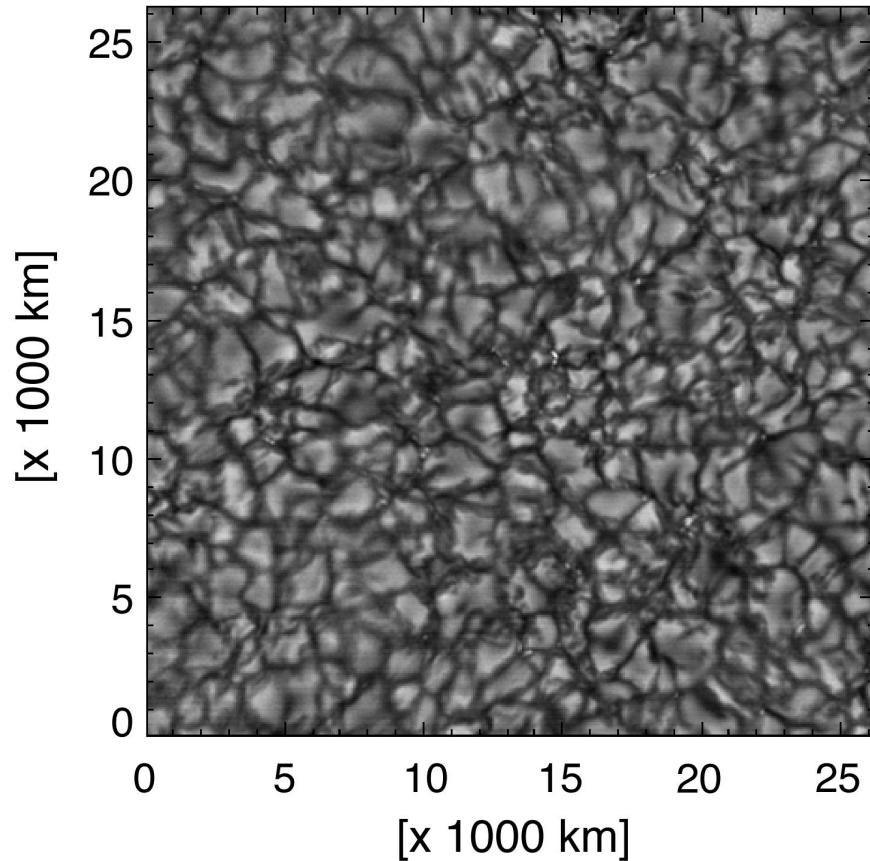




An unexpected solar-terrestrial connection?

Although the hydromagnetic waves we measure at a ground site are temporal, the solar wind is supersonic and superalfvenic.

In short, it's flying past the spacecraft at a million or so MPH --- the variations we record are approximately spatial.



Questions? Comments?

