

# NO MATH SPACE PHYSICS\*

\*a very short intro to

# CONTENT

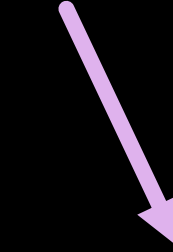
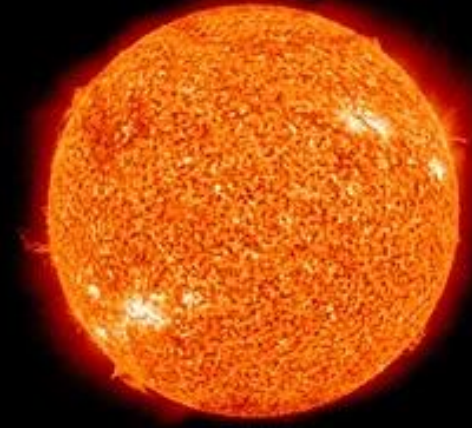
Basic plasma physics concepts



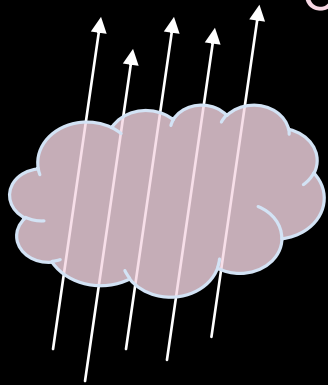
The Sun



The Solar Wind



The Earth's Magnetic Field



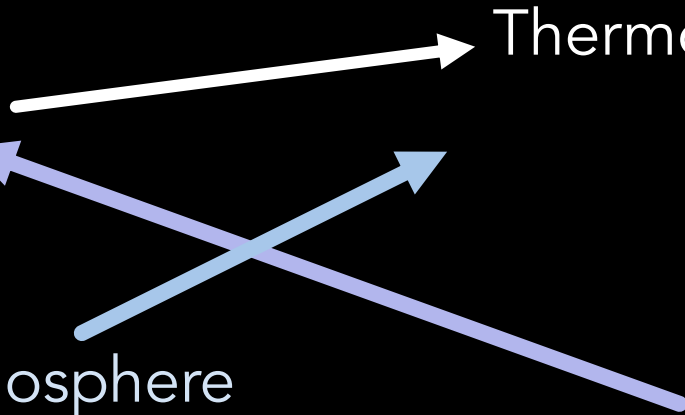
Thermosphere

Aurora



Our Ionosphere

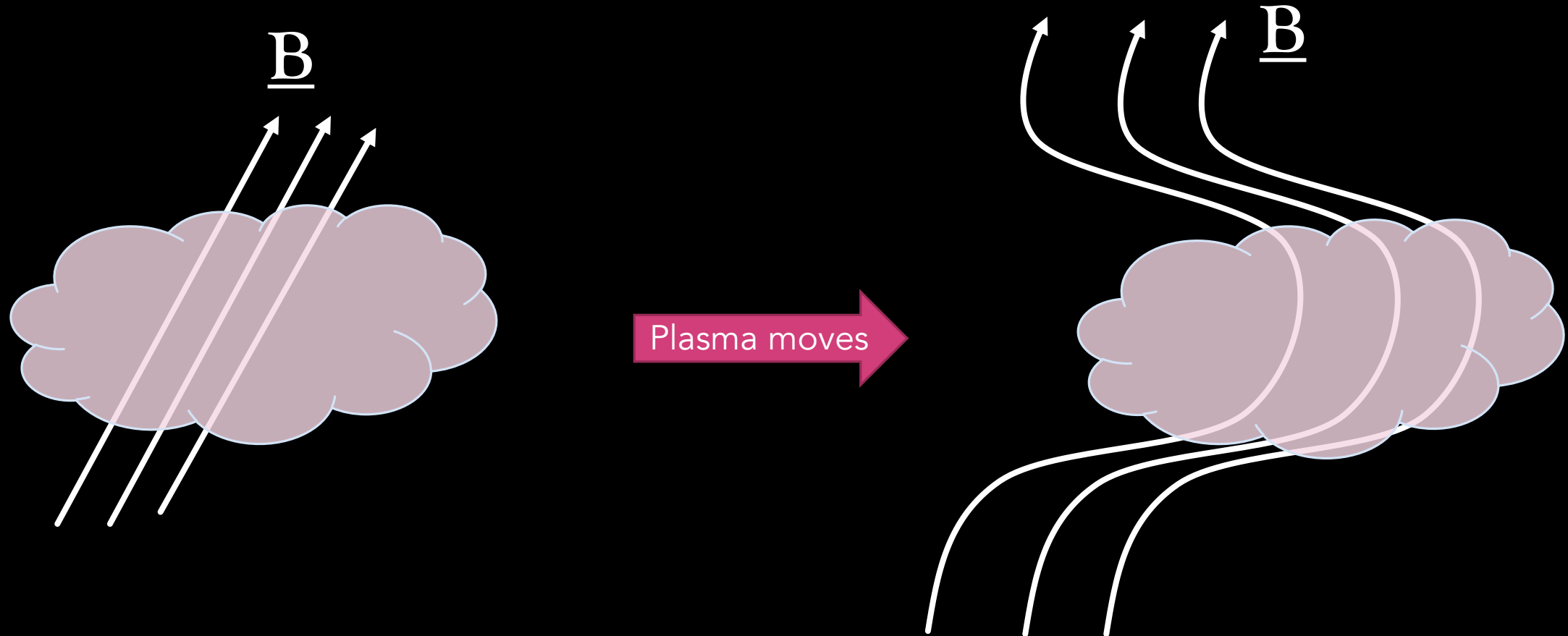
Earth's Magnetosphere in response to the Solar Wind



# PLASMA PHYSICS: FROZEN IN THEOREM

One:

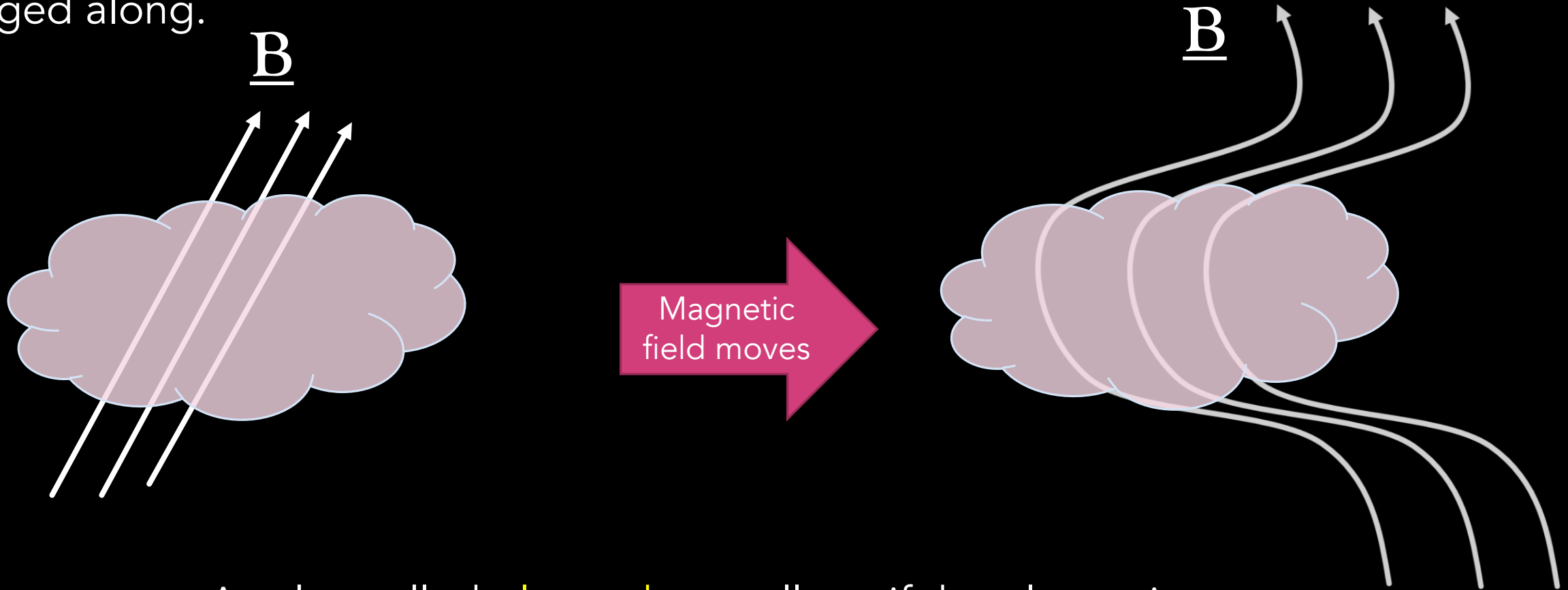
Plasma is moving and the magnetic field gets dragged along with it:



# PLASMA PHYSICS: FROZEN IN THEOREM

## Two:

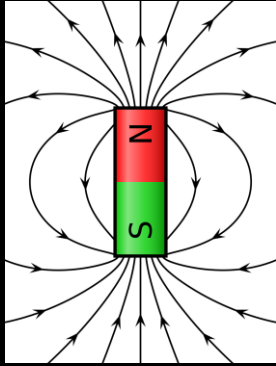
Magnetic field is moving and the plasma 'weighs' it down but it eventually gets dragged along.



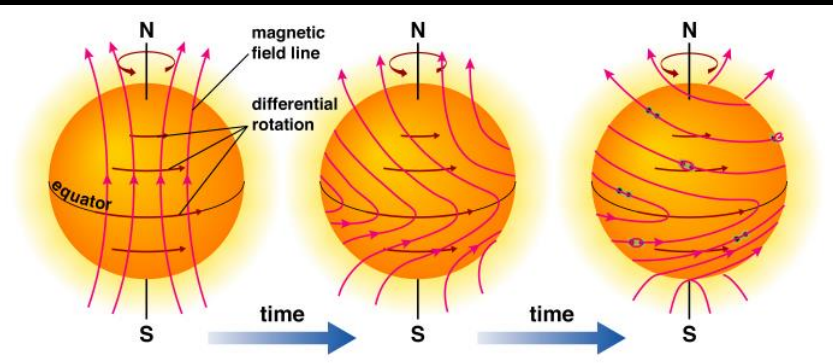
A value called **plasma beta** tells us if the plasma is the one in control, or the magnetic field is in control.

# THE SUN

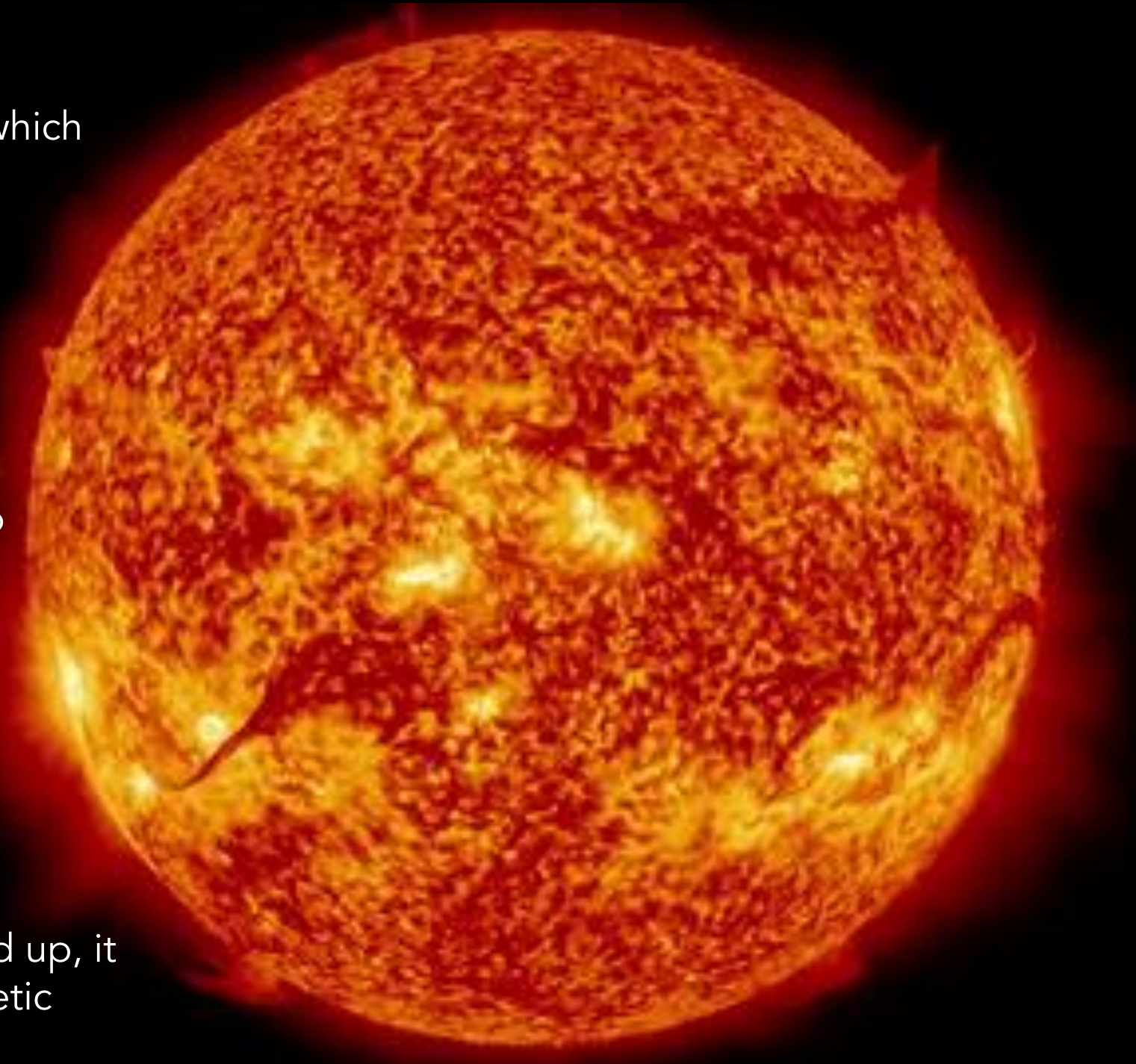
The Sun has a very large magnetic field which originally looked like a dipole



Over time it got pretty messed up due to differential rotation of all the **plasma**



And every now and then it gets so wound up, it fires off large blobs of plasma and magnetic field away from the surface





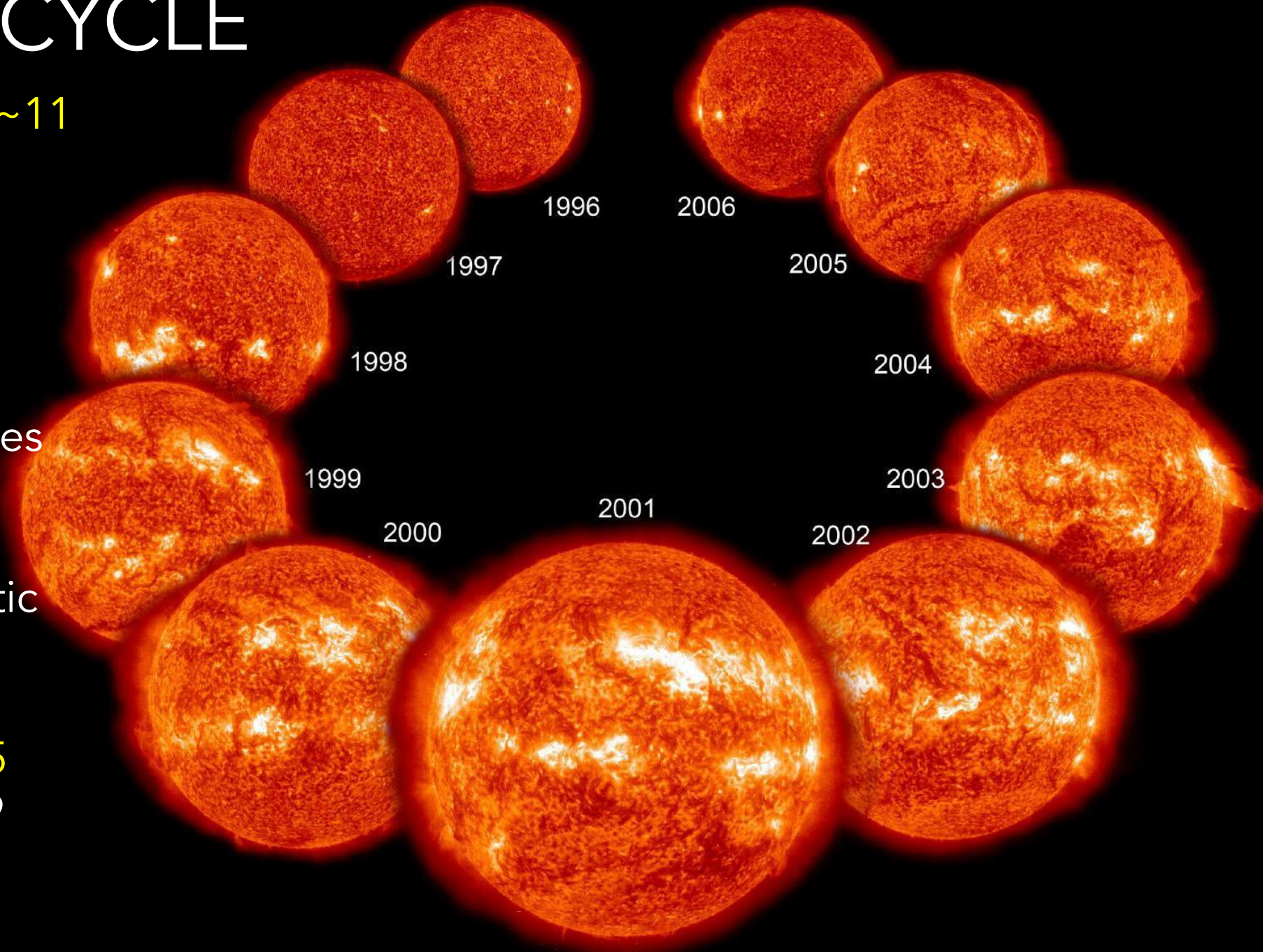
# THE SOLAR CYCLE

The Sun has a cycle of ~11 years measured by number of sunspots

Activity on the surface increases to a 'solar maximum' and decreases to a 'solar minimum'

After which the magnetic polarity switches

The current cycle is #25 and began in Dec 2019



# THE SOLAR WIND

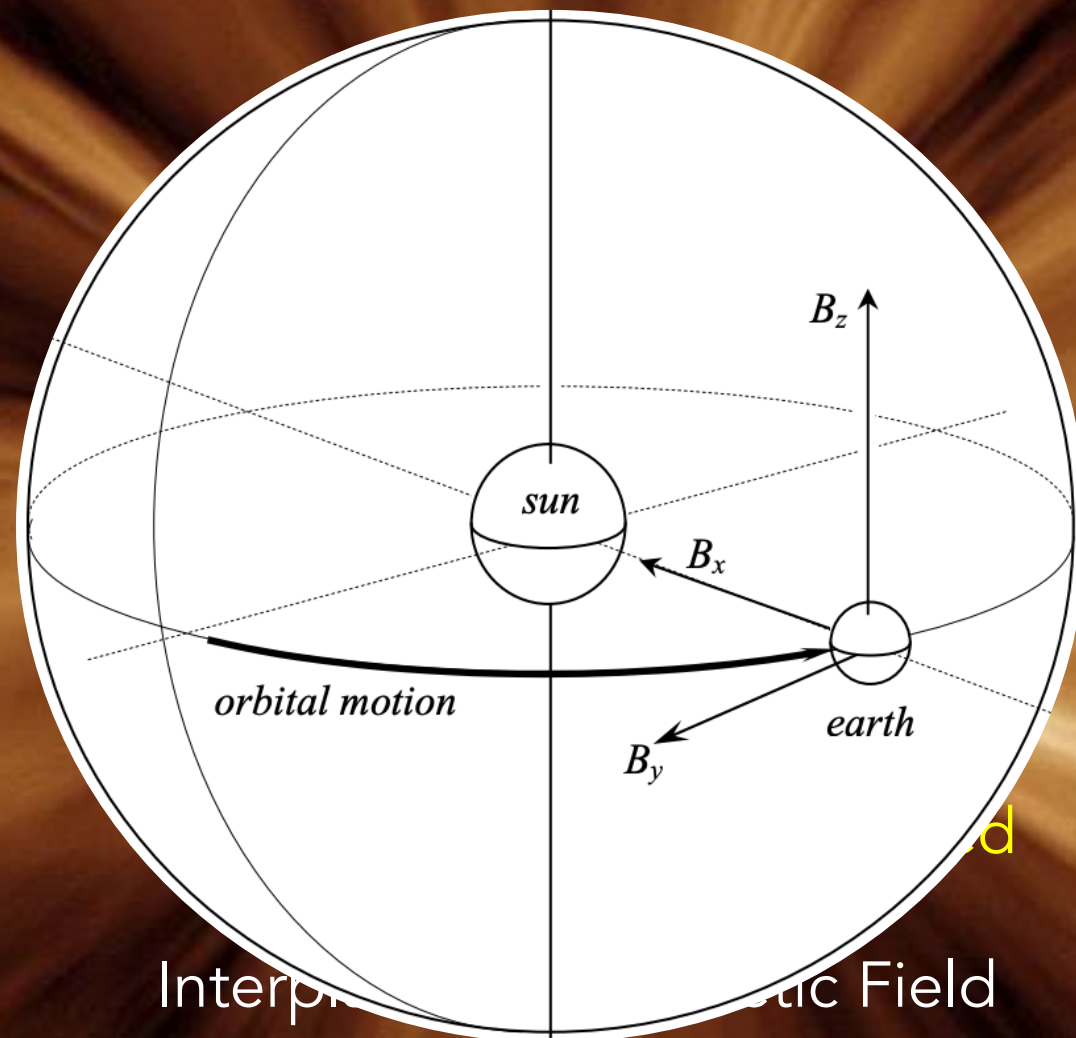
Constant stream of particles/plasma and magnetic field moving away from the Sun

By the time it reaches Earth, can be fast (700km/h) or slow (300km/h) but always supersonic

Magnetic field can be oriented in many ways – IMF  
Interplanetary Magnetic Field



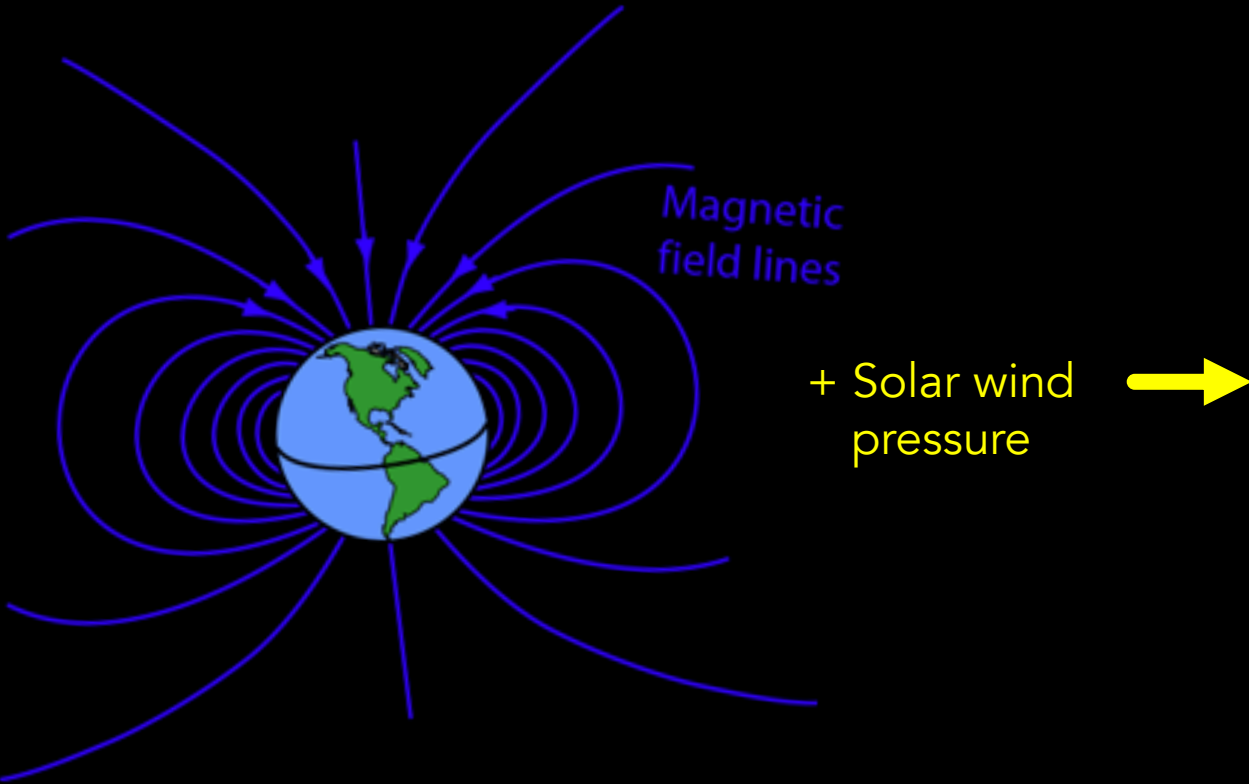
# THE SOLAR WIND



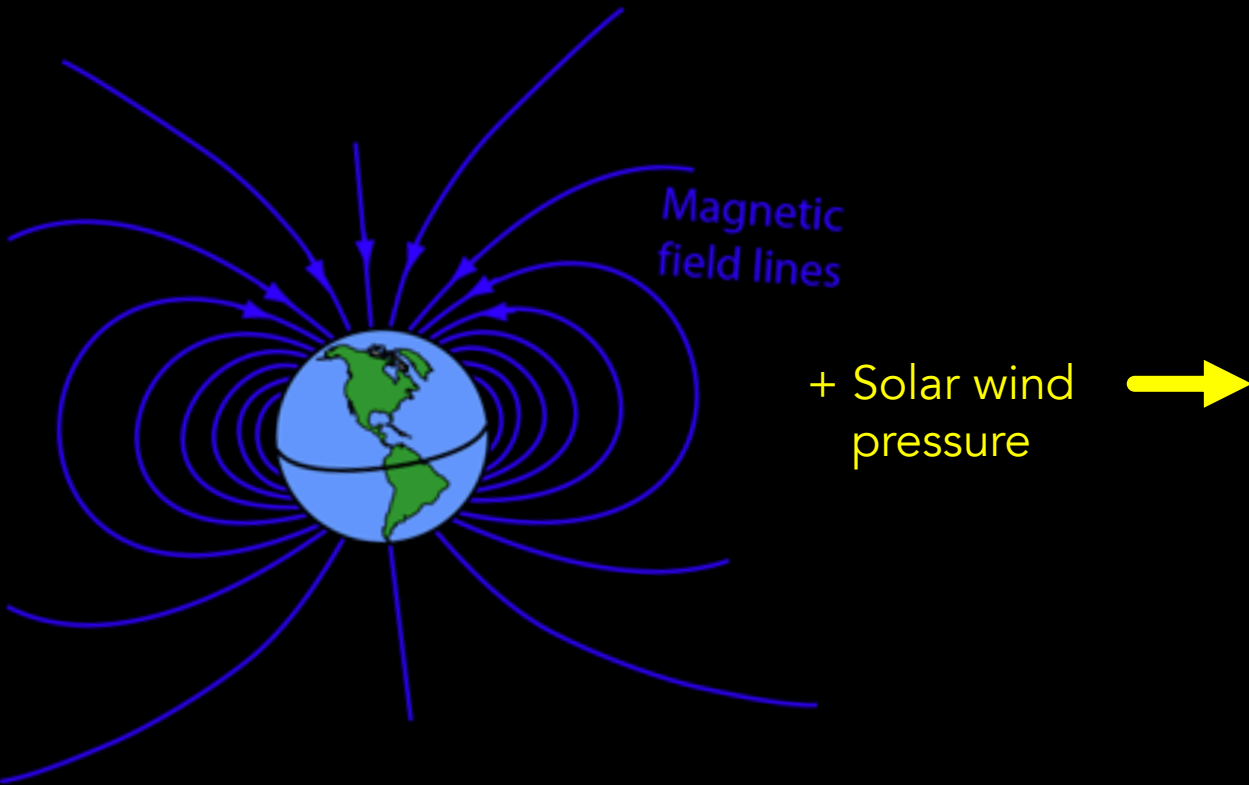
Interplanetary Magnetic Field



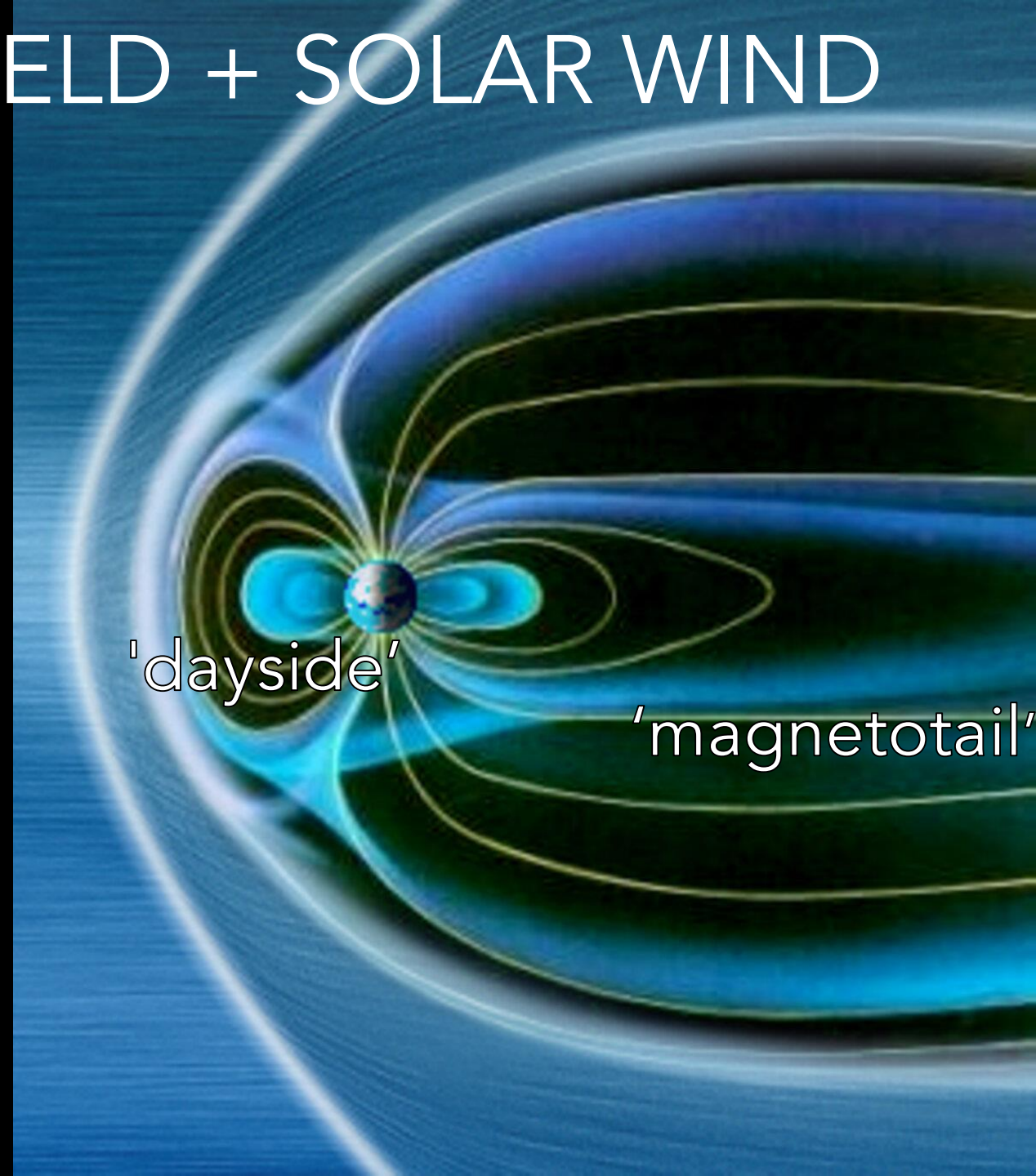
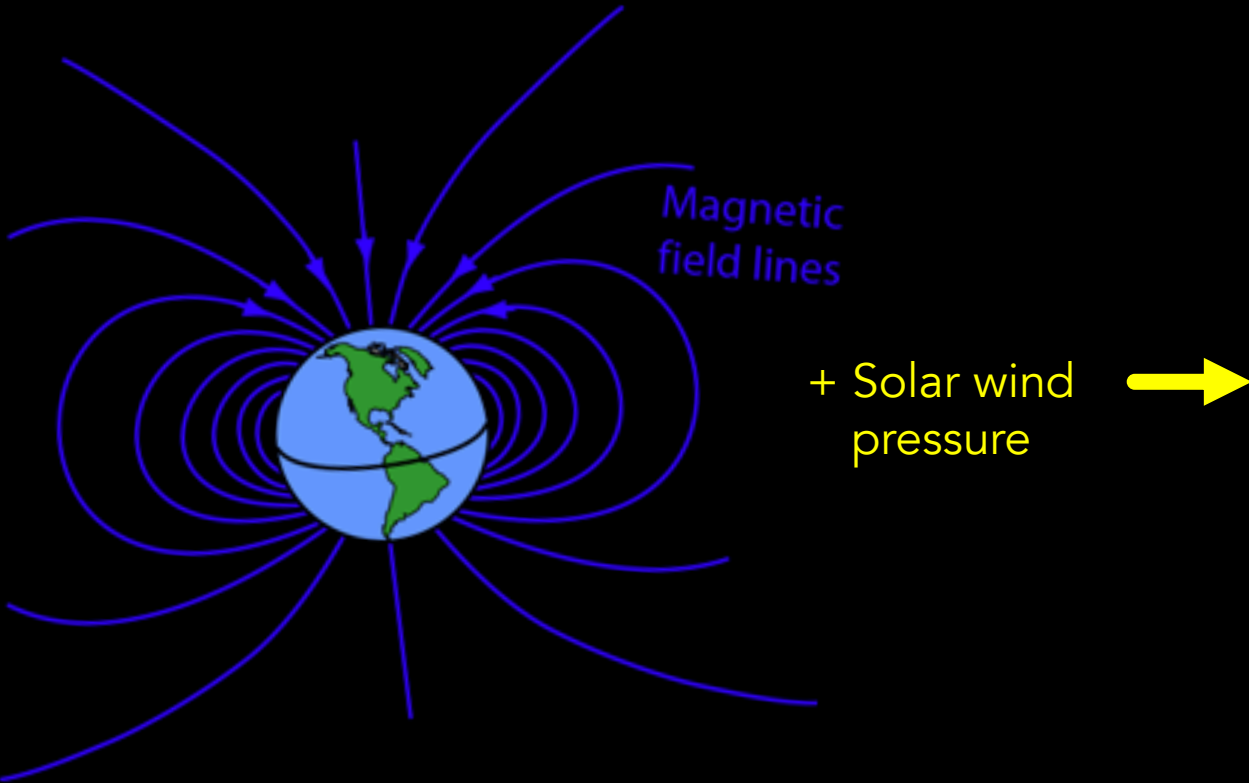
# EARTH'S MAGNETIC FIELD + SOLAR WIND



# EARTH'S MAGNETIC FIELD + SOLAR WIND

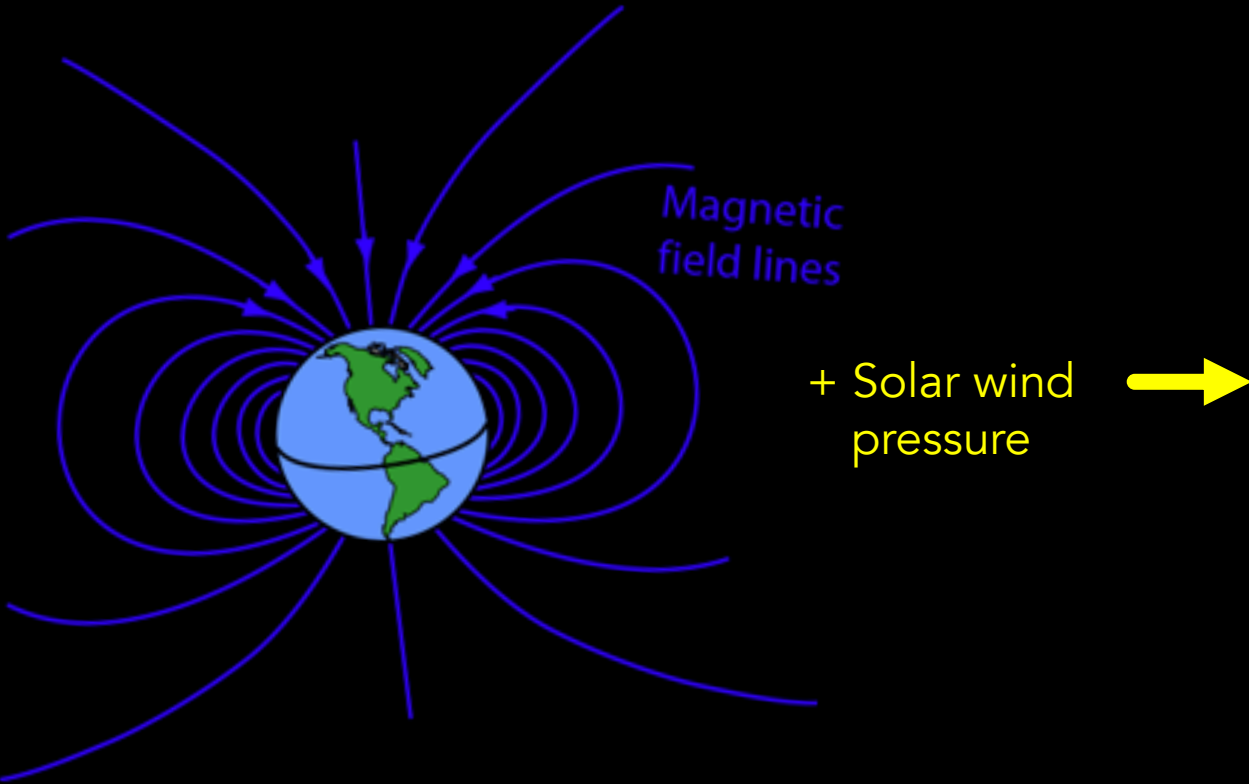


# EARTH'S MAGNETIC FIELD + SOLAR WIND

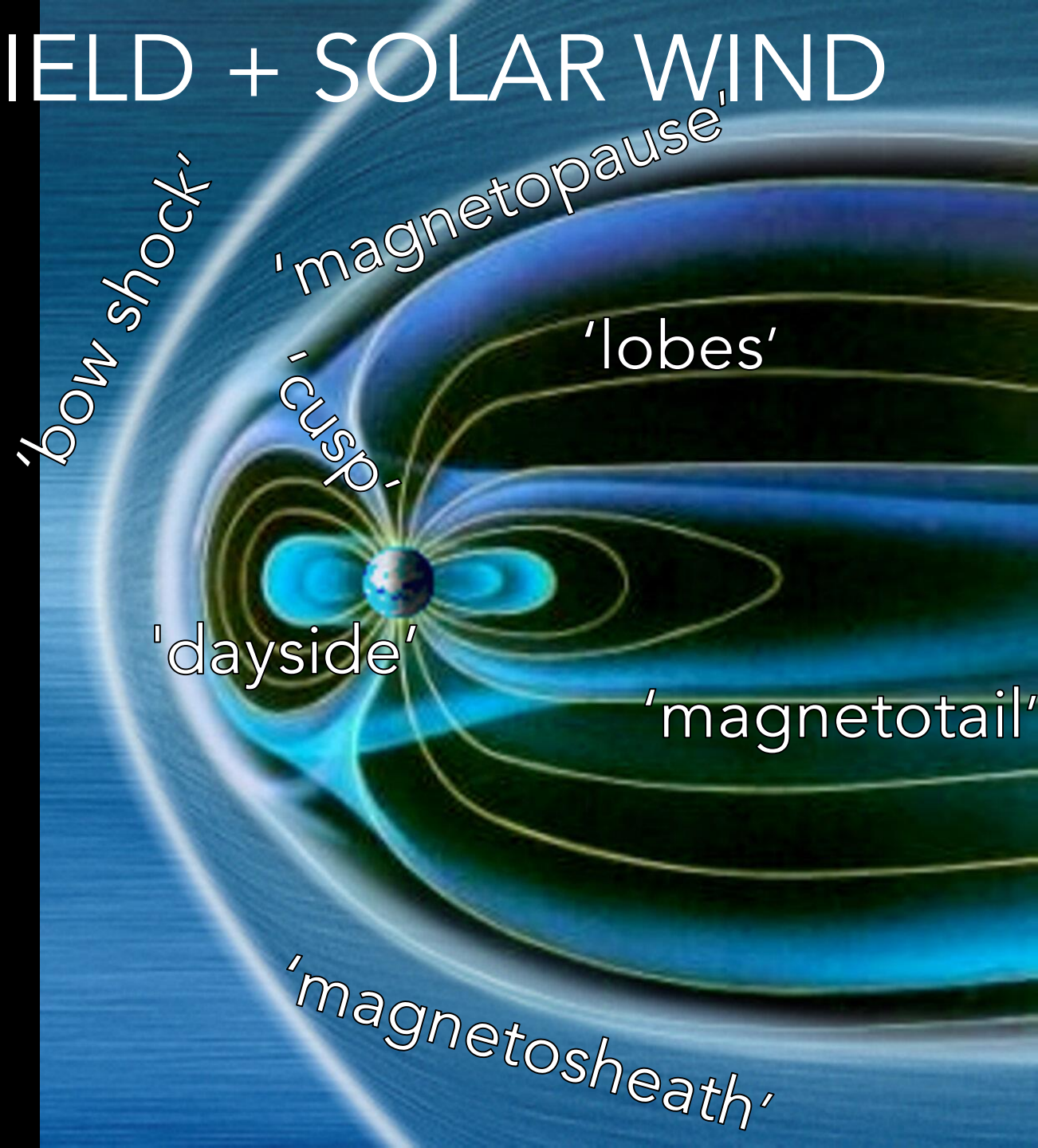
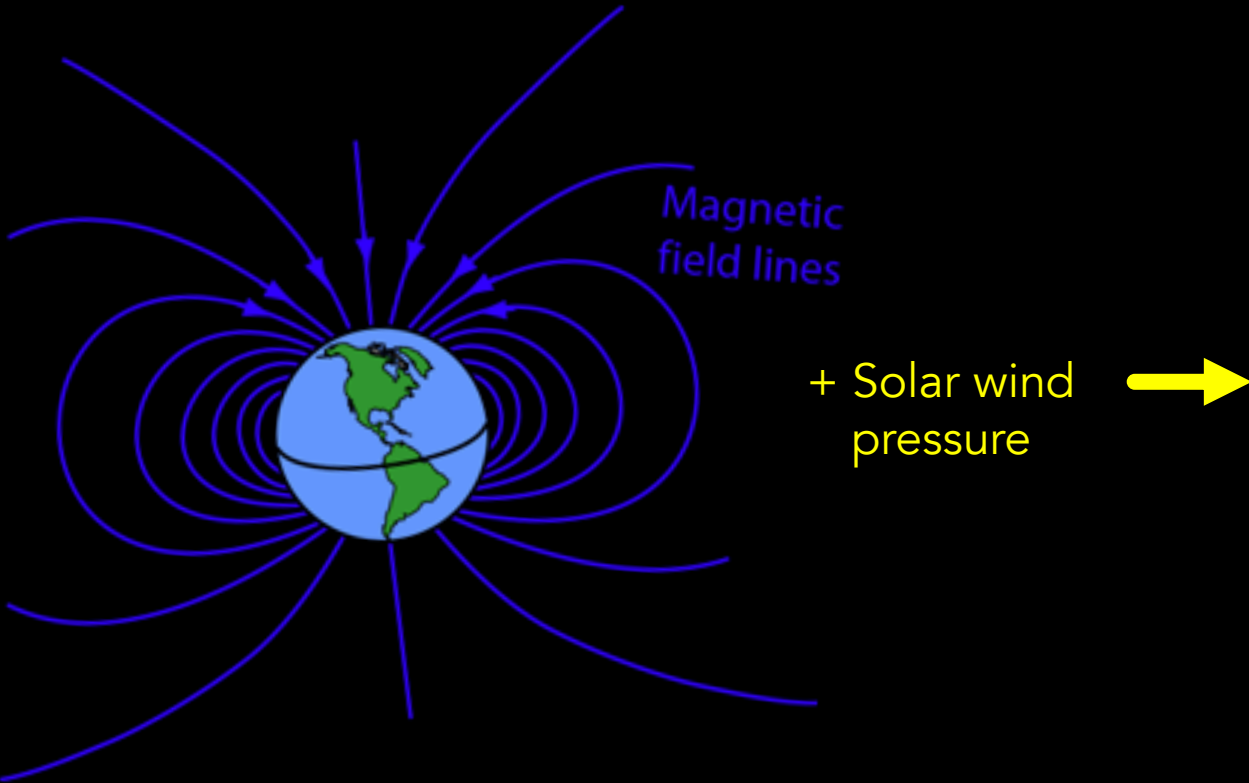




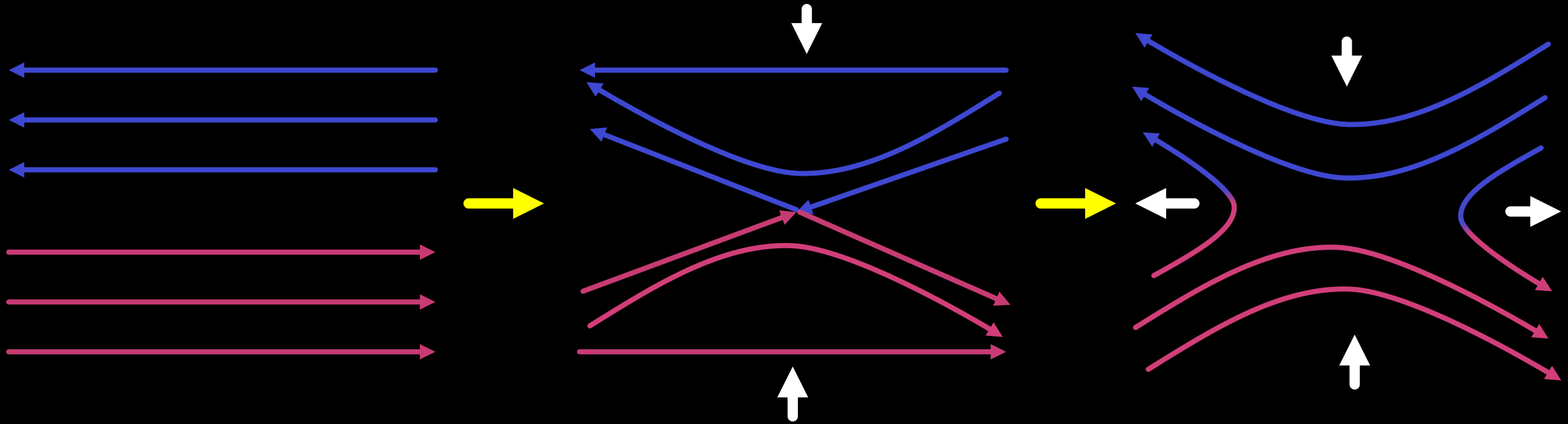
# EARTH'S MAGNETIC FIELD + SOLAR WIND



# EARTH'S MAGNETIC FIELD + SOLAR WIND

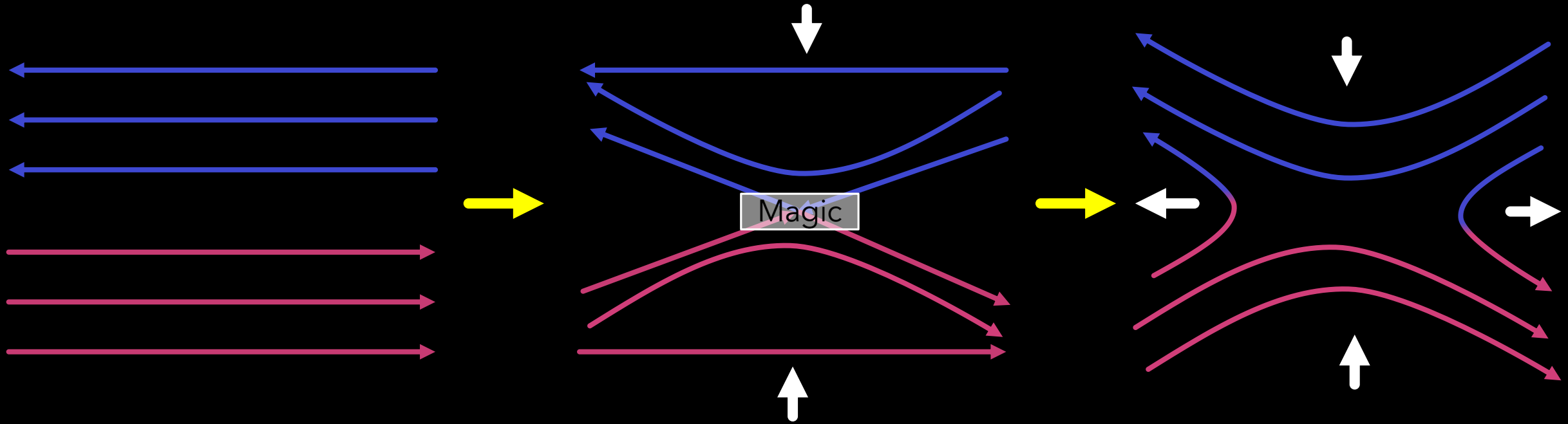


# EARTH IN THE SOLAR WIND: ADDING IN MAGNETIC FIELDS RECONNECTION

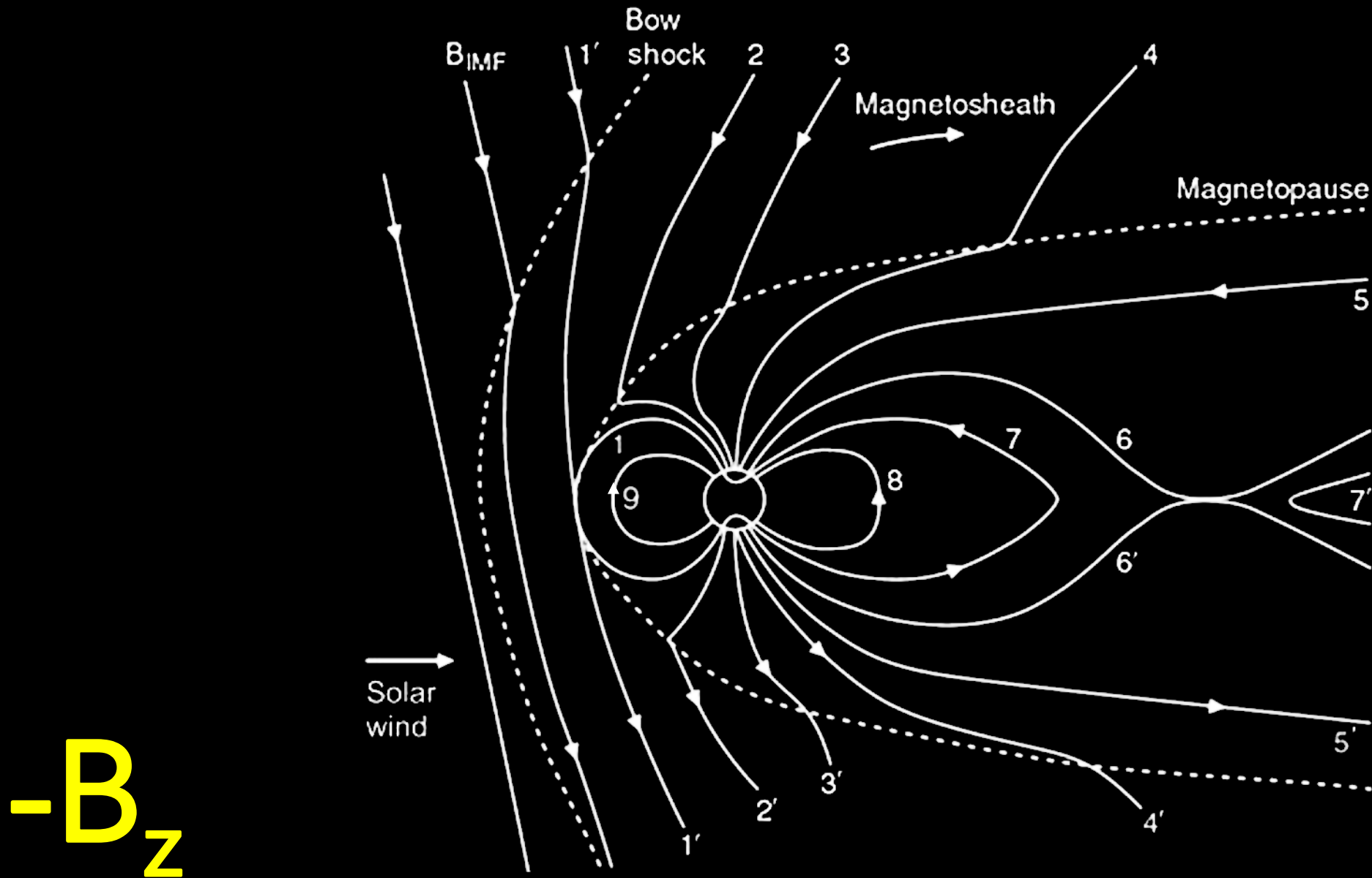




# EARTH IN THE SOLAR WIND: ADDING IN MAGNETIC FIELDS RECONNECTION



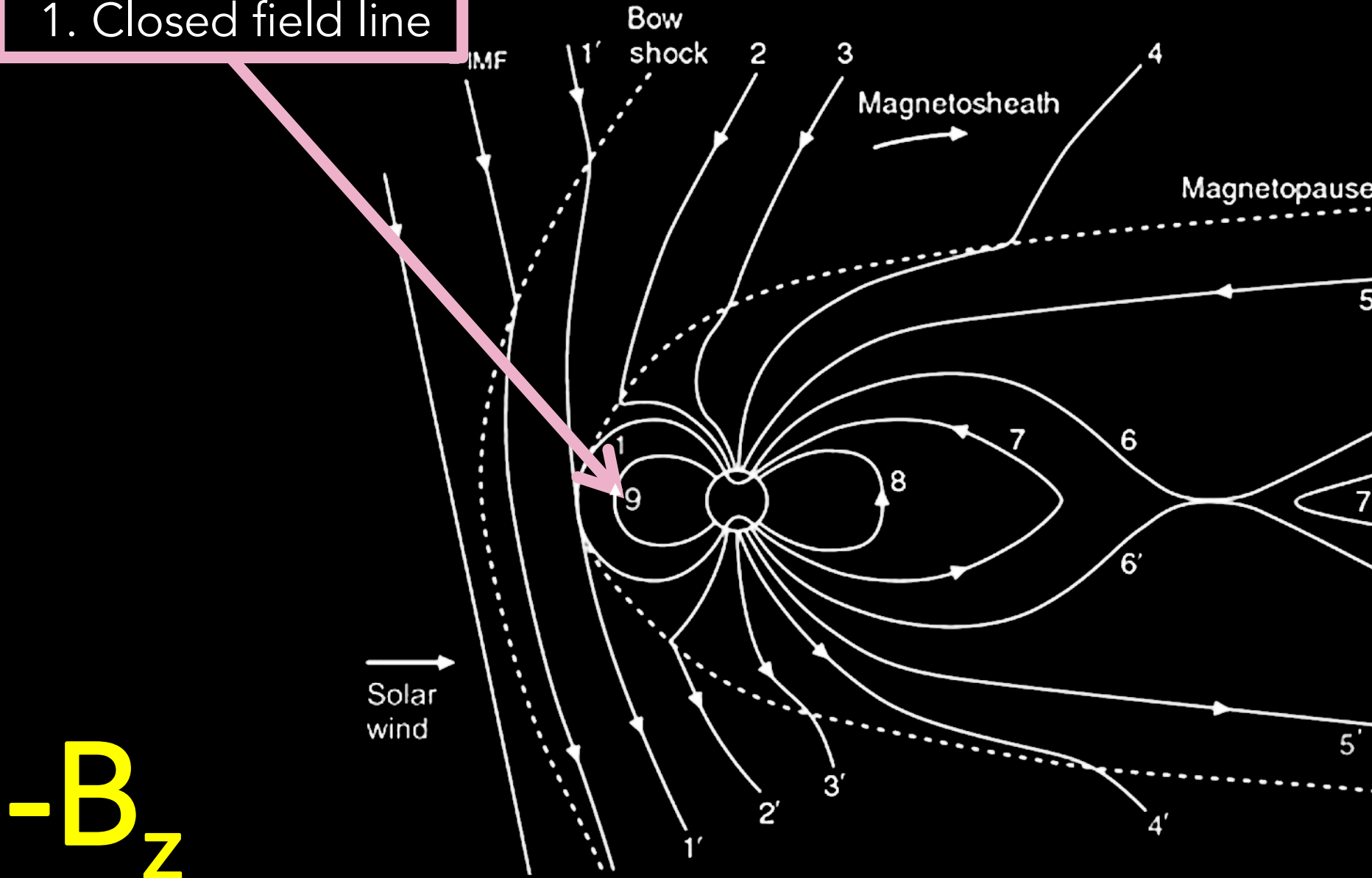
# EARTH IN THE SOLAR WIND: DUNGEY CYCLE



$-B_z$

# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

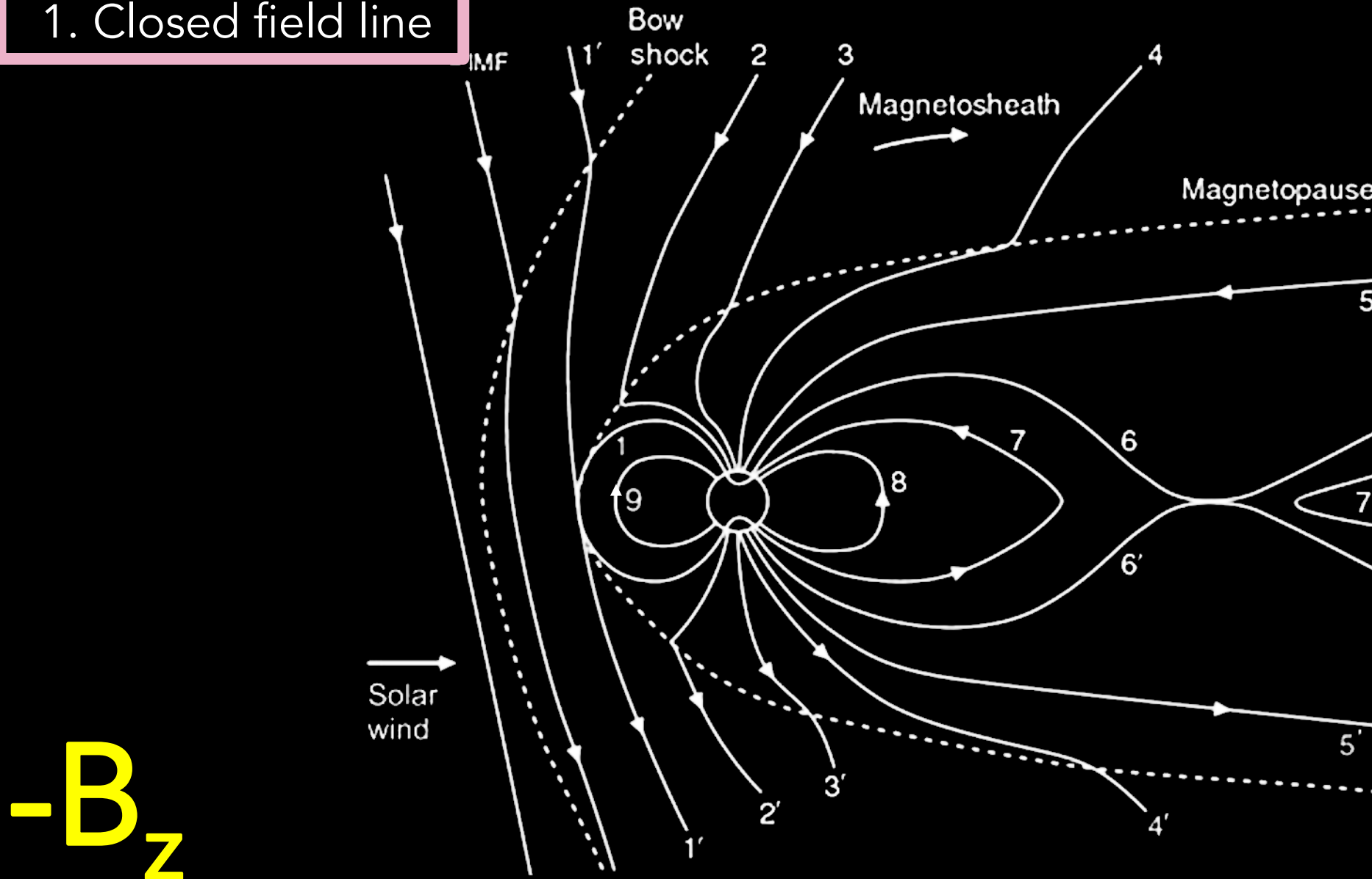


$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

## 1. Closed field line



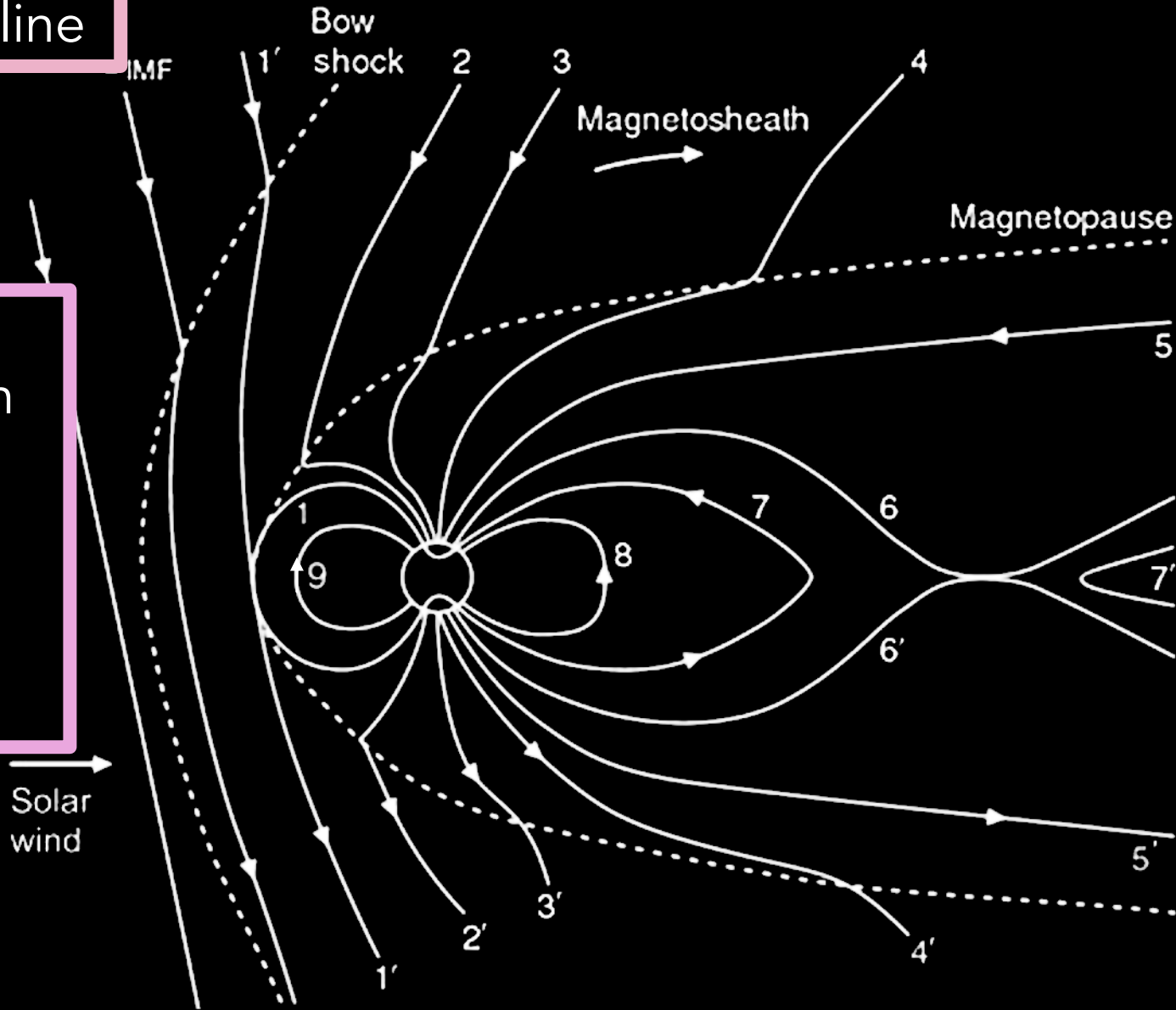
$-B_z$

# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

2. Dayside Reconnection

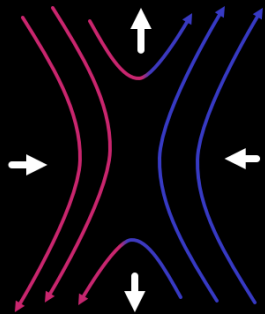
$-B_z$



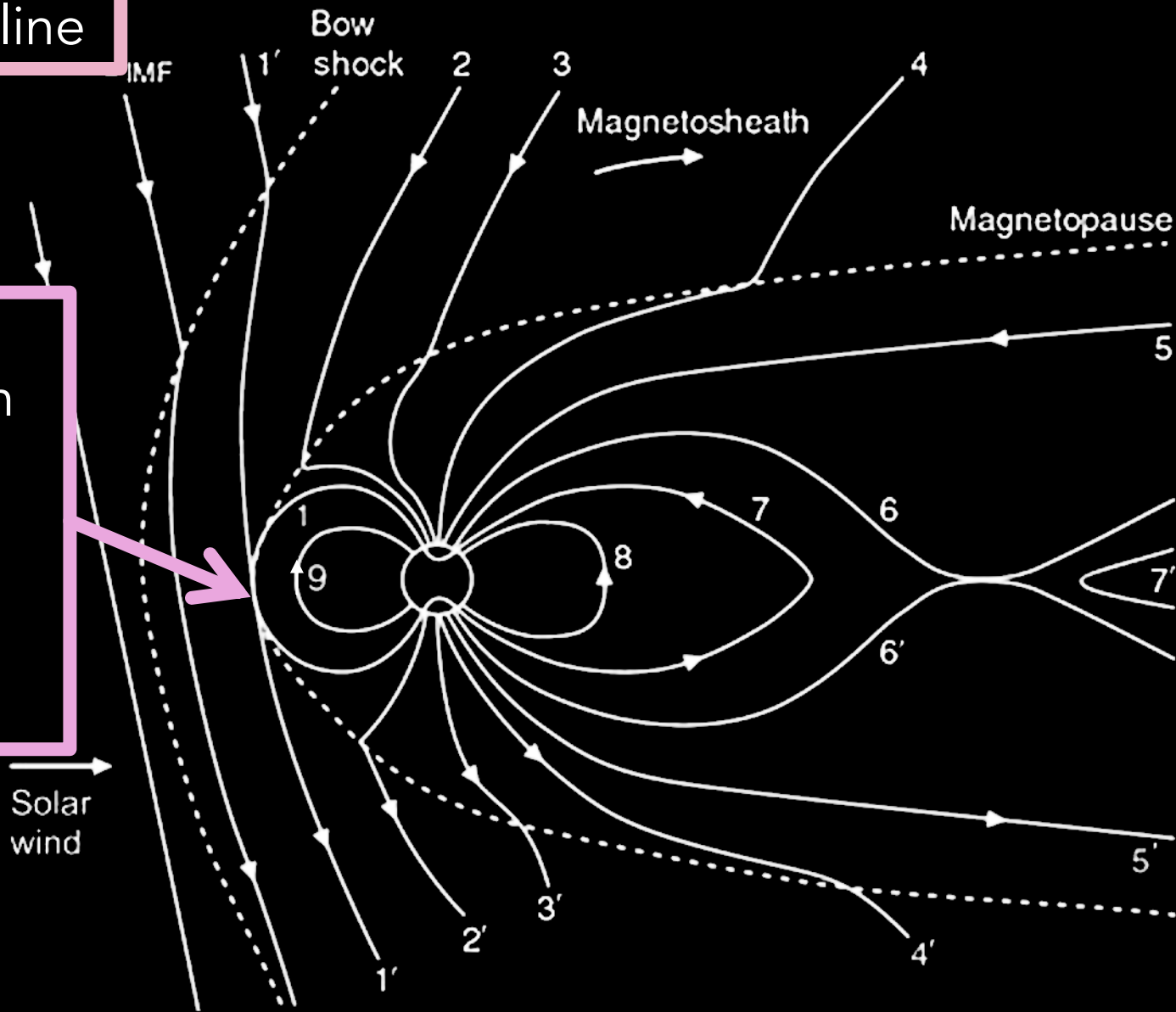
# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

2. Dayside Reconnection



$-B_z$

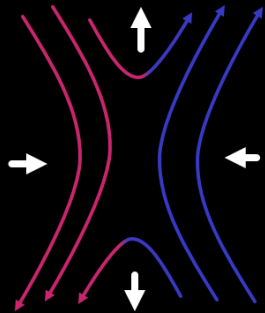




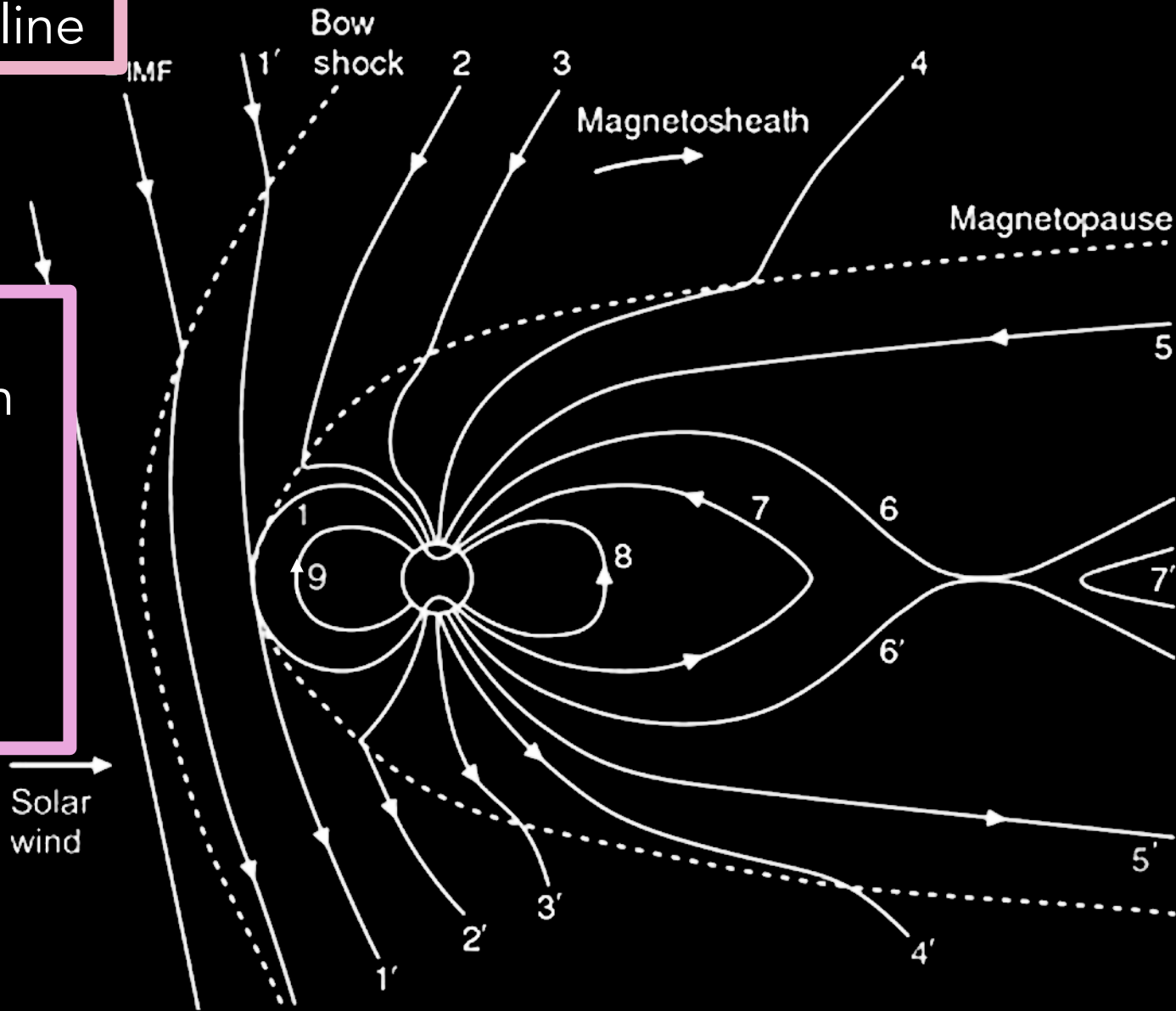
# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

2. Dayside Reconnection



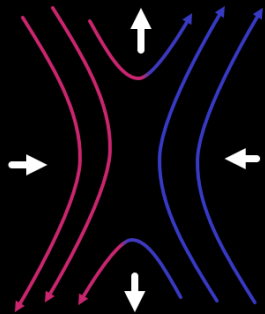
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

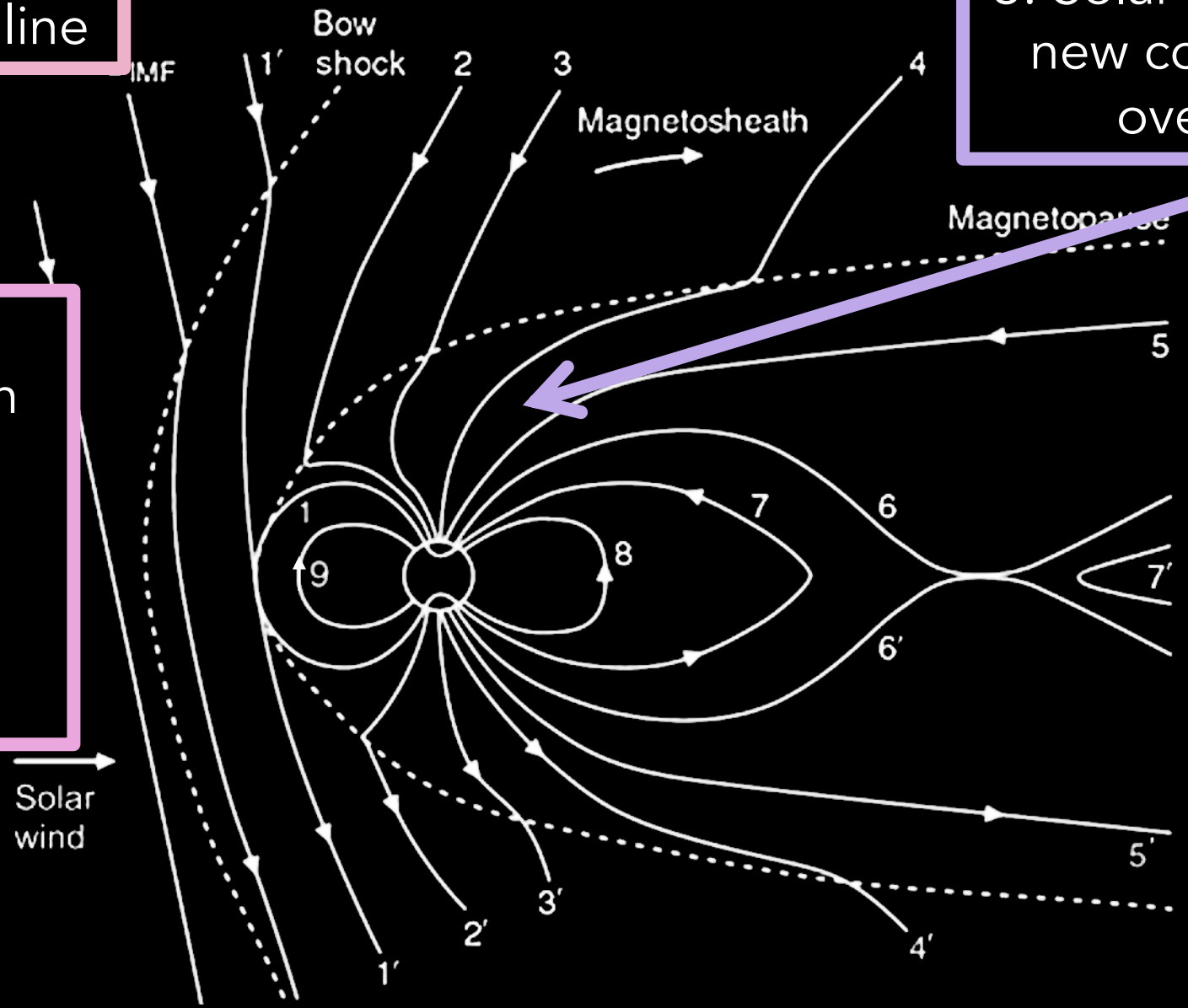
1. Closed field line

2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

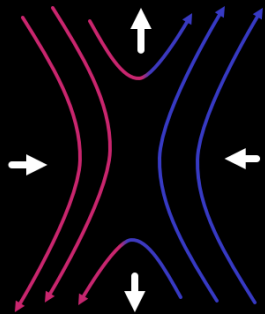
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

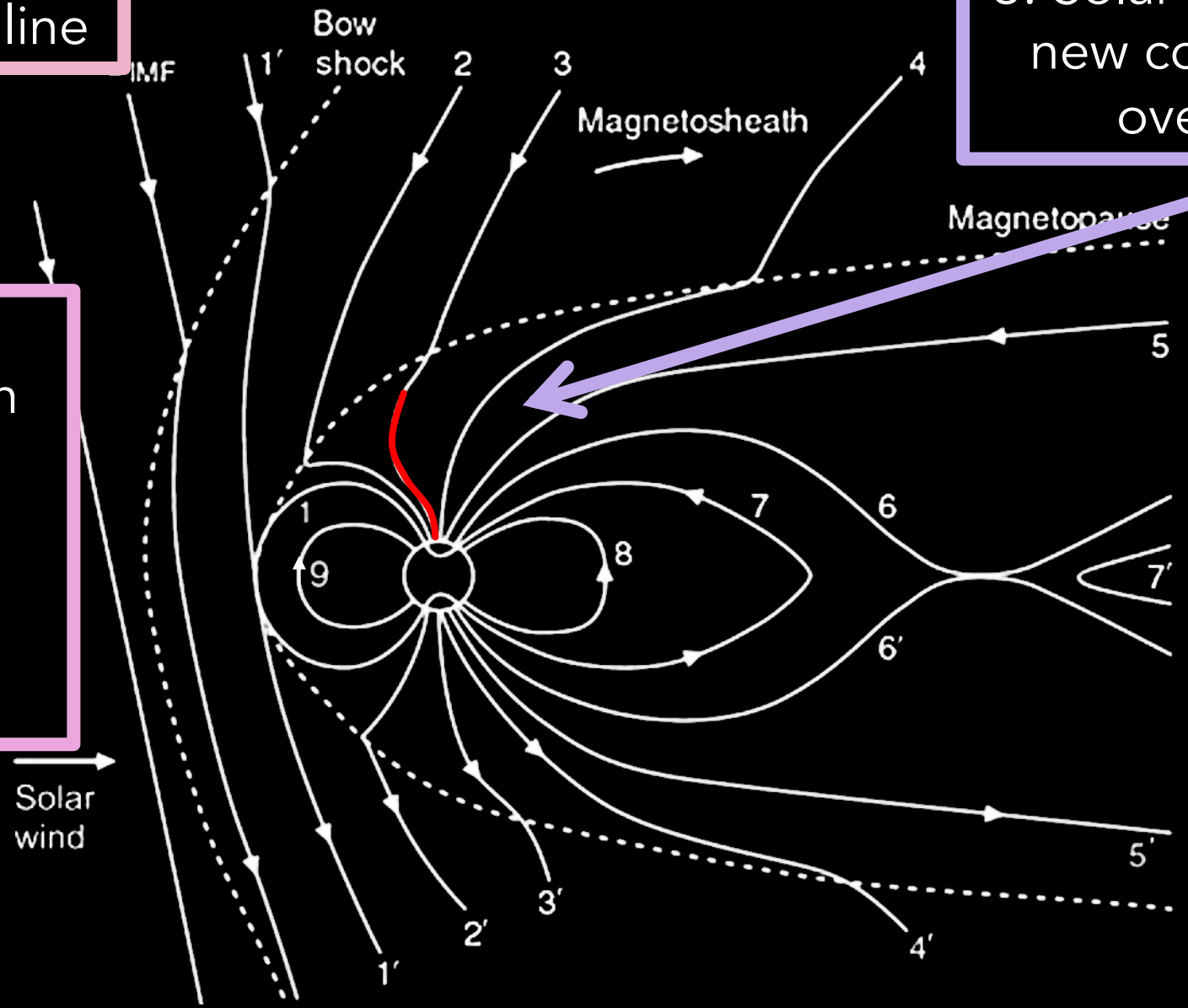
1. Closed field line

2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

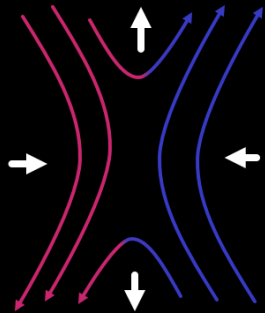
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

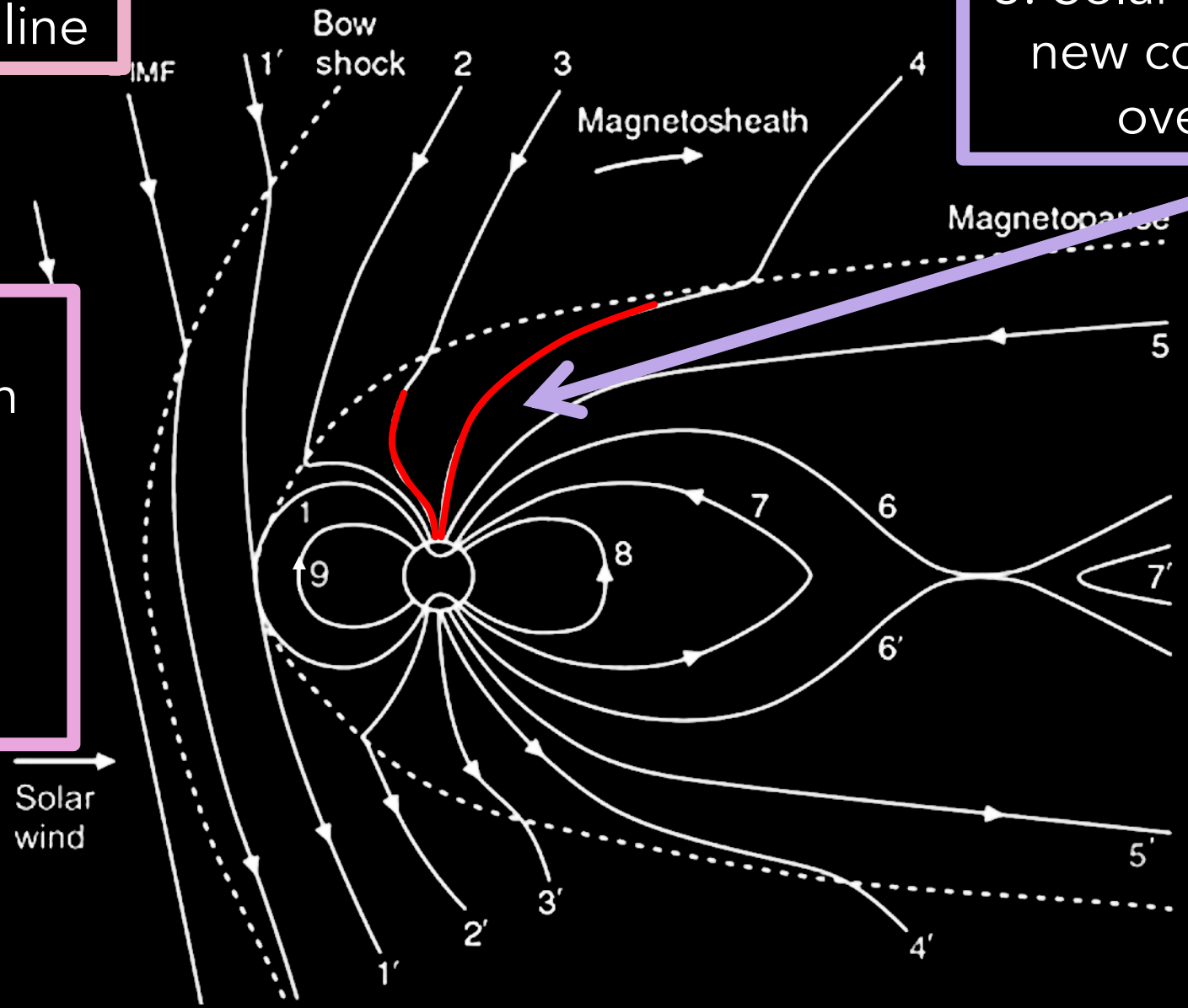
1. Closed field line

2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

$-B_z$

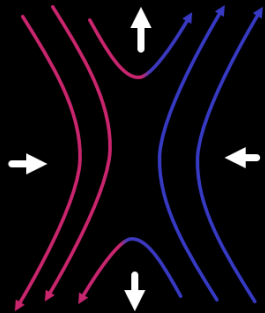




# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

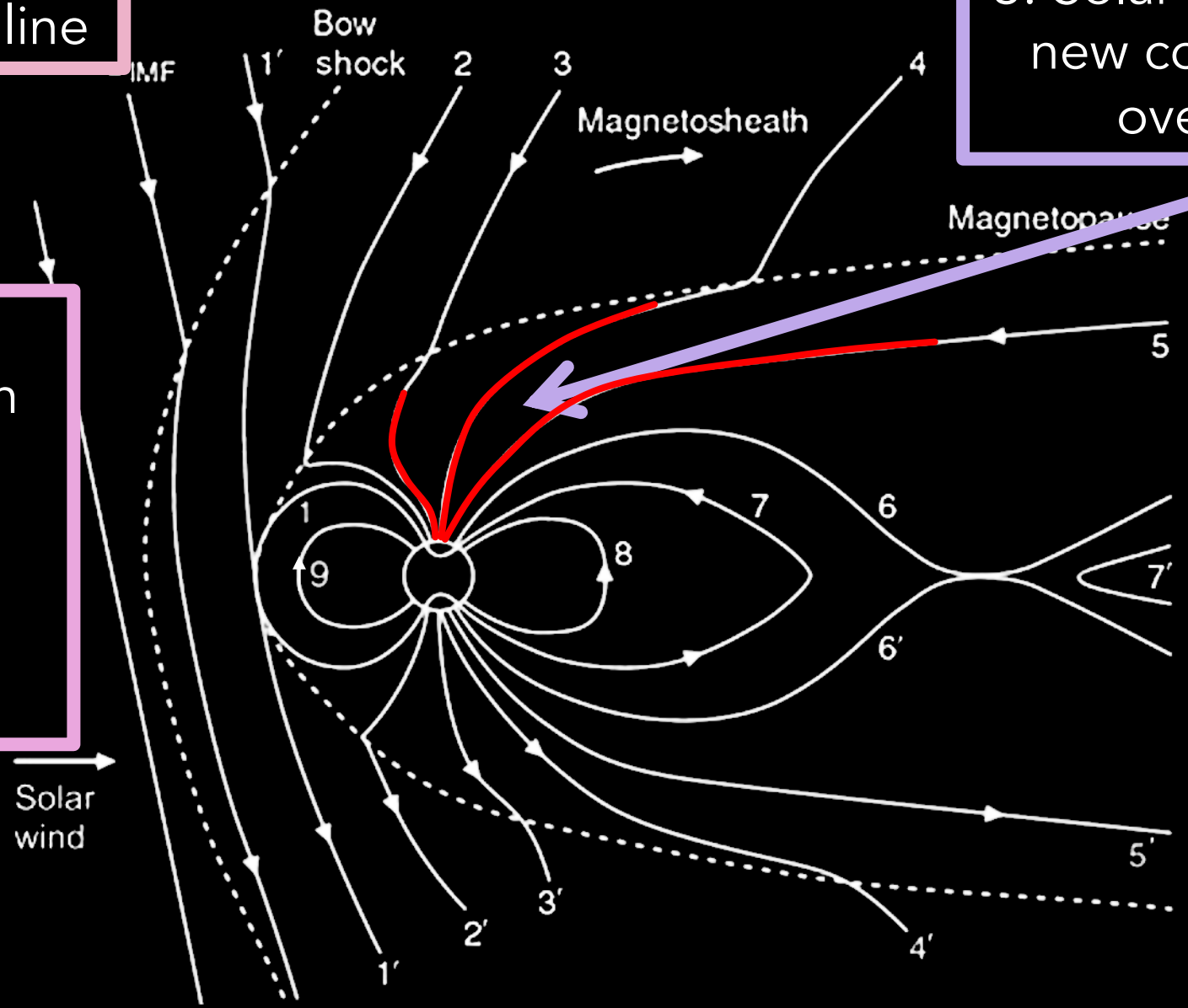
1. Closed field line

2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

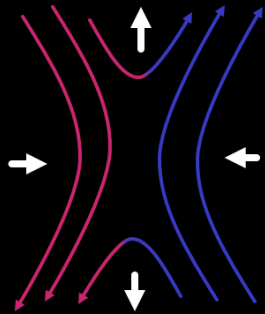
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

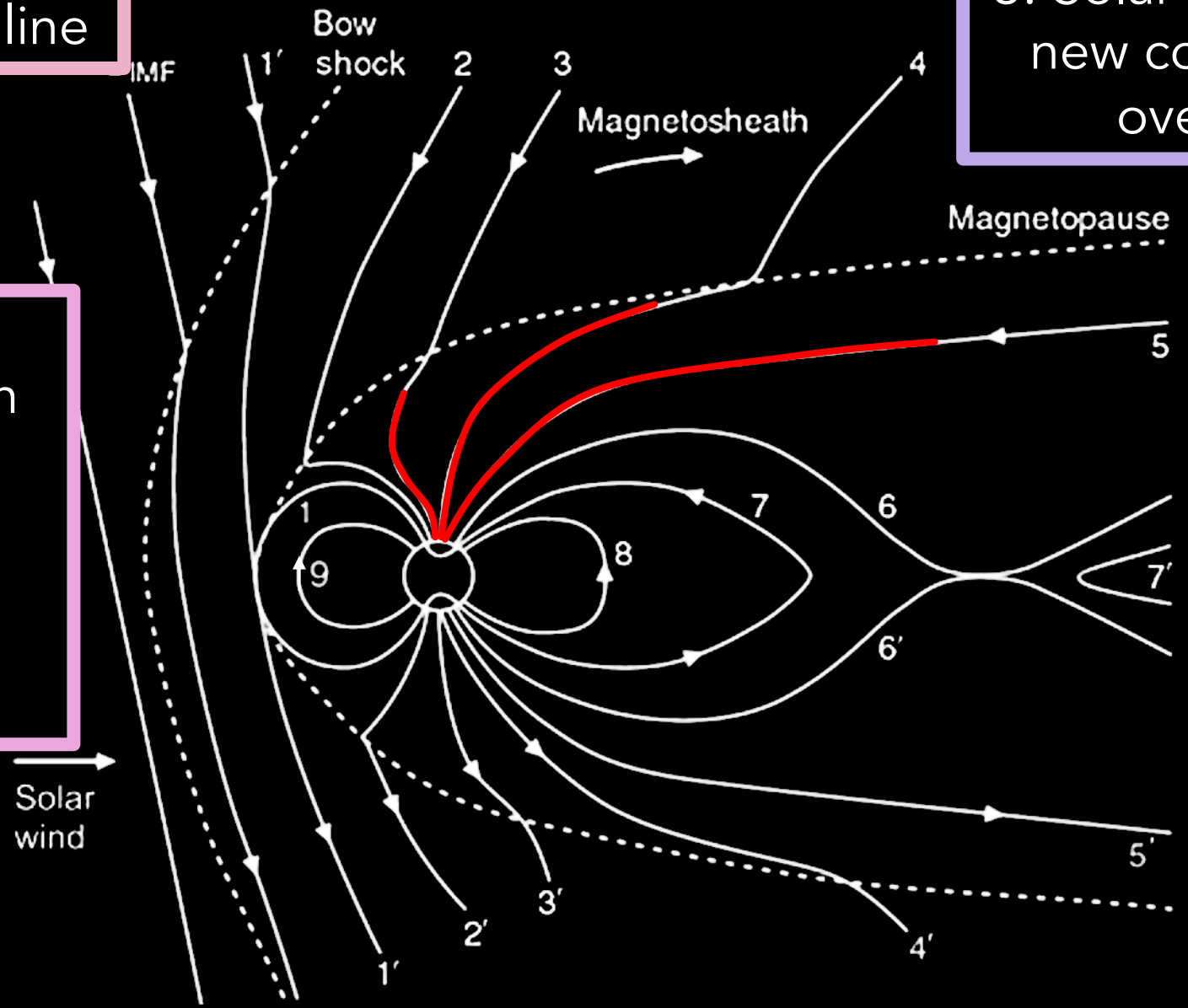
1. Closed field line

2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

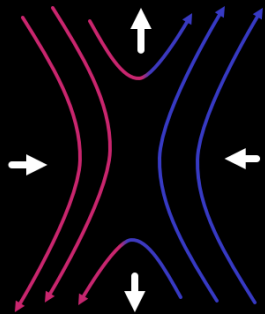
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

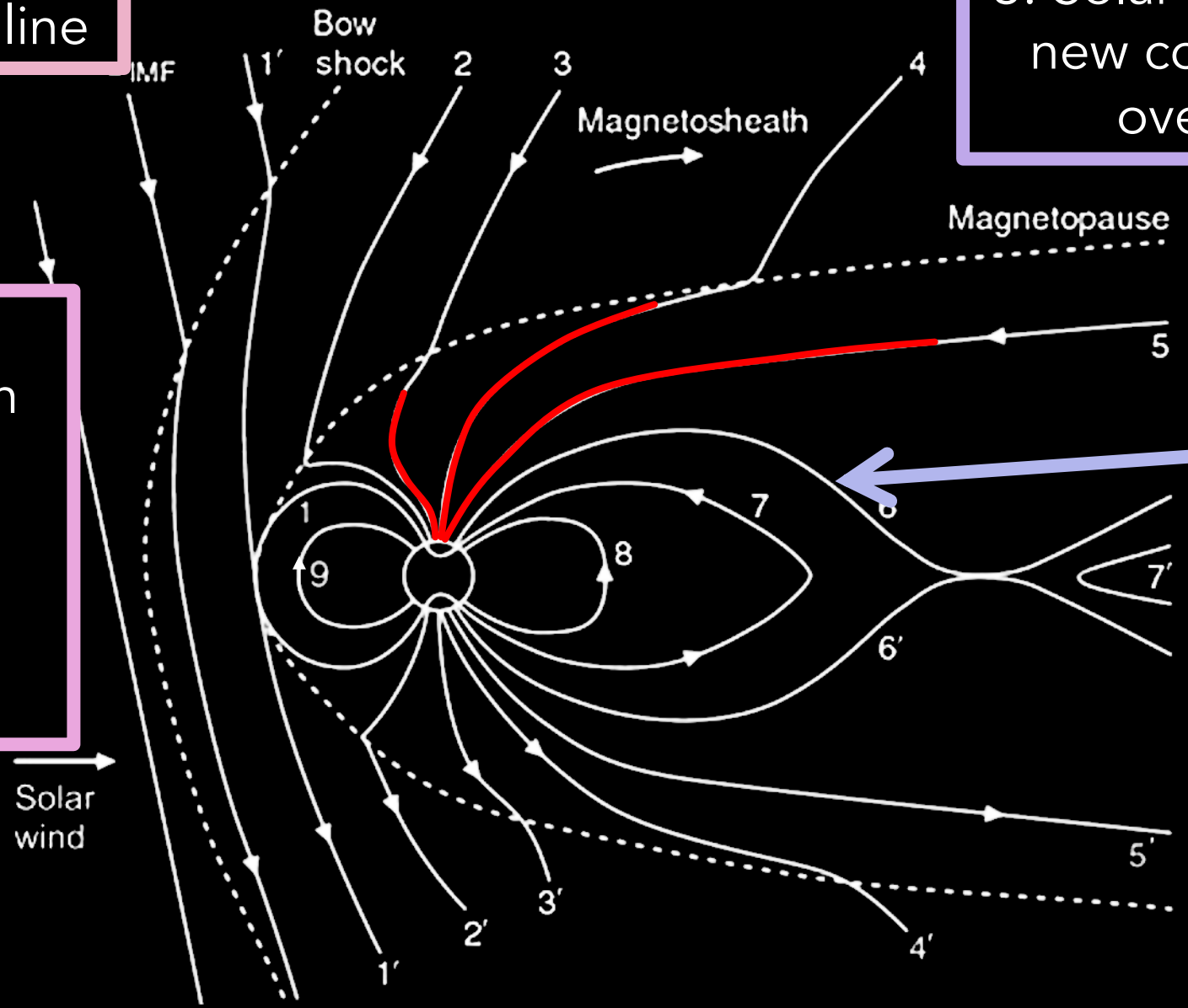
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

4. Field line sinks into tail

$-B_z$



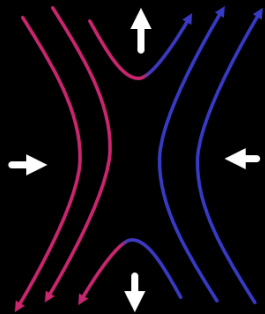




# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

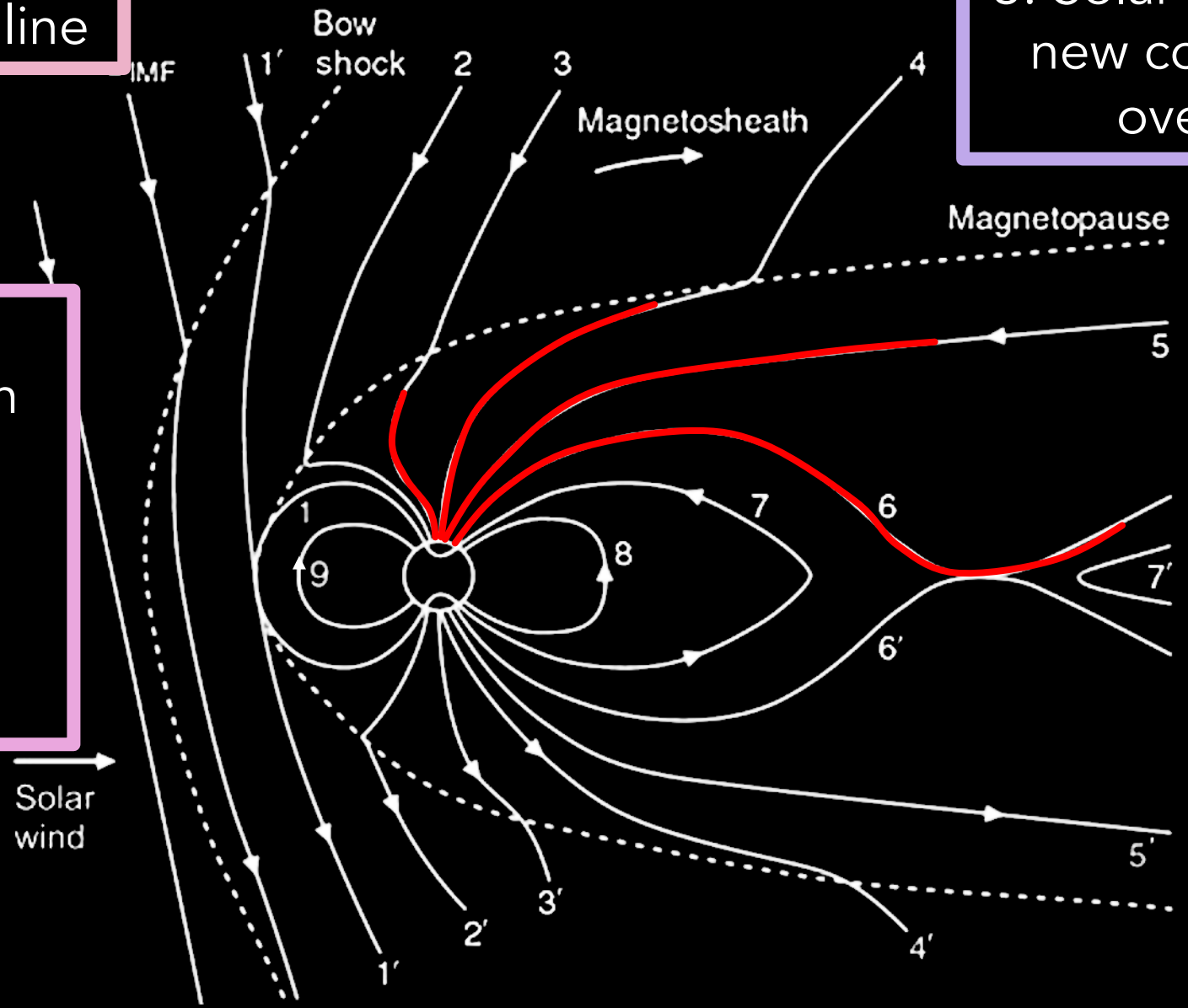
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

4. Field line sinks into tail

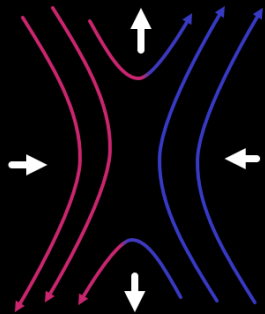
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

2. Dayside Reconnection

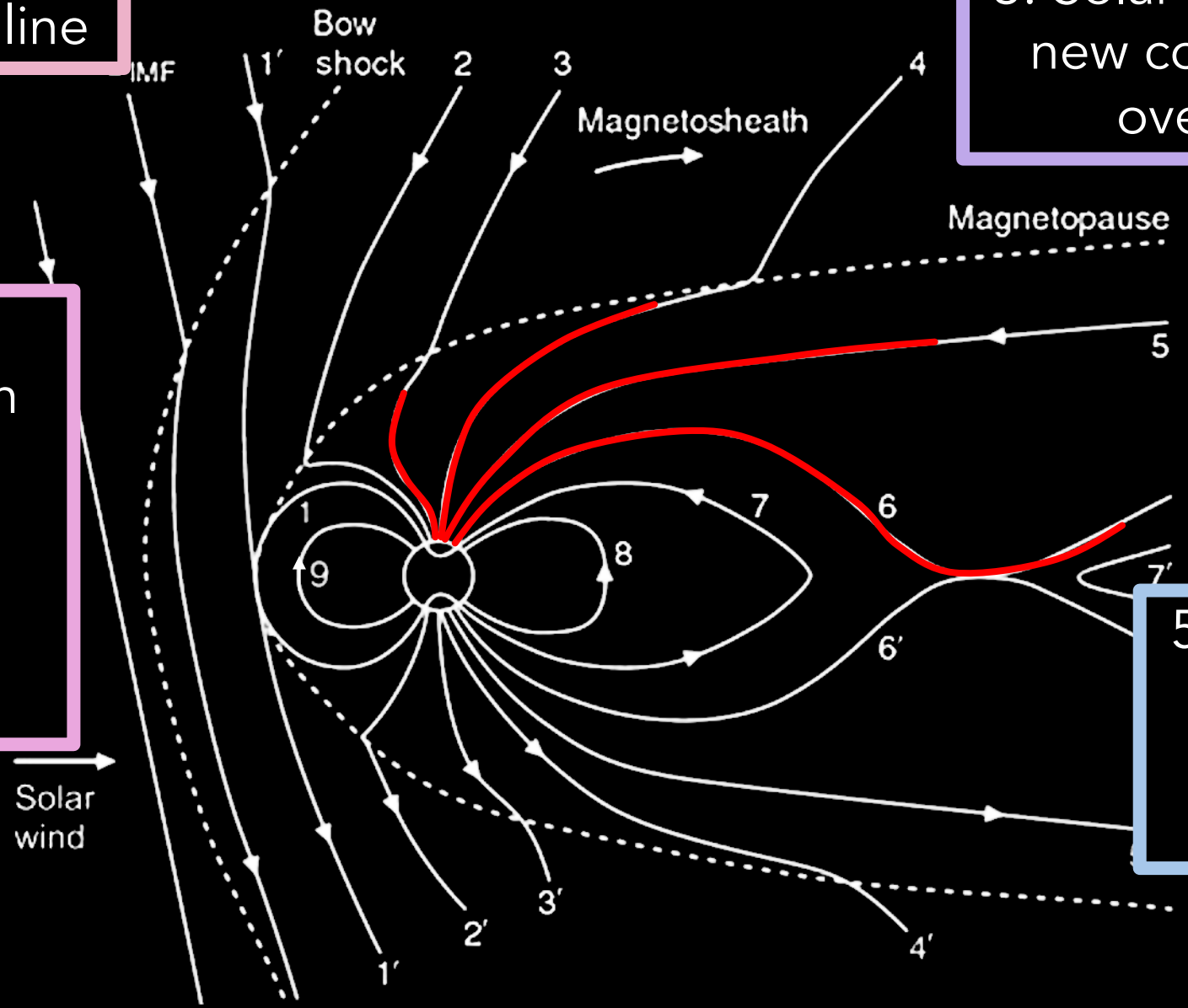


3. Solar wind MFL drags the new connected field lines over the polar cap

4. Field line sinks into tail

5. Tail Reconnection

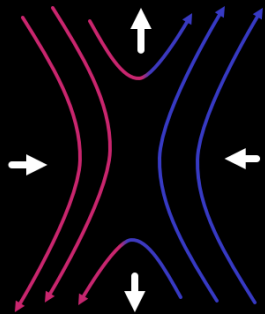
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

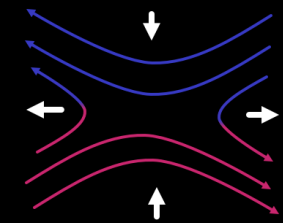
2. Dayside Reconnection



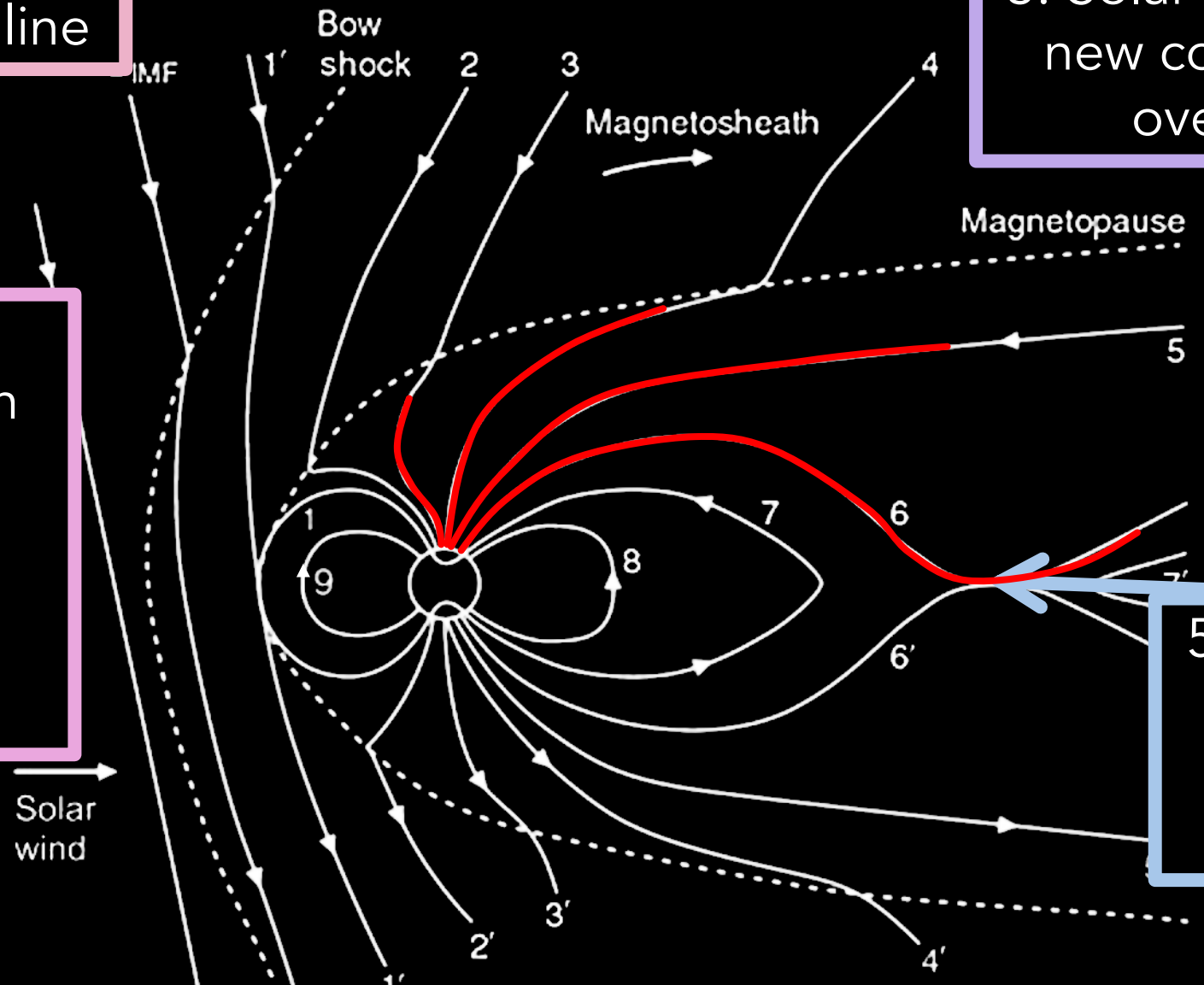
3. Solar wind MFL drags the new connected field lines over the polar cap

4. Field line sinks into tail

5. Tail Reconnection



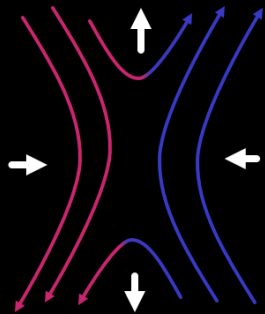
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

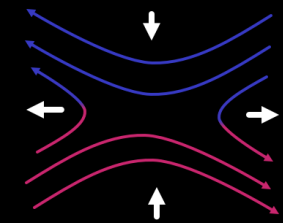
2. Dayside Reconnection



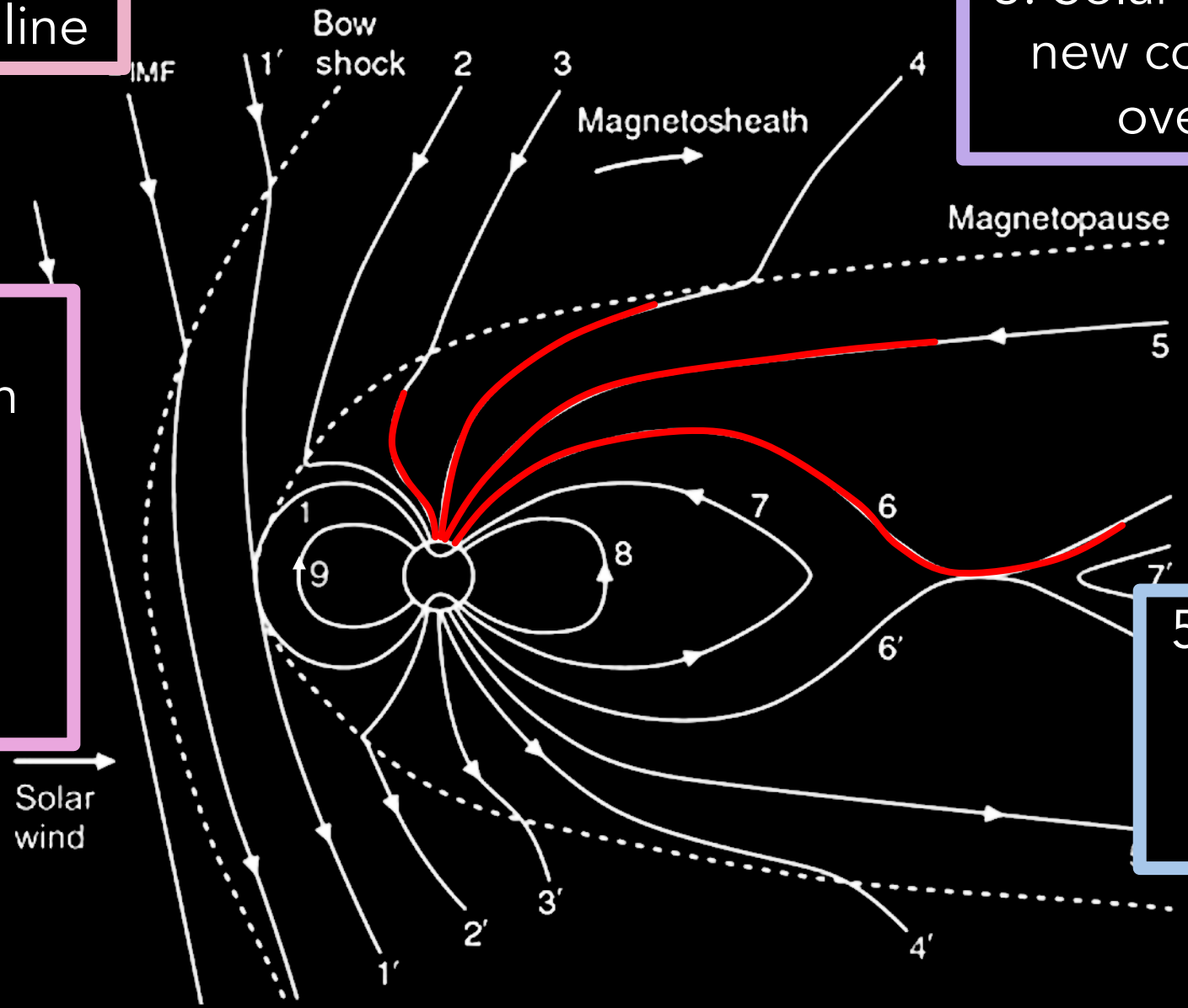
3. Solar wind MFL drags the new connected field lines over the polar cap

4. Field line sinks into tail

5. Tail Reconnection



$-B_z$

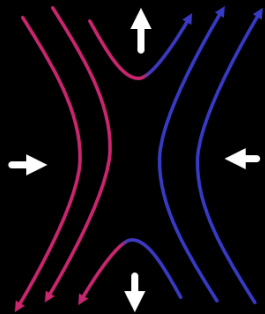




# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

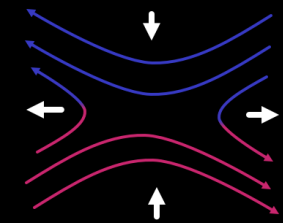
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

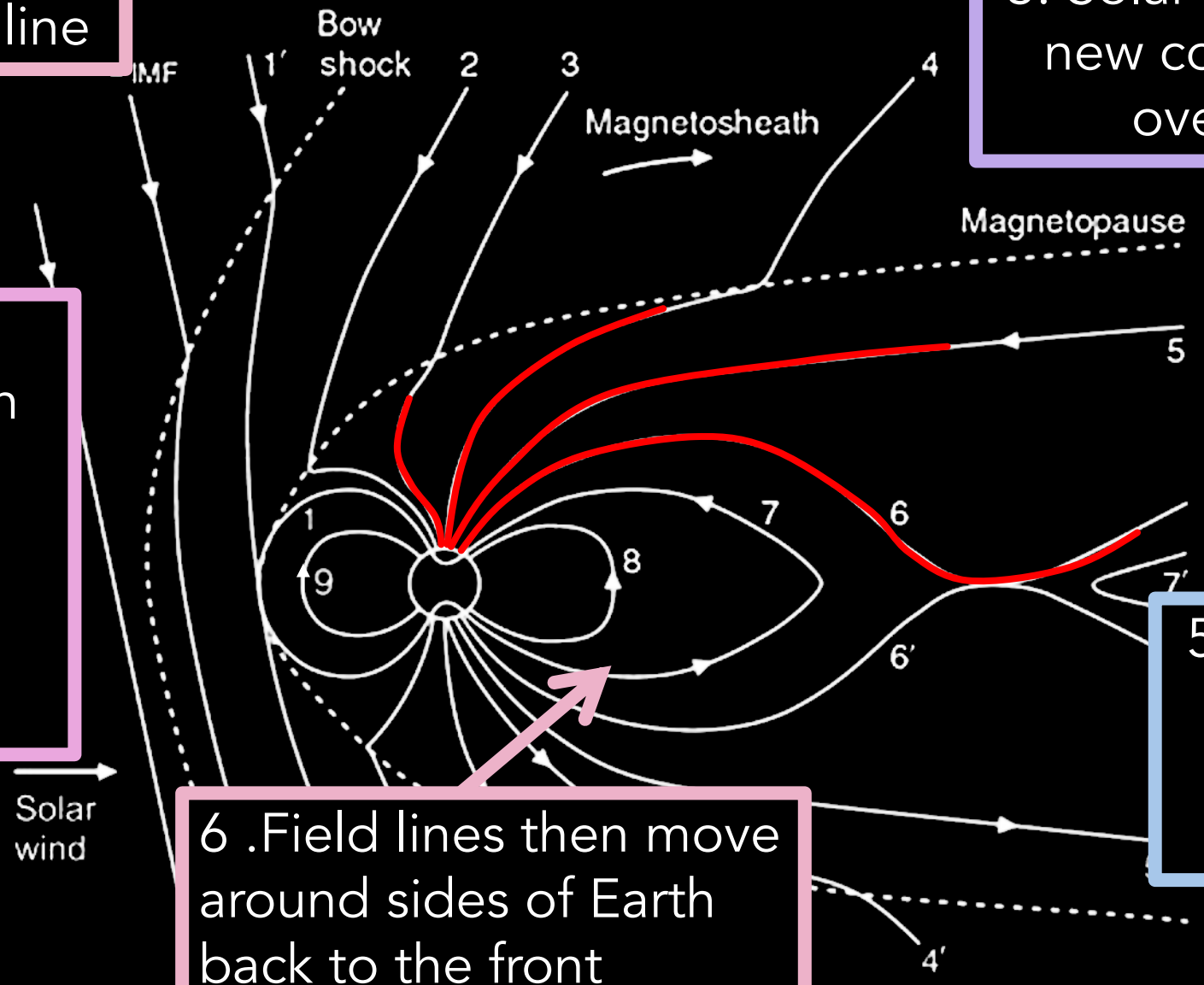
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

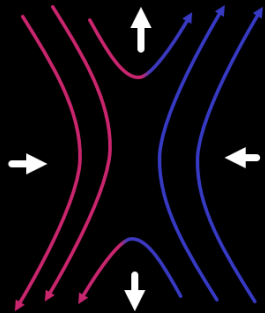
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

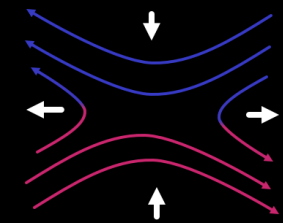
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

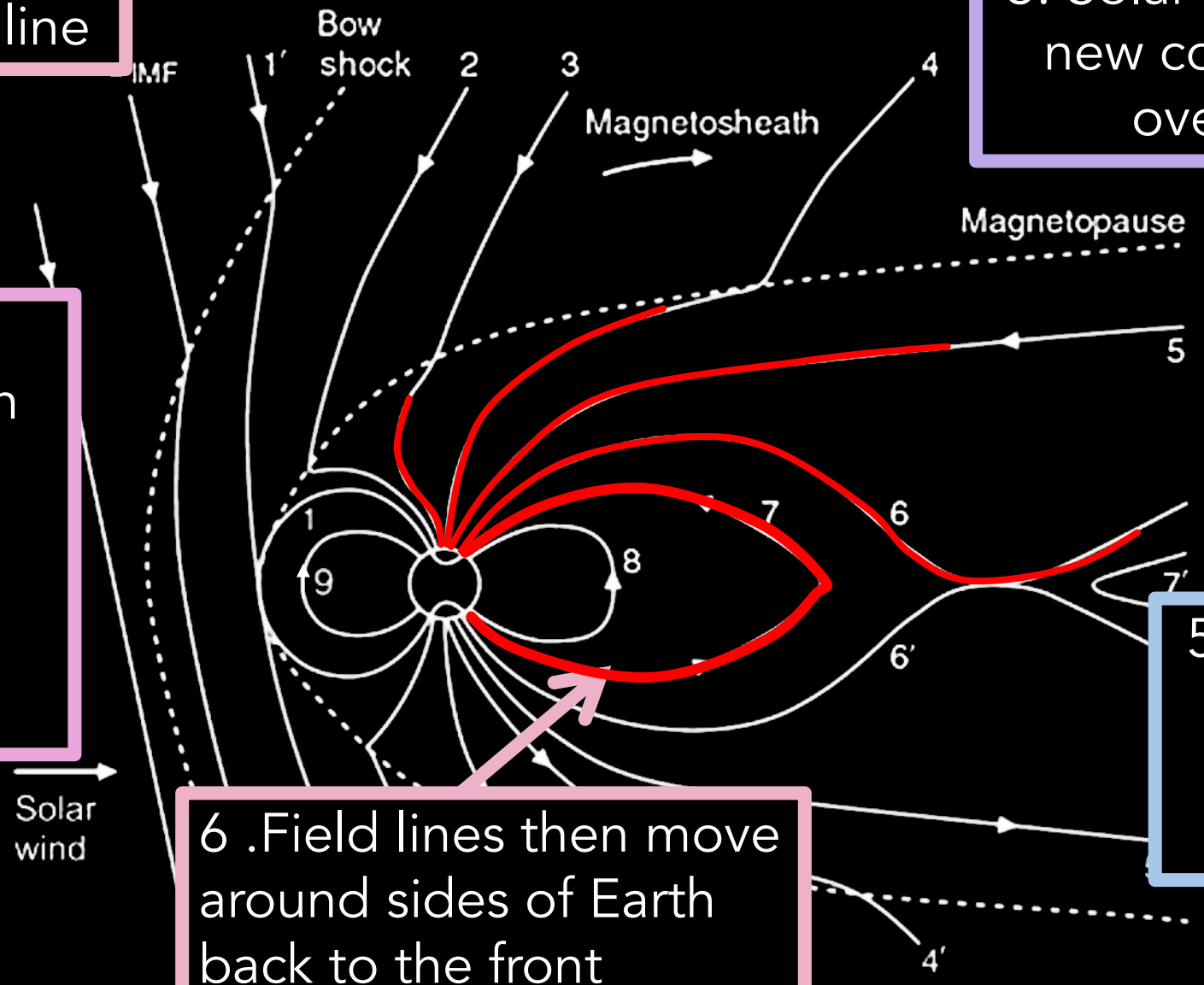
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

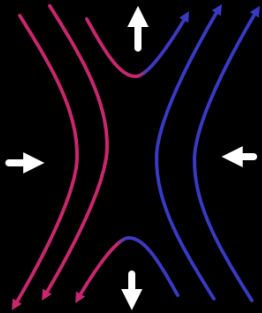
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

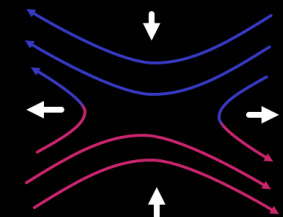
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

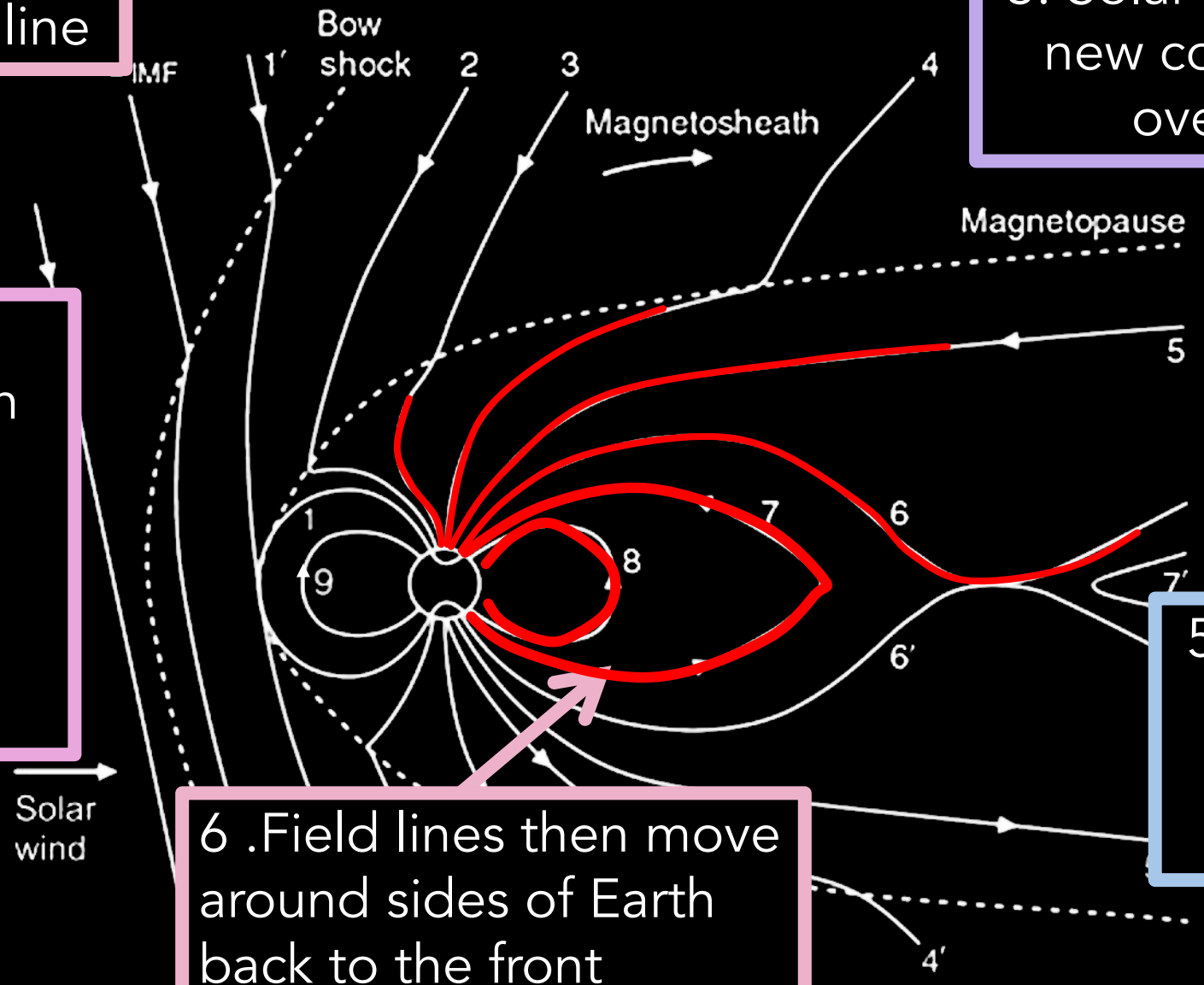
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

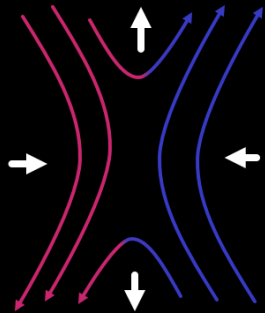
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

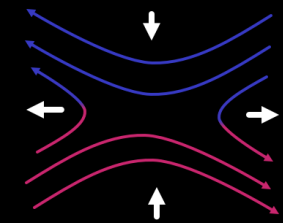
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

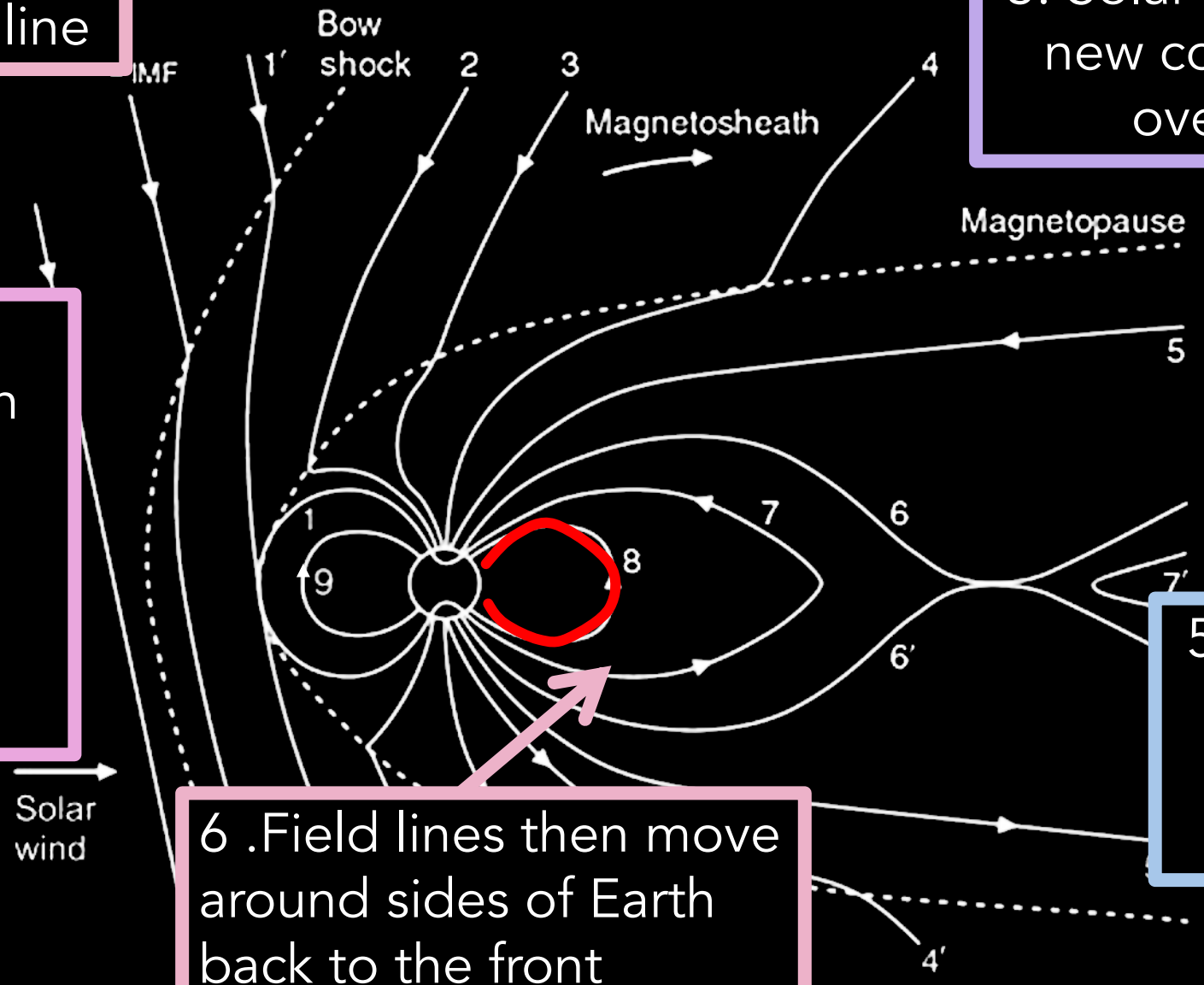
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

$-B_z$

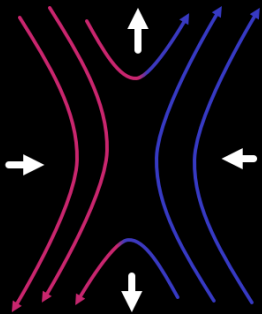




# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

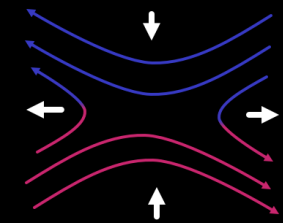
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

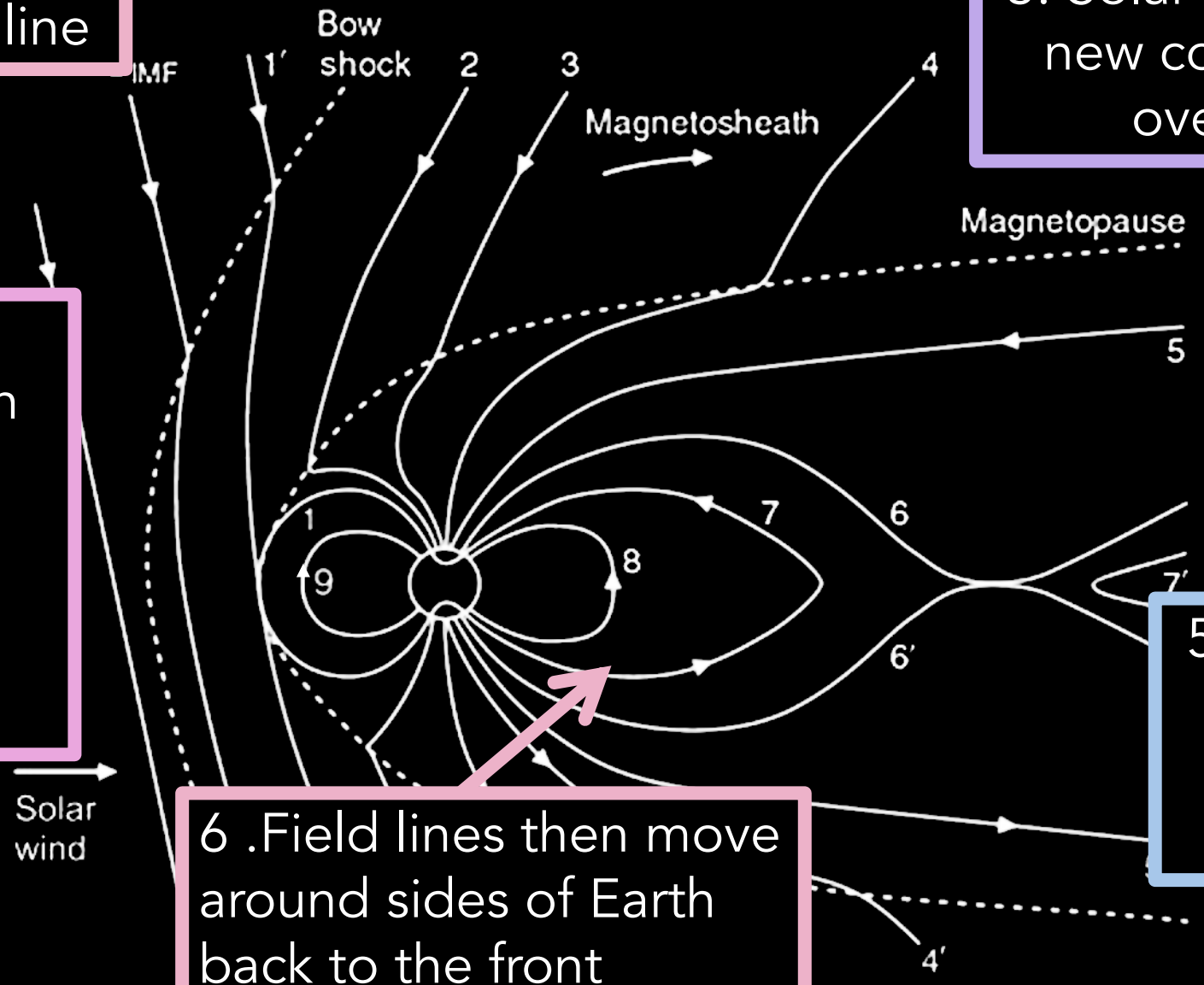
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

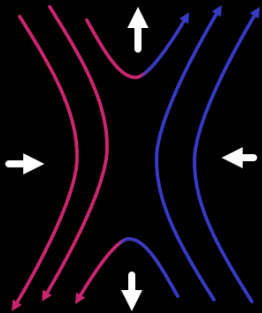
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

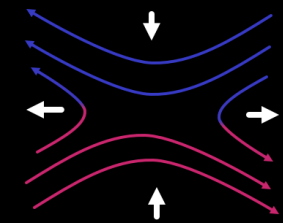
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

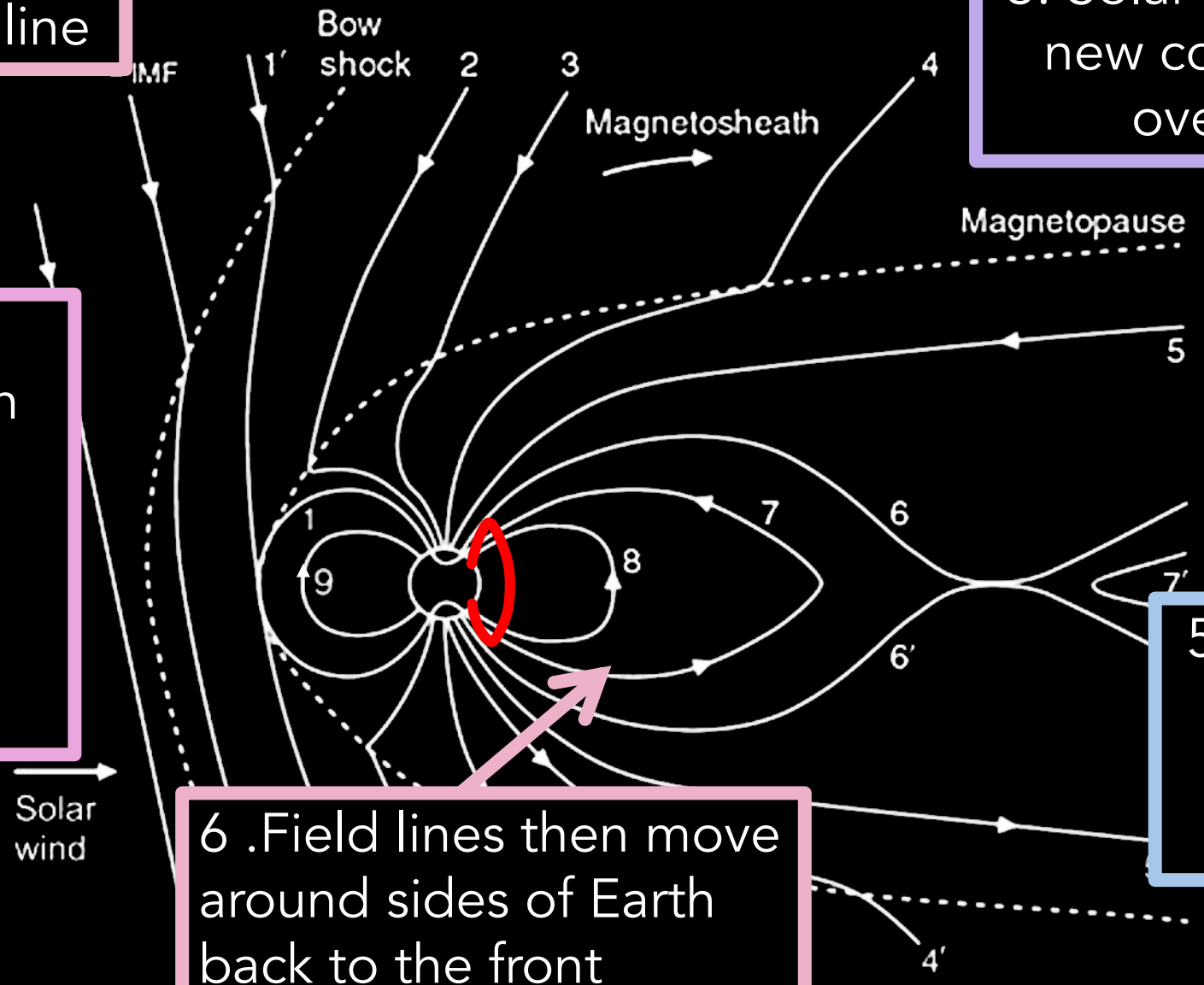
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

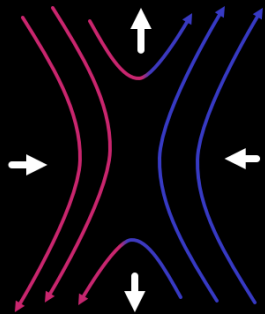
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

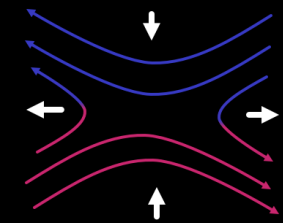
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

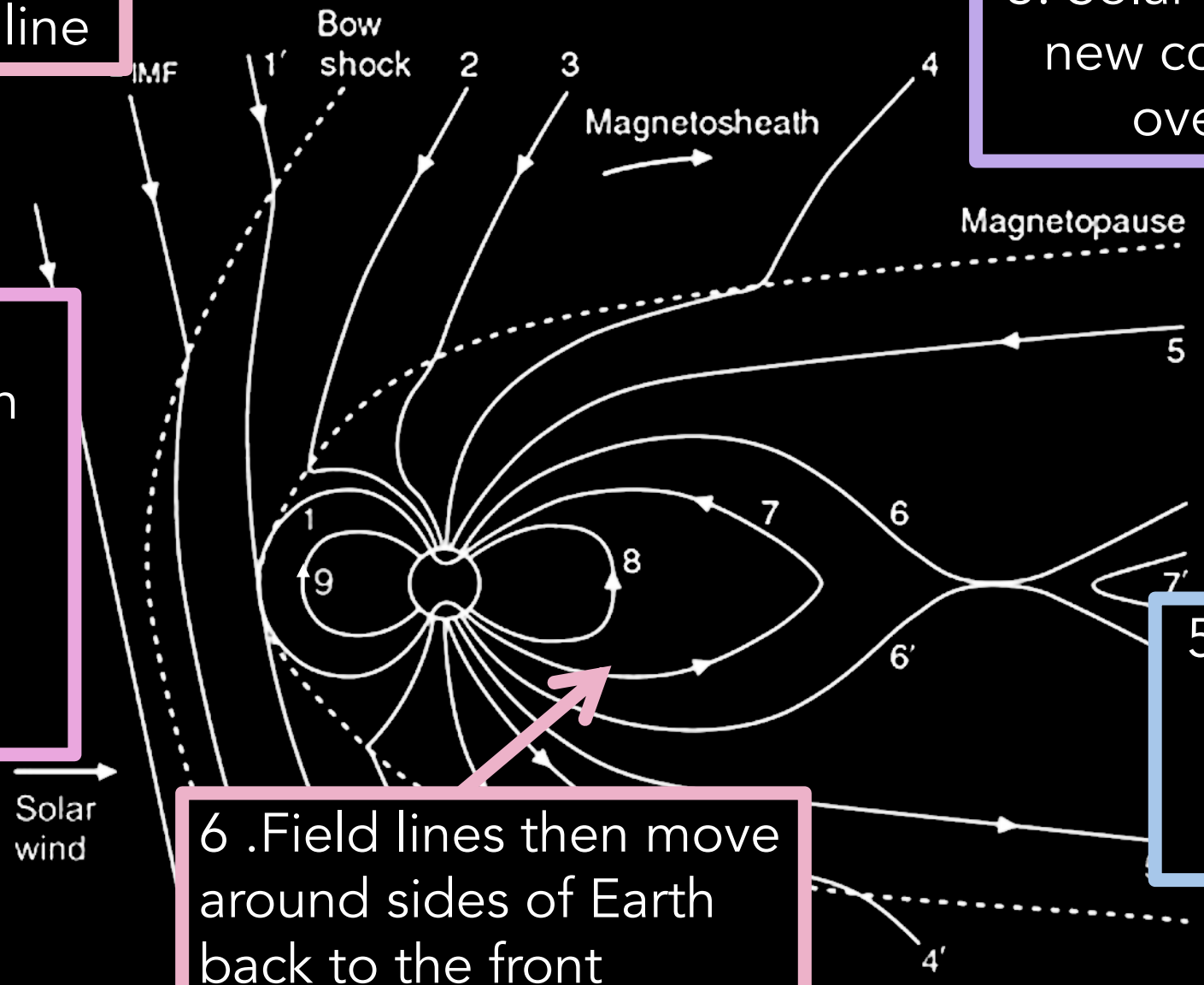
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

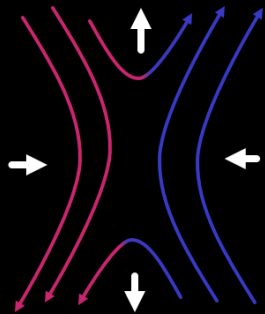
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

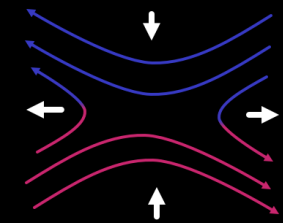
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

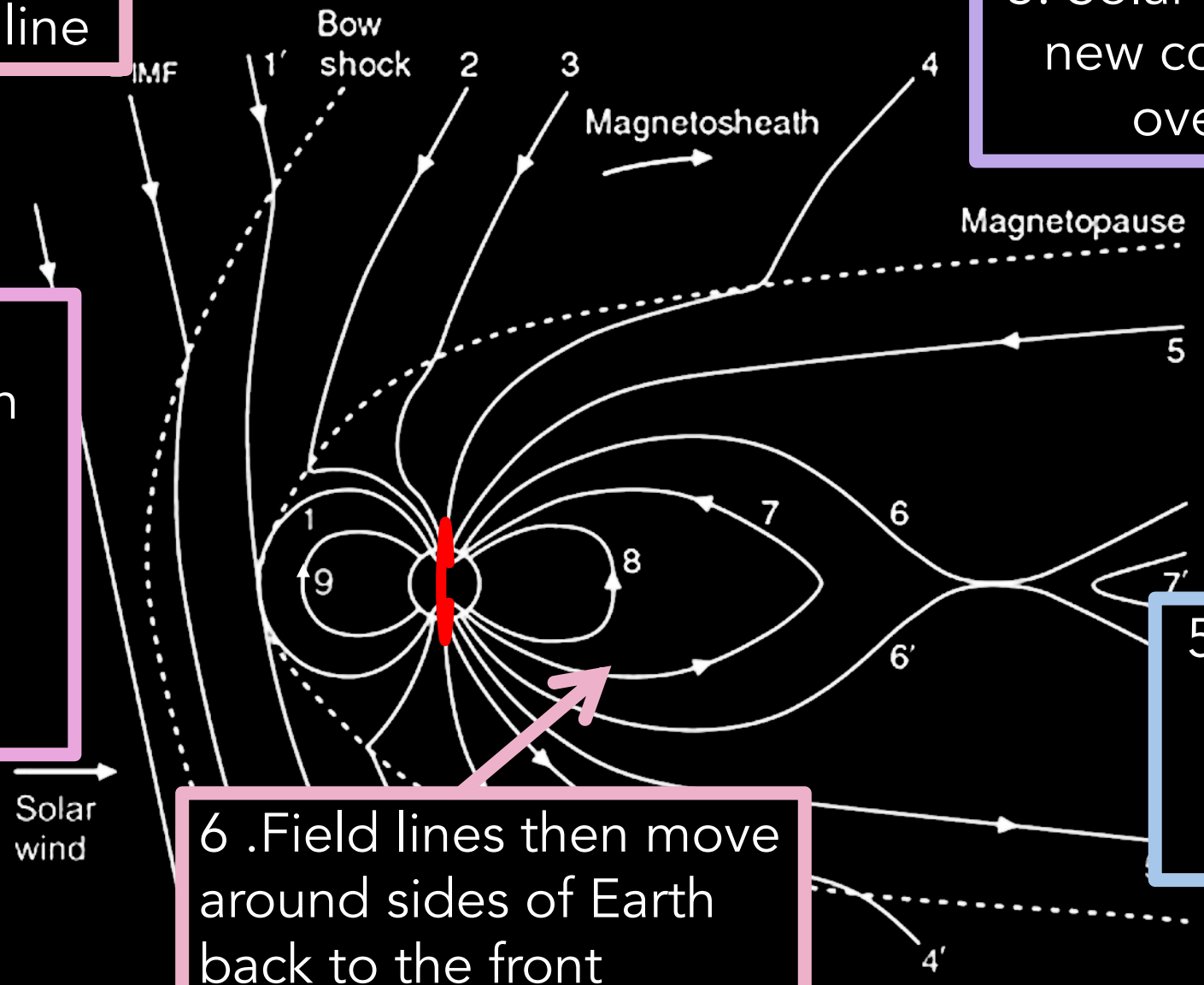
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

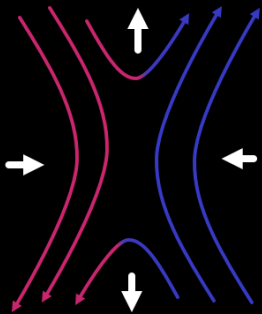
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

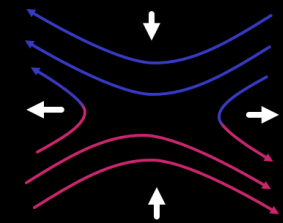
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

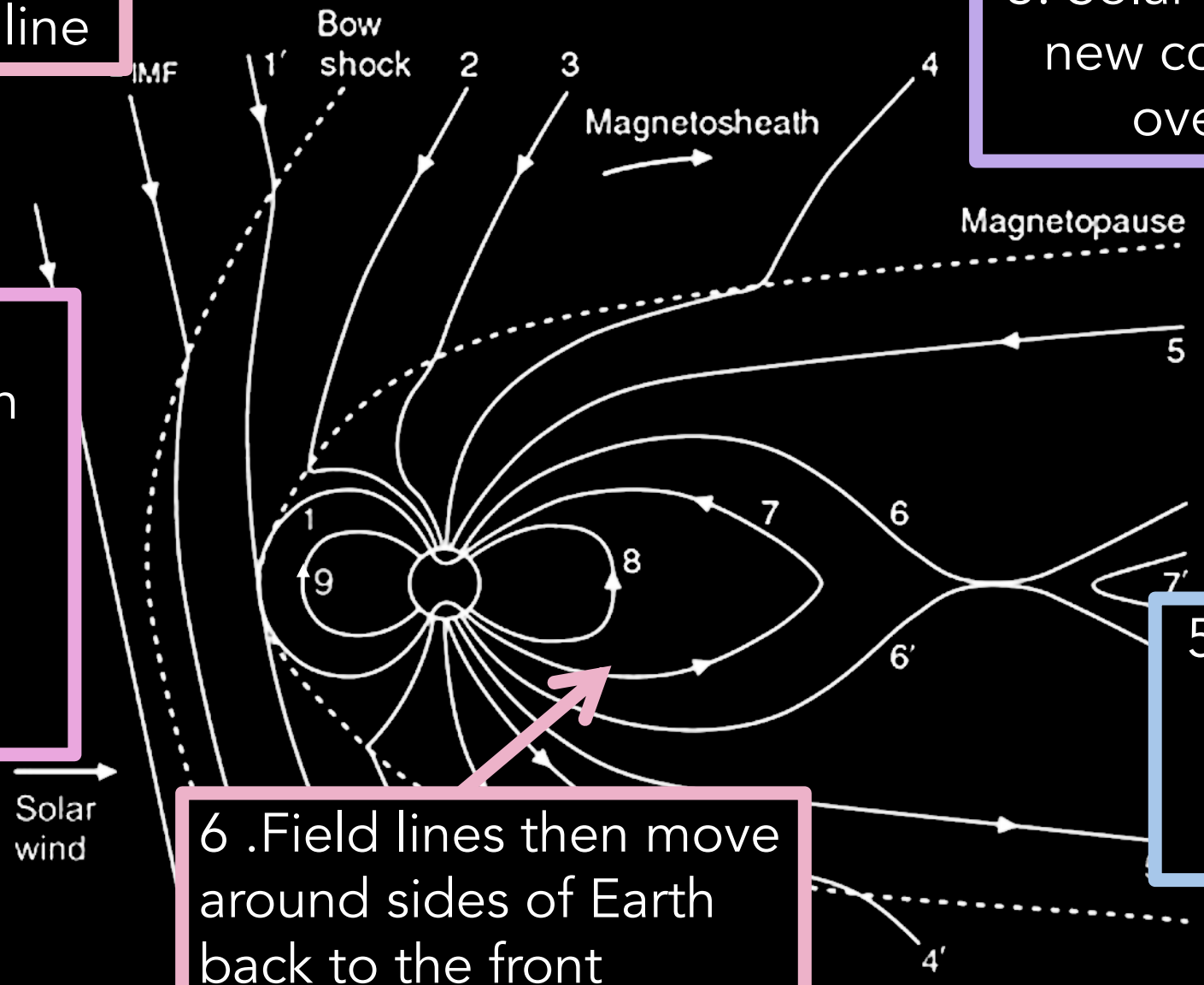
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

$-B_z$

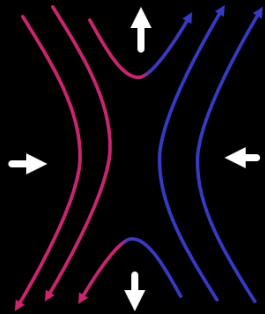




# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

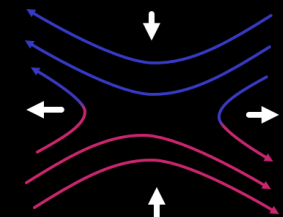
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

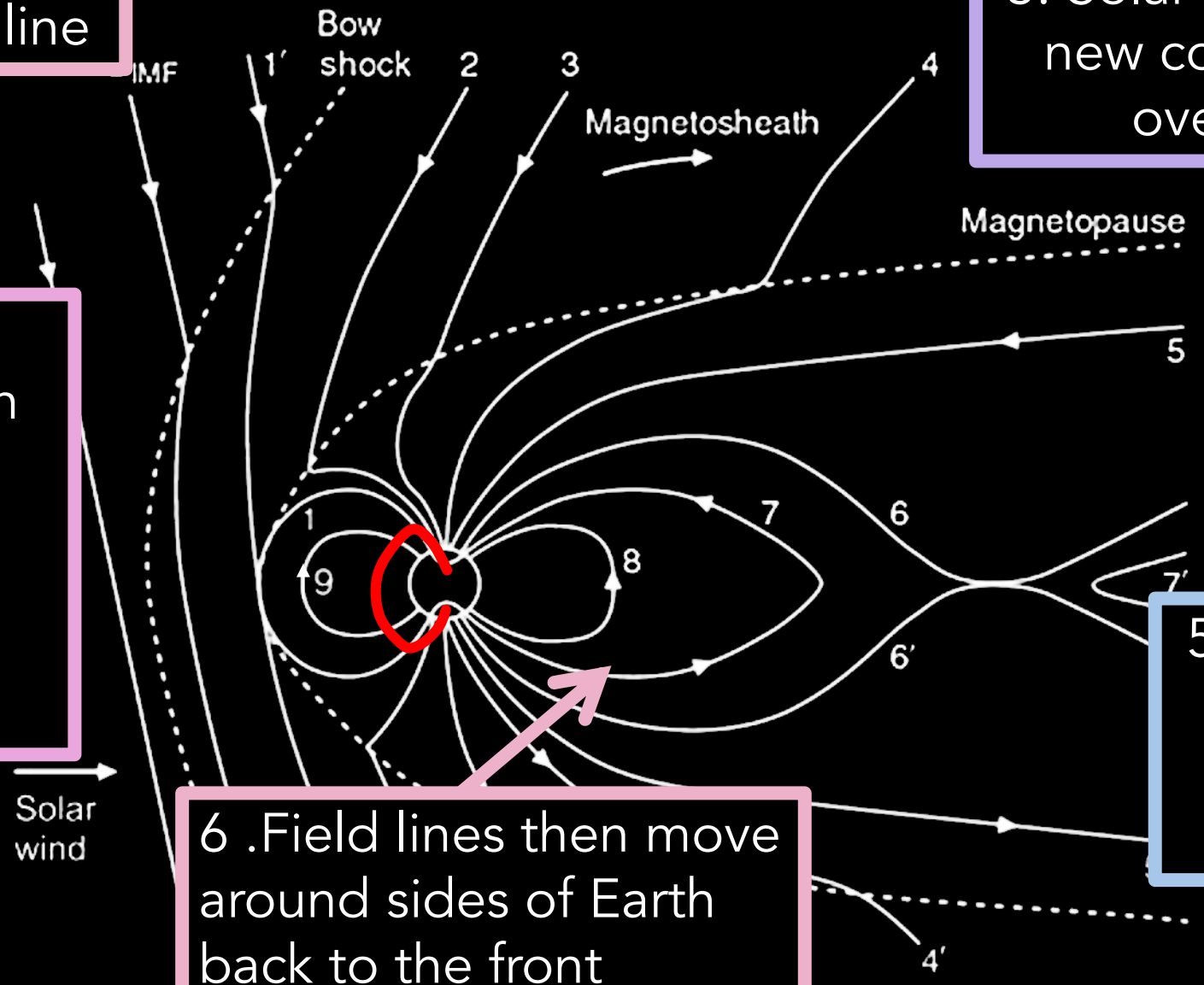
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

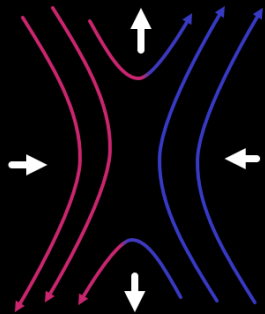
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

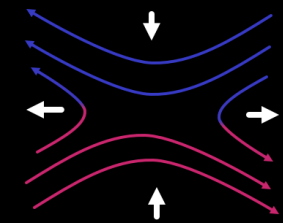
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

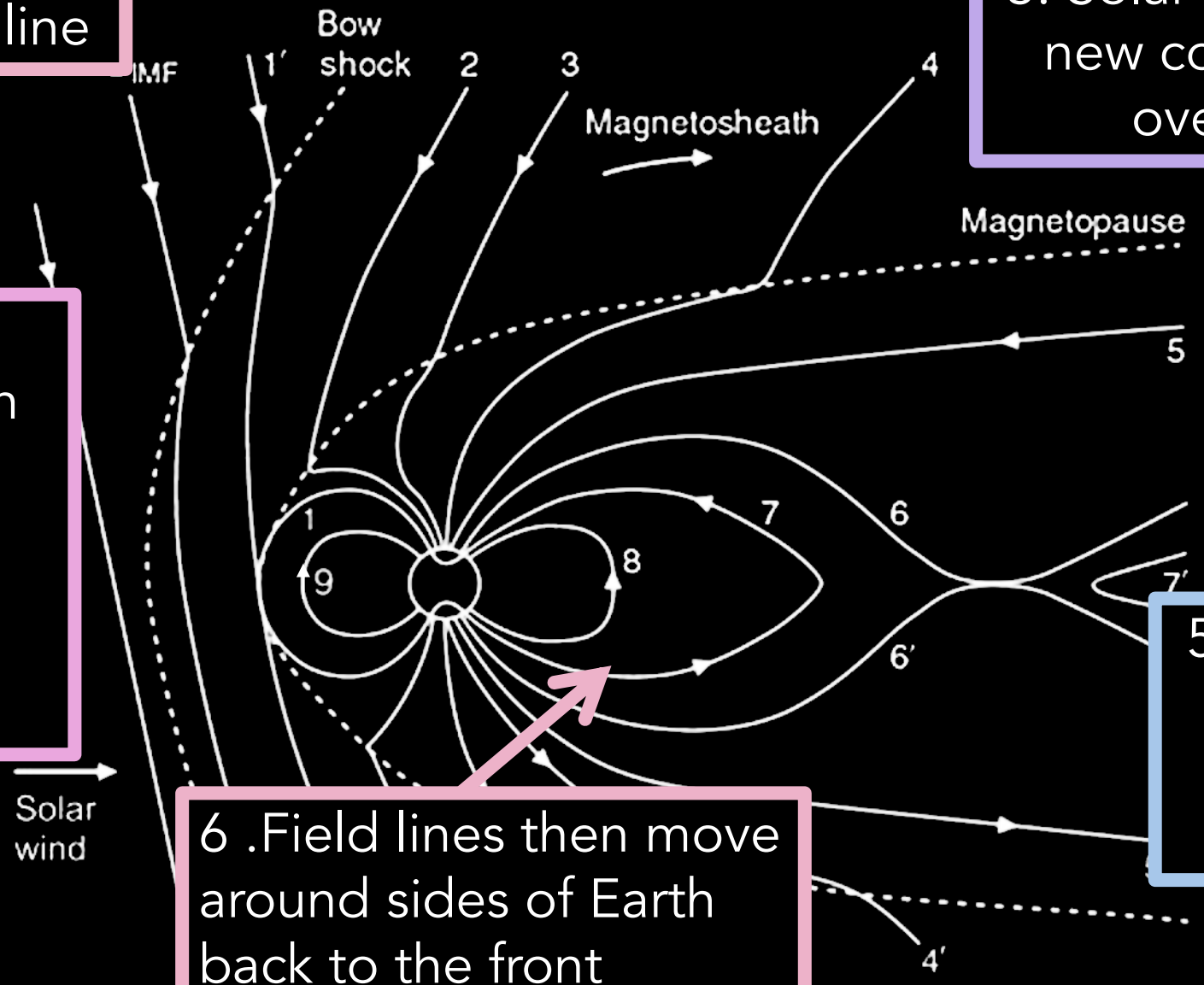
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

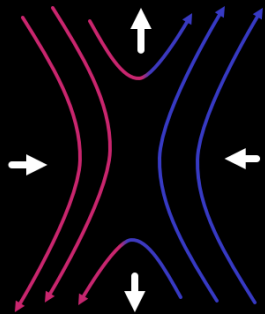
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

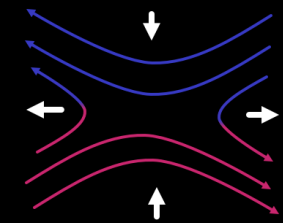
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

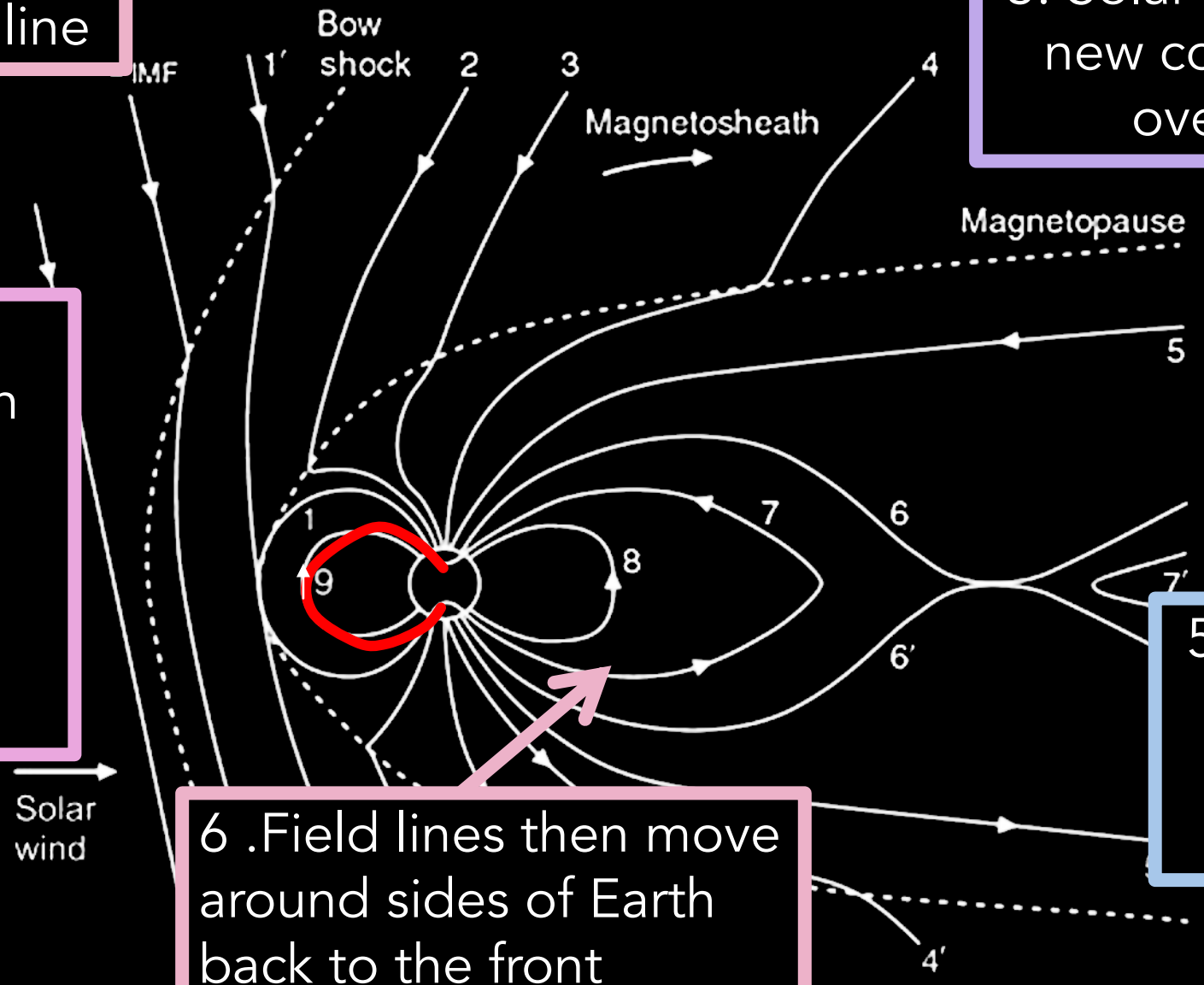
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

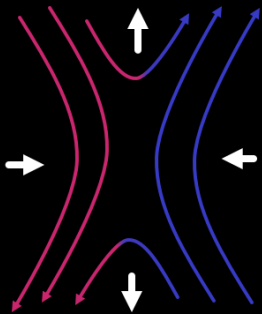
$-B_z$



# EARTH IN THE SOLAR WIND: DUNGEY CYCLE

1. Closed field line

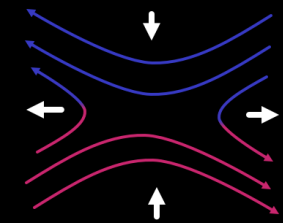
2. Dayside Reconnection



3. Solar wind MFL drags the new connected field lines over the polar cap

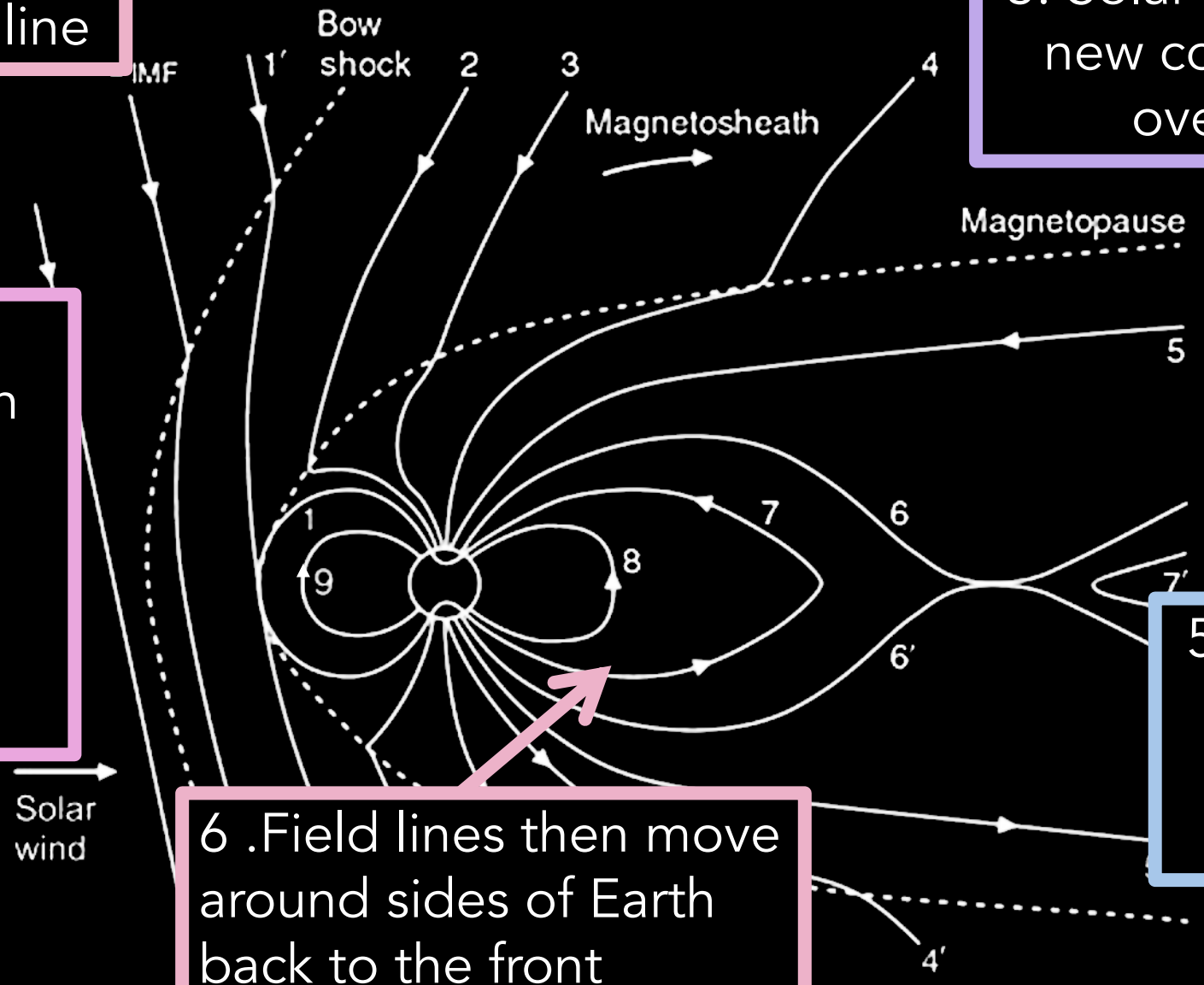
4. Field line sinks into tail

5. Tail Reconnection



6. Field lines then move around sides of Earth back to the front

$-B_z$



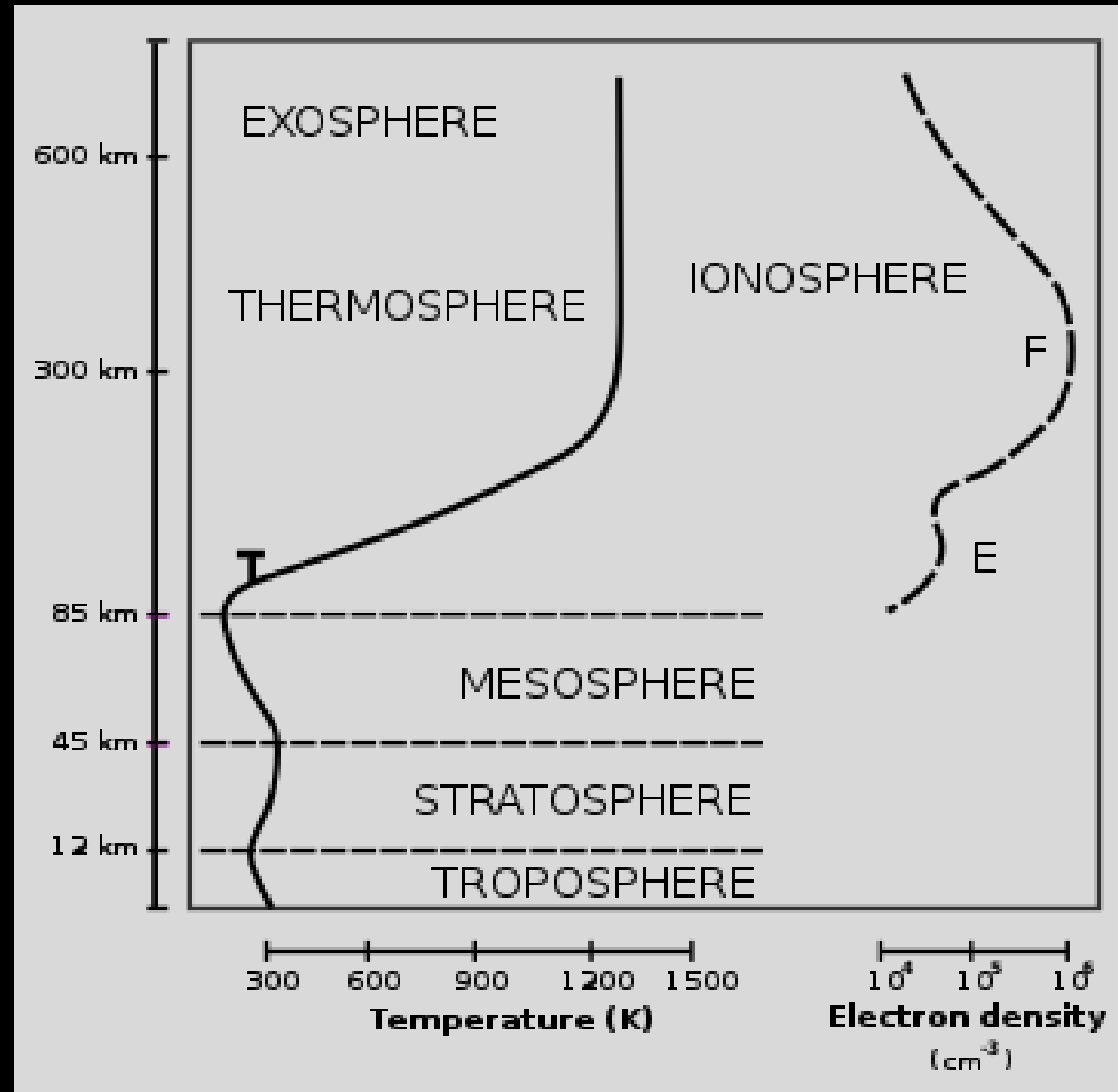
# EARTH'S IONOSPHERE

The Ionosphere at Earth exists from ~50 to 1000+ km above the Earth's surface

Coincident with the neutral thermosphere

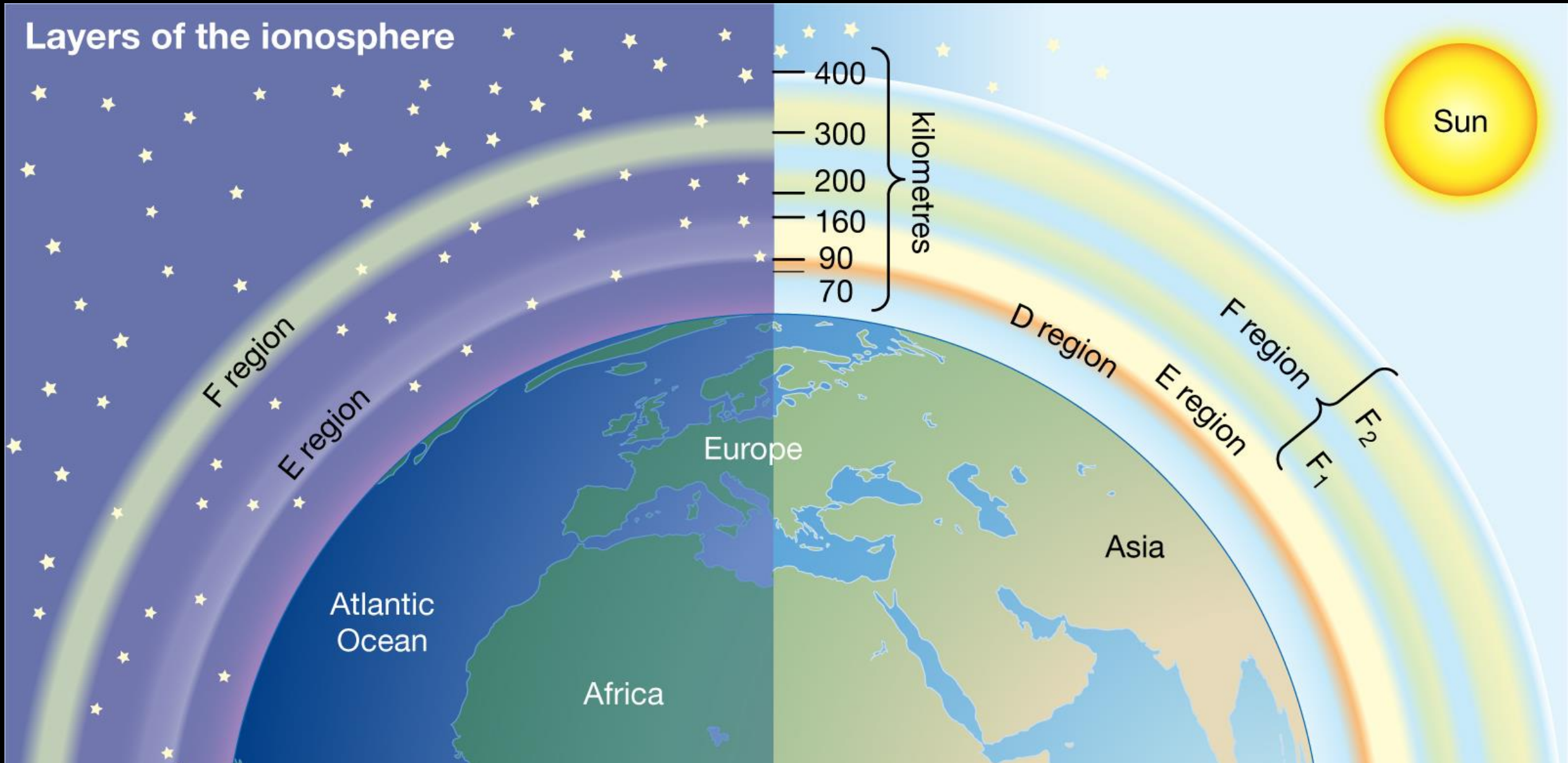
Mainly caused by solar radiation ionizing the atoms/molecules in the upper atmosphere to create ions and free electrons – a plasma

Comes in layers which are due to a balance of source rate and loss rate of ions dependent on density/solar activity/collisions etc. etc.





# EARTH'S IONOSPHERE



# TRANSLATE TO THE IONOSPHERE: CONVECTION



To Sun



# TRANSLATE TO THE IONOSPHERE: CONVECTION

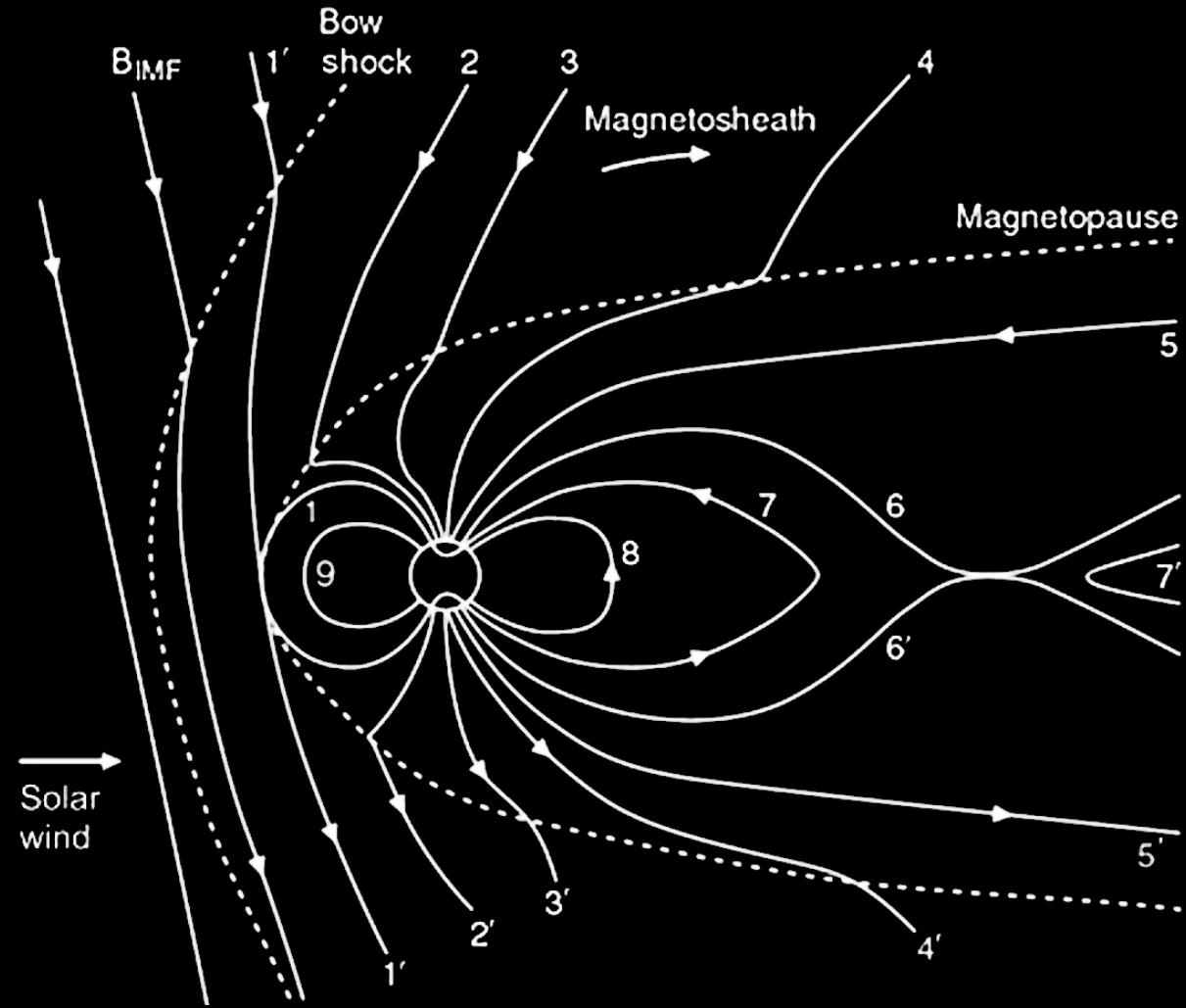


To Sun

# TRANSLATE TO THE IONOSPHERE: CONVECTION



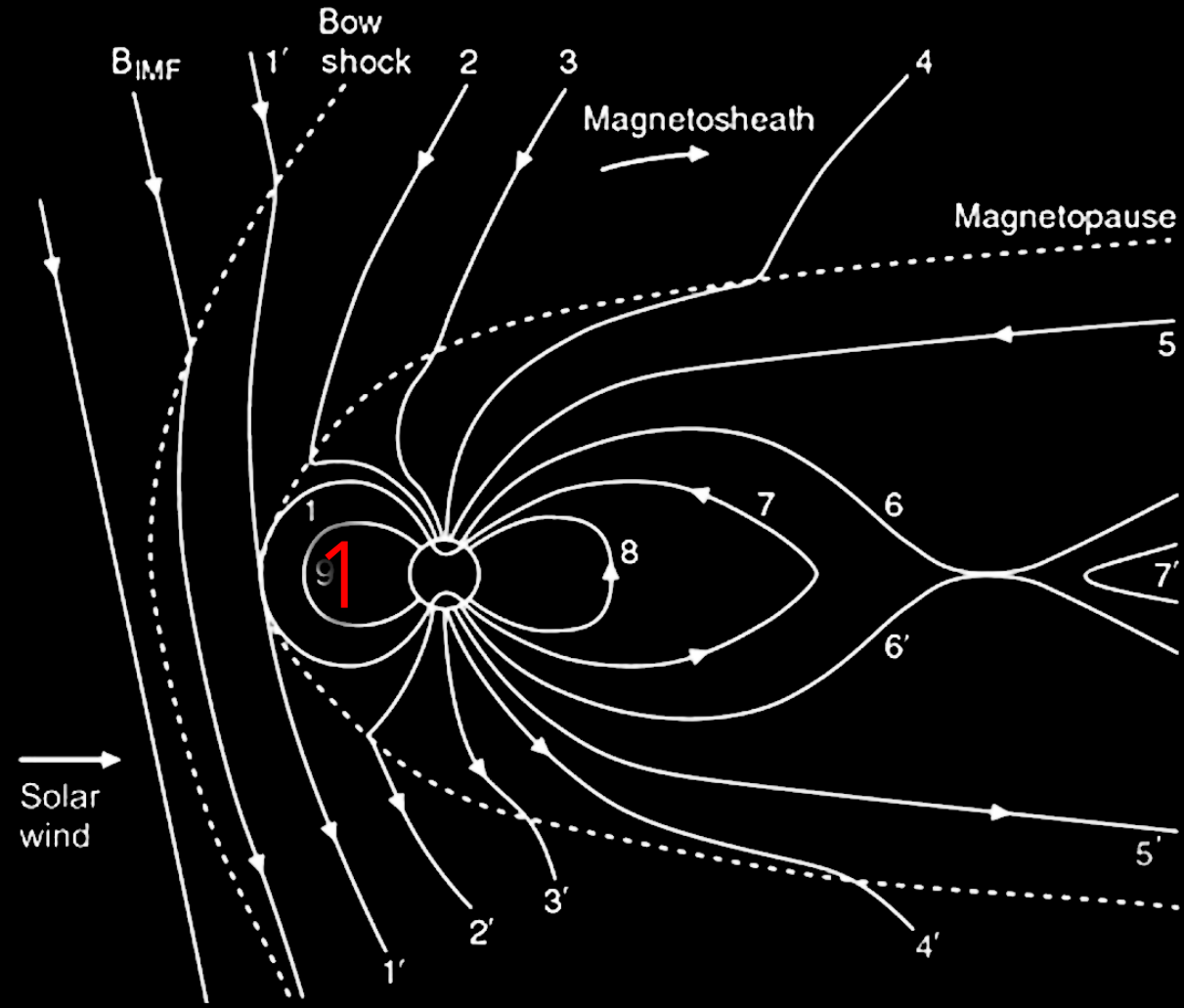
 To Sun



Hughes 1995

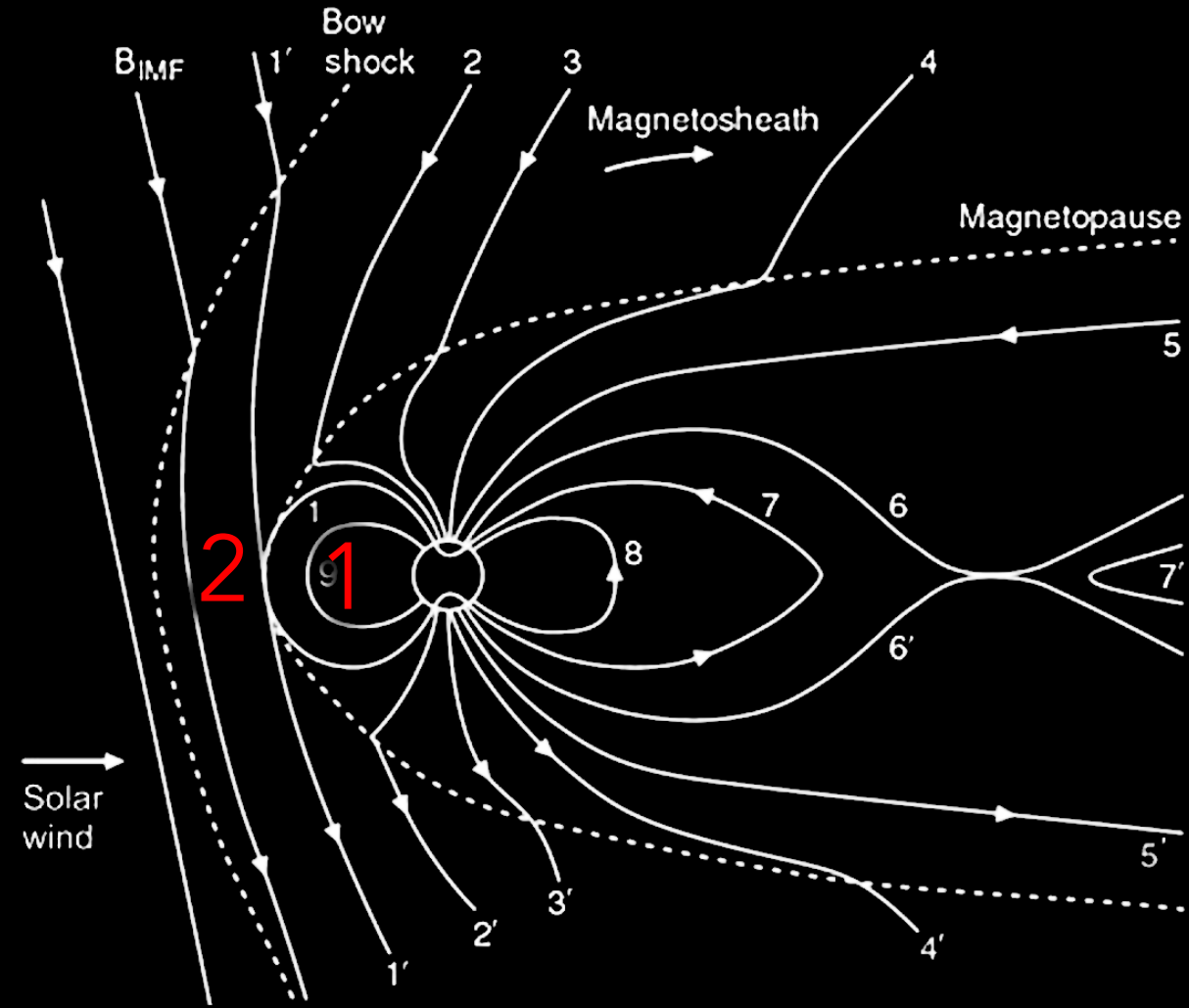
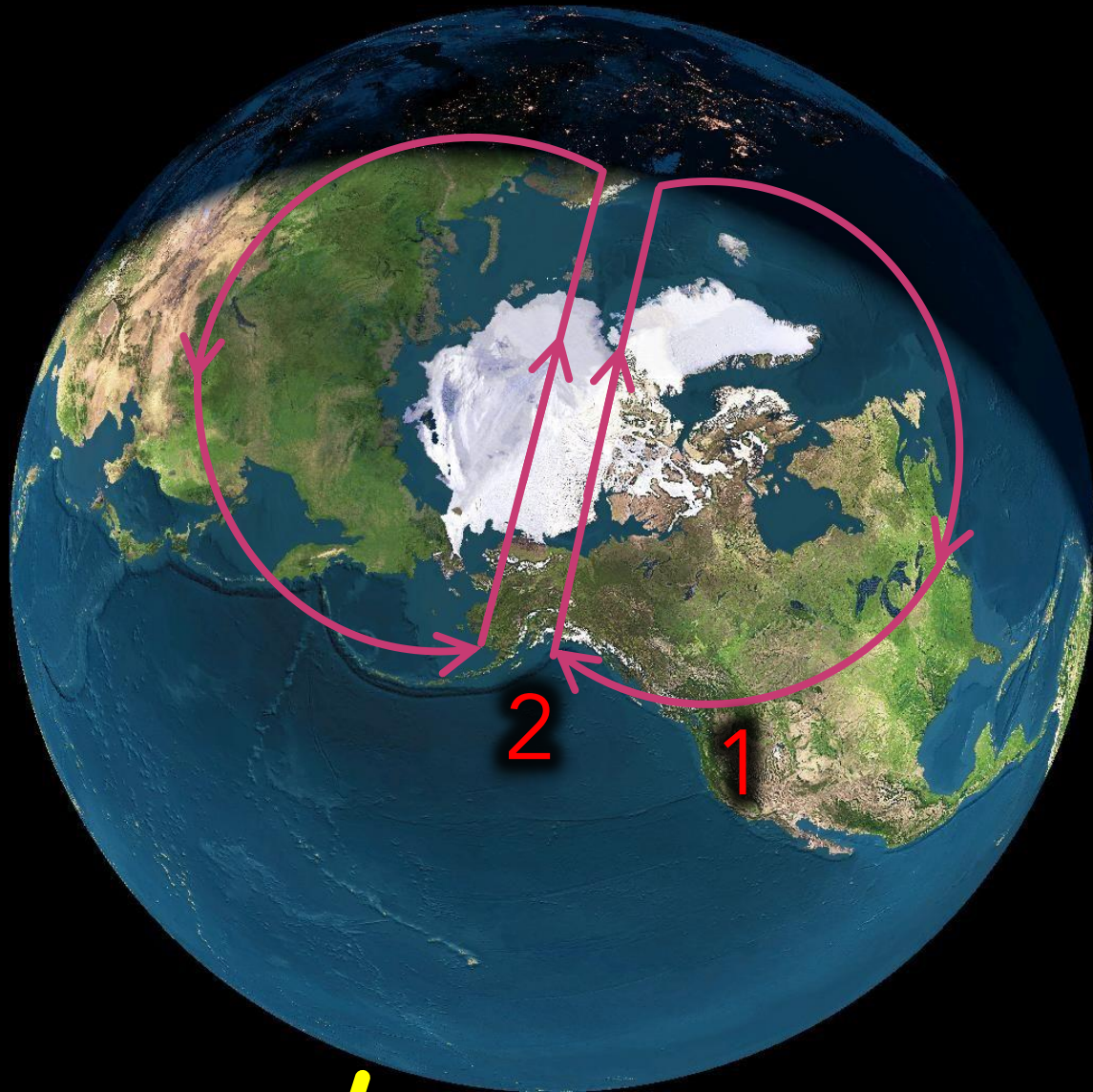


# TRANSLATE TO THE IONOSPHERE: CONVECTION

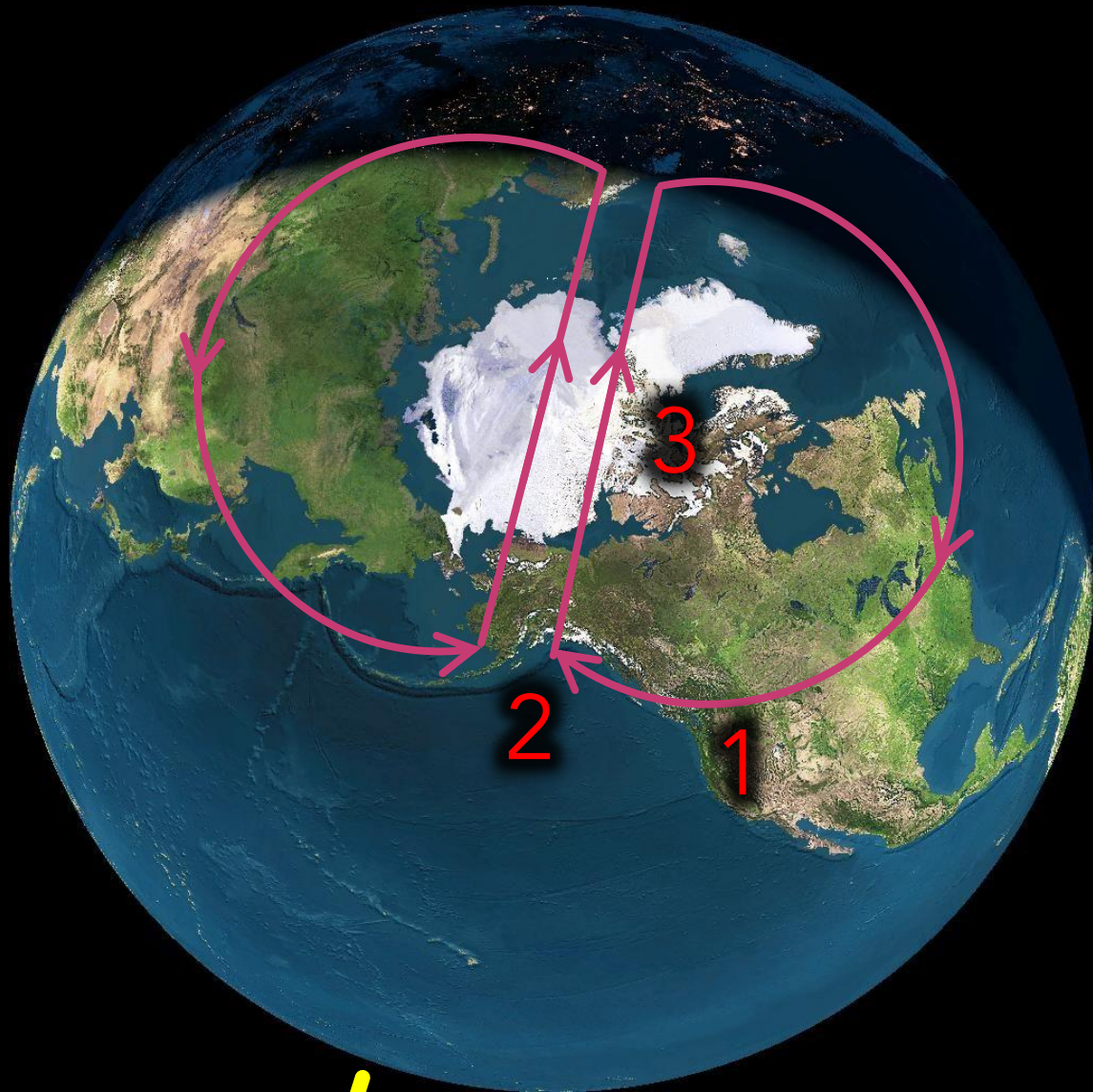




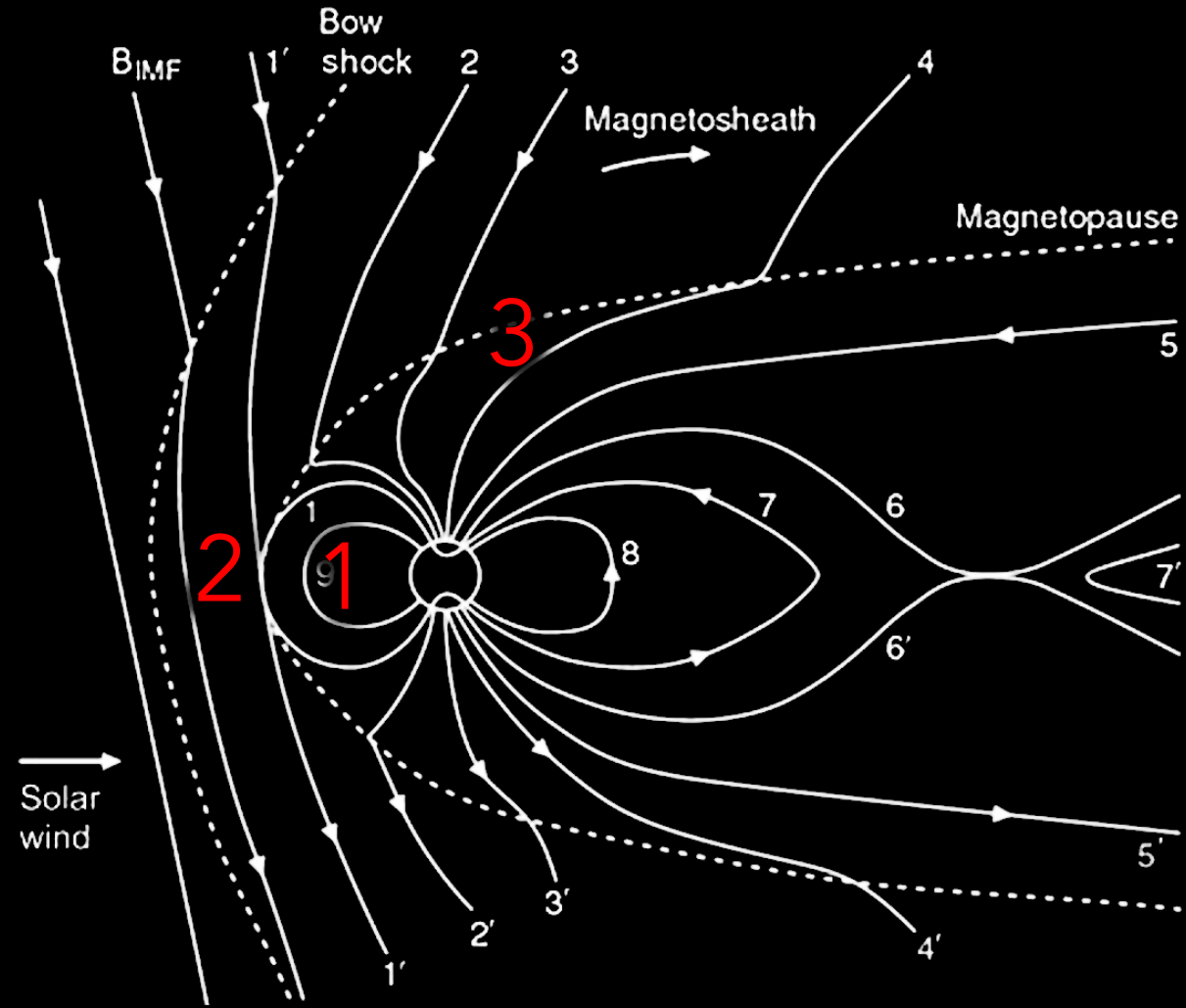
# TRANSLATE TO THE IONOSPHERE: CONVECTION



# TRANSLATE TO THE IONOSPHERE: CONVECTION



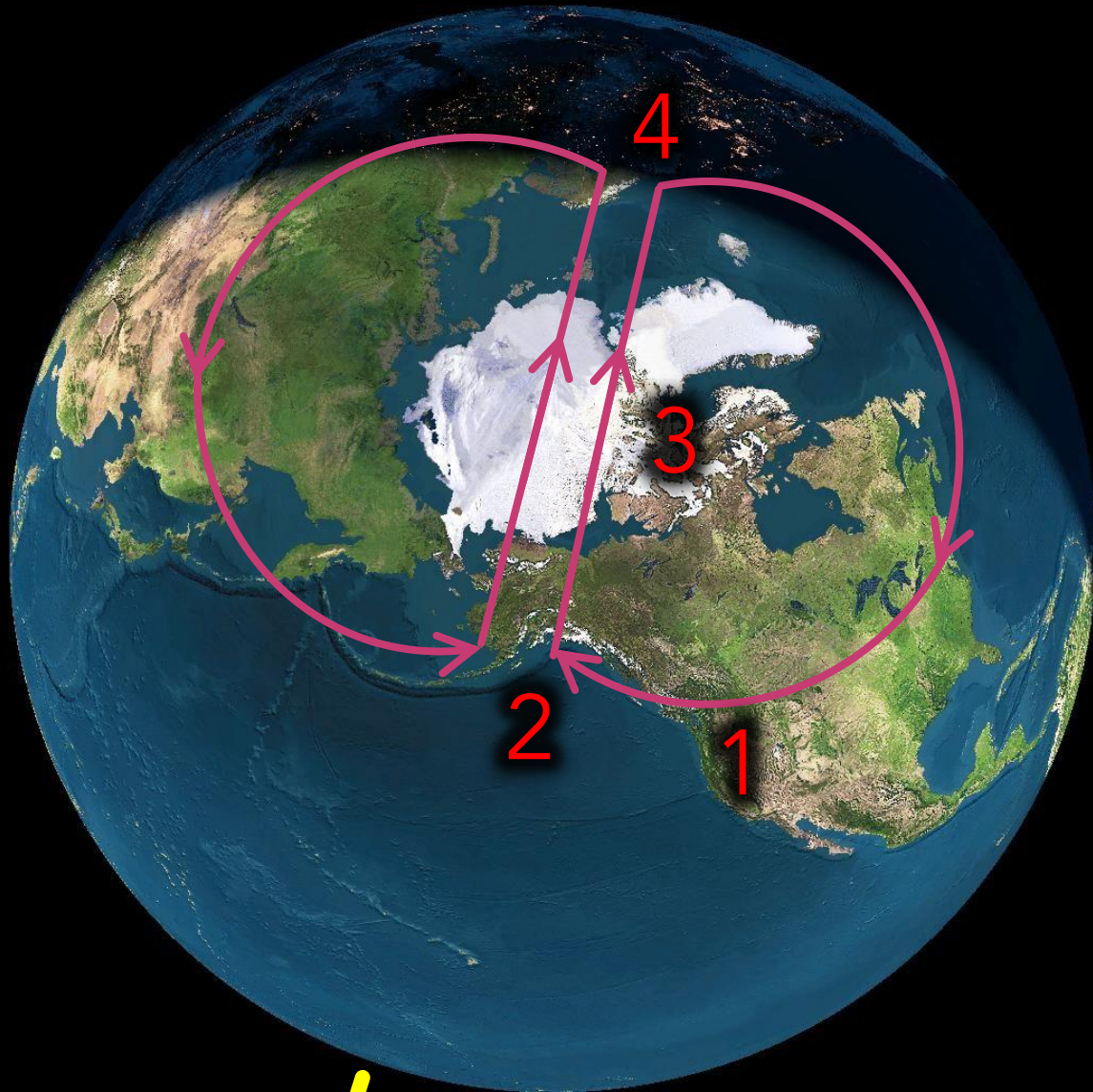
To Sun



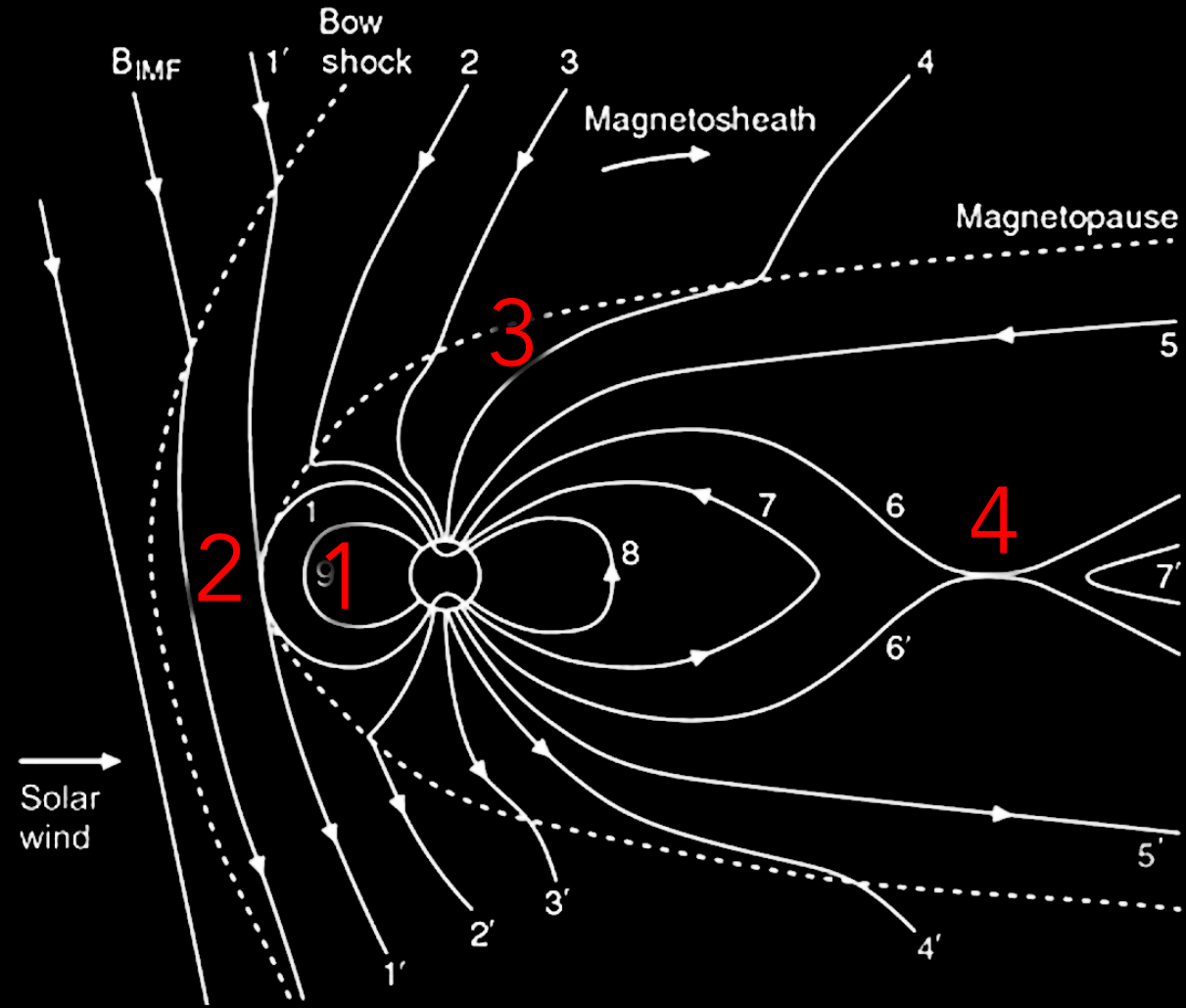
Hughes 1995



# TRANSLATE TO THE IONOSPHERE: CONVECTION



 To Sun

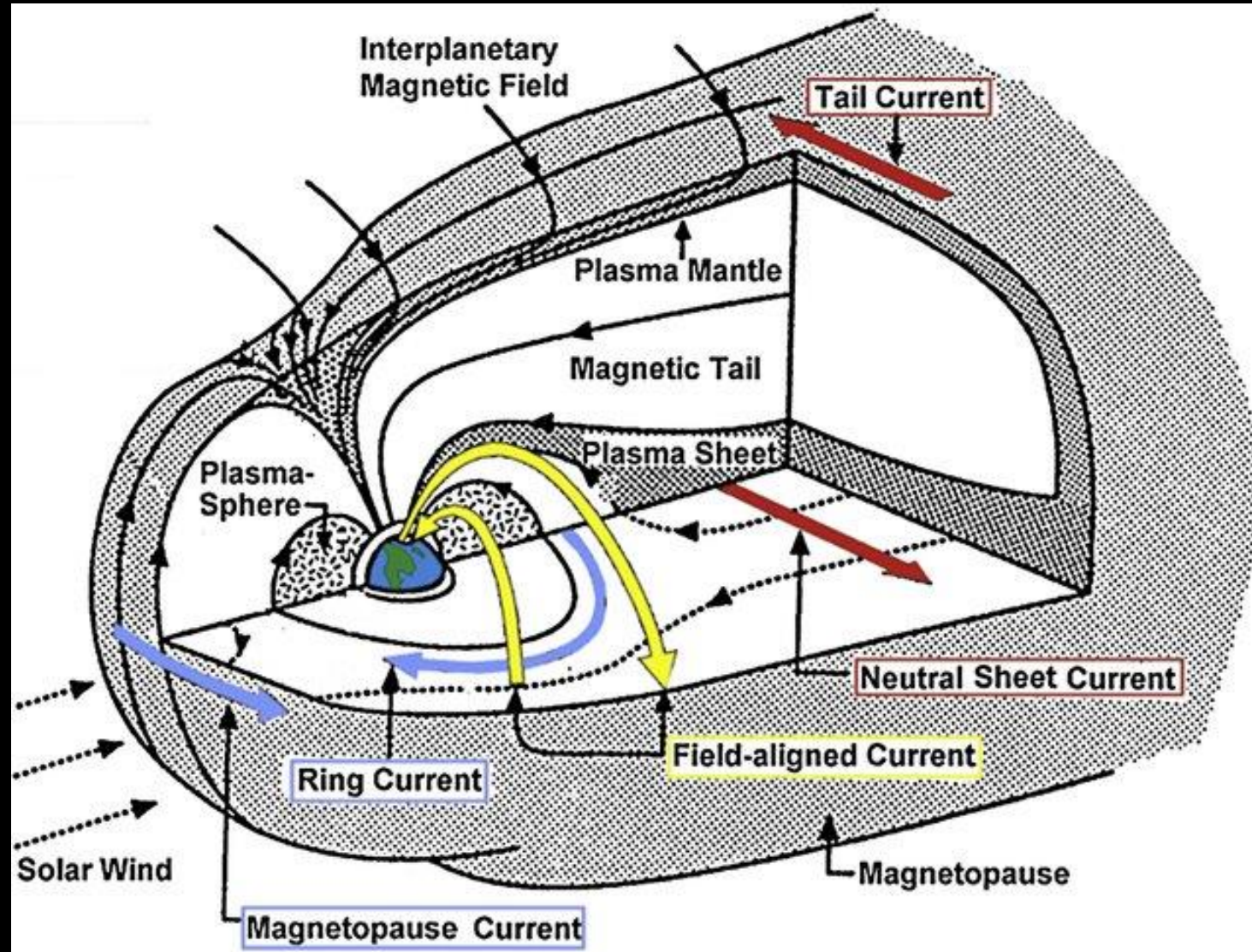


Hughes 1995





# CURRENT SYSTEMS – THE MAGNETOSPHERE





# PLASMA PHYSICS: SINGLE PARTICLE MOTION

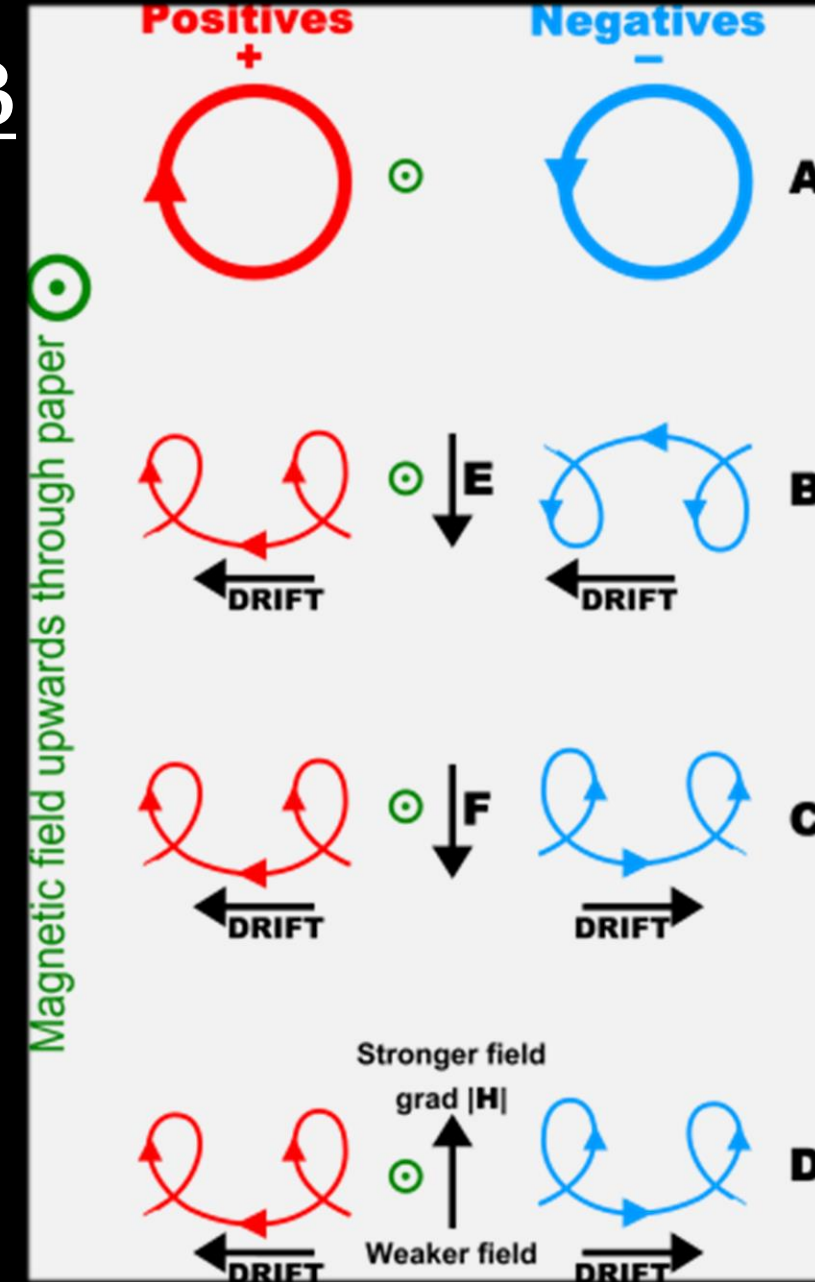
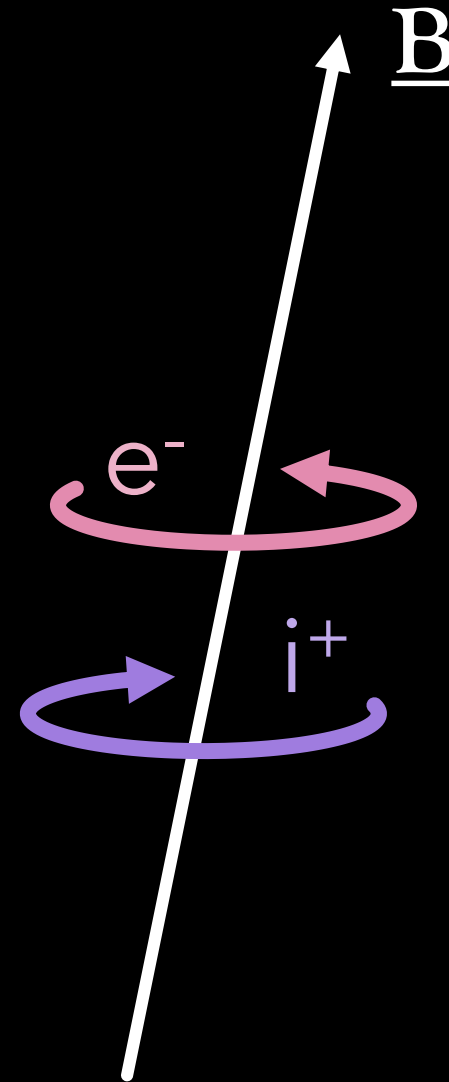
i.e., why we get space currents

Plasma is just a super heated gas, with electrons that have **enough energy** to be released from the pull of the nucleus

The remaining plasma is made up of the **free electrons** (neg charge) and the leftover **nuclei** which are positively charged

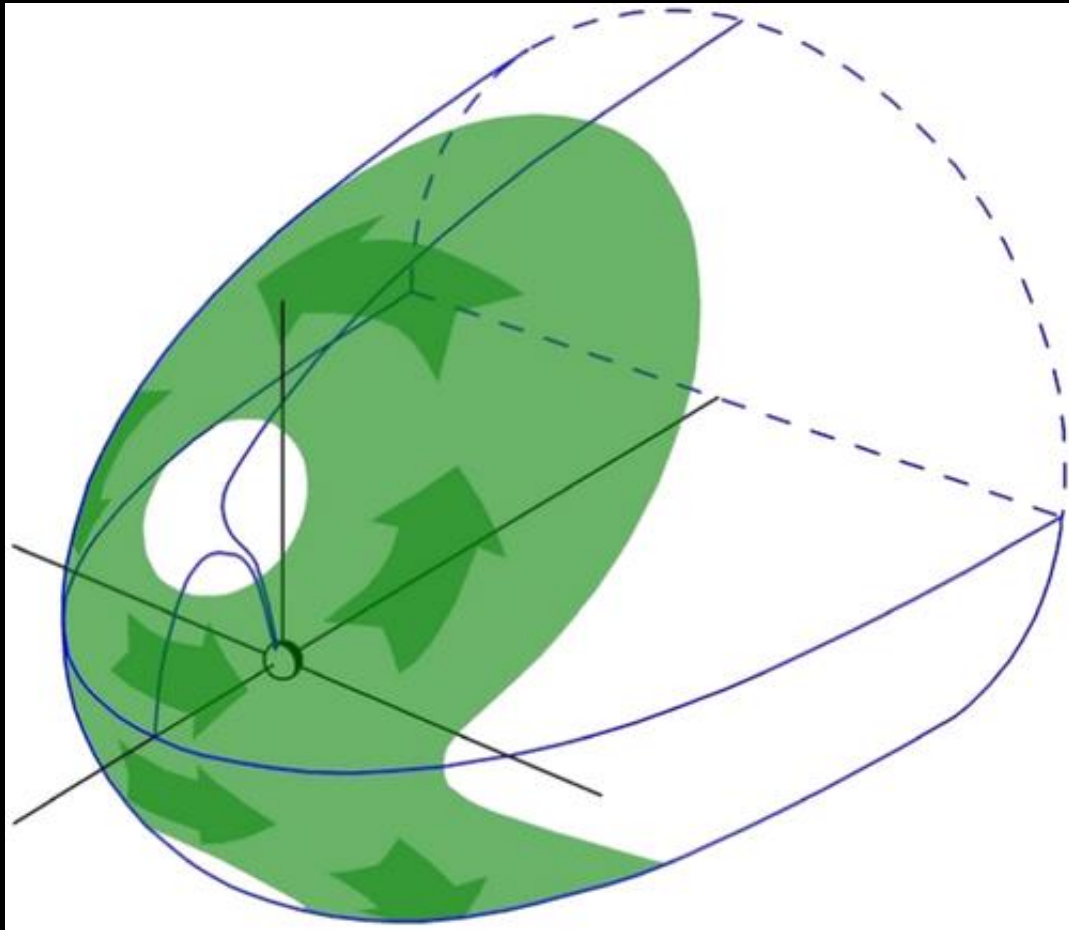
When a magnetic field is applied, these charged particles like to **gyrate** around it and as such, plasma and magnetic fields like to stick together

Currents arise when ions and electrons have **differential motion**



# CURRENT SYSTEMS – THE MAGNETOSPHERE

## MAGNETOPAUSE/CHAPMAN-FERRARO CURRENT



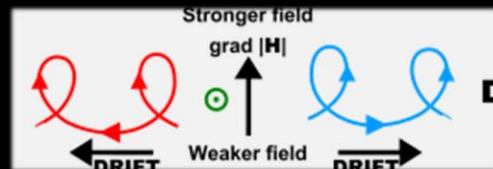
A boundary between Earth-dominated magnetic fields and solar wind-dominated fields.

Flows across the magnetopause, which sits between the **magnetosheath** and **inner magnetosphere**.

The magnetosheath is where the **supersonic** solar wind becomes **sub-sonic** as it encounters the Earth's field.

Ions and electrons drift in opposite directions when encountering a **changing field** - **Gradient drift**.

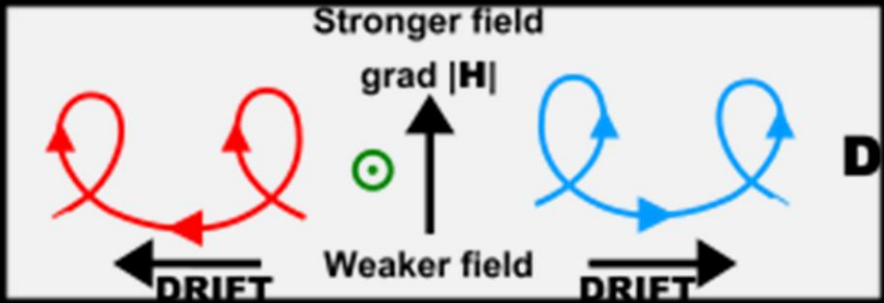
Ganushkina et al., 2018



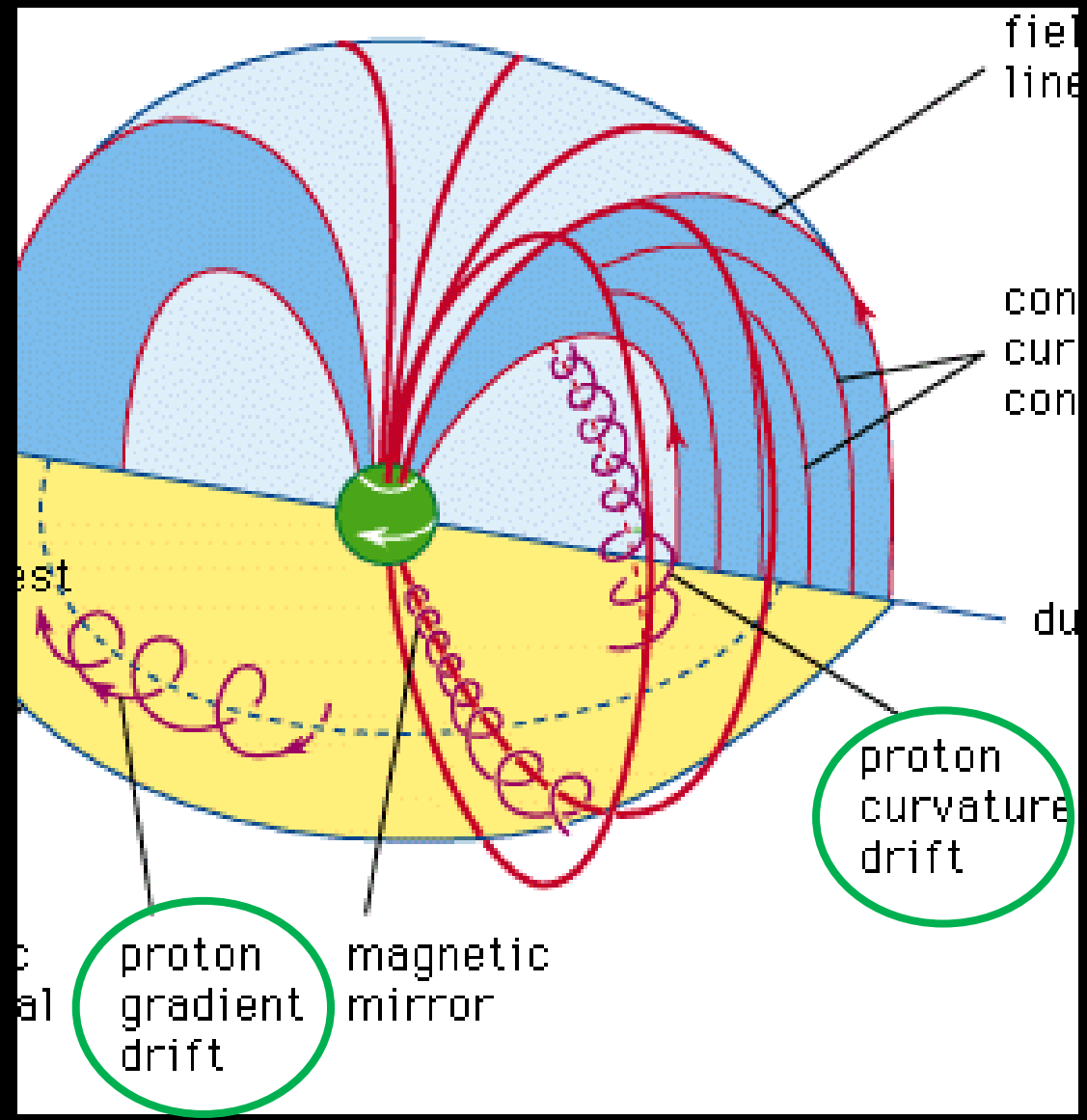
# CURRENT SYSTEMS – THE MAGNETOSPHERE

## RING CURRENT

Earth's field varies in strength with distance from Earth. There is another **gradient drift**.

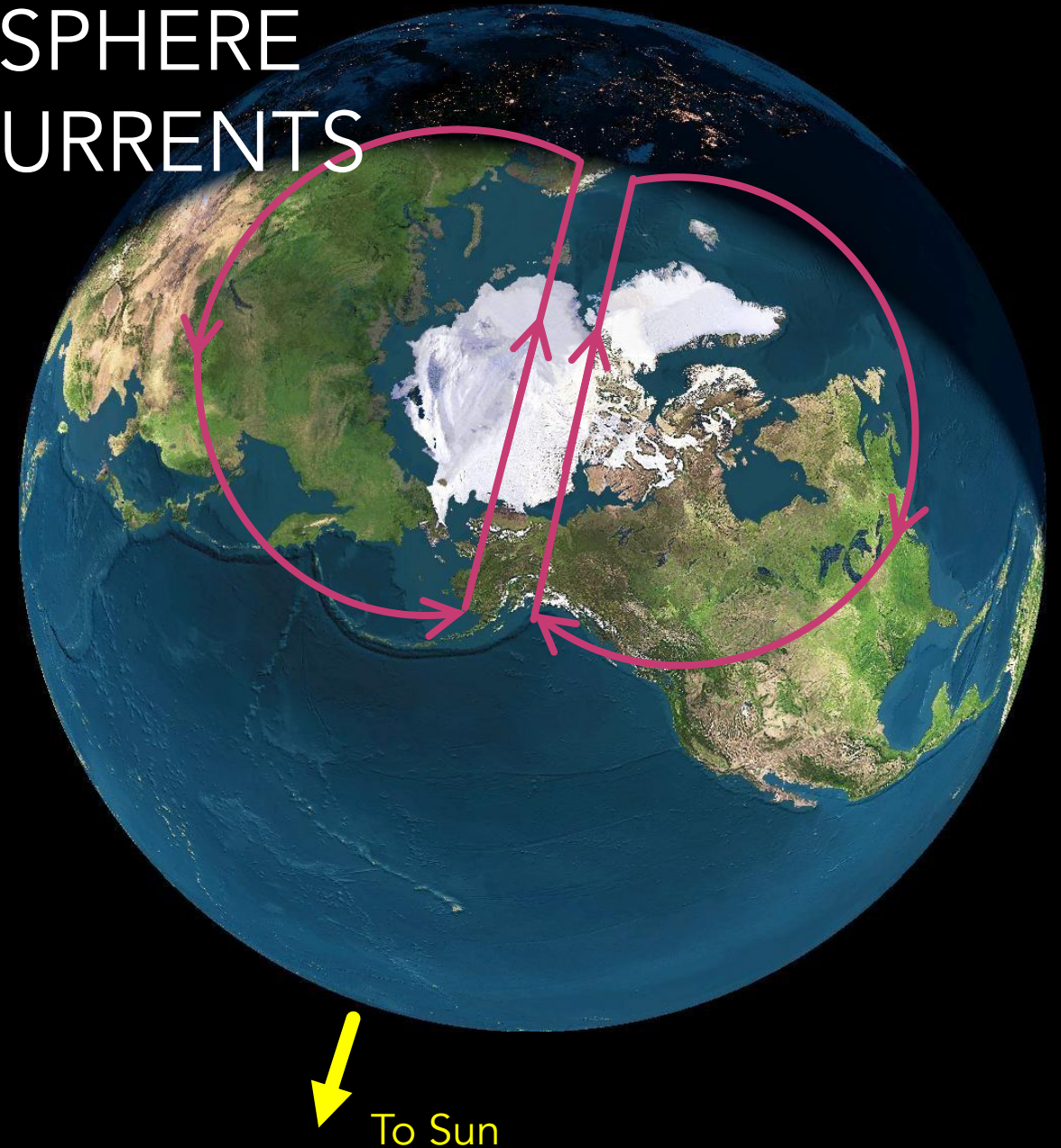
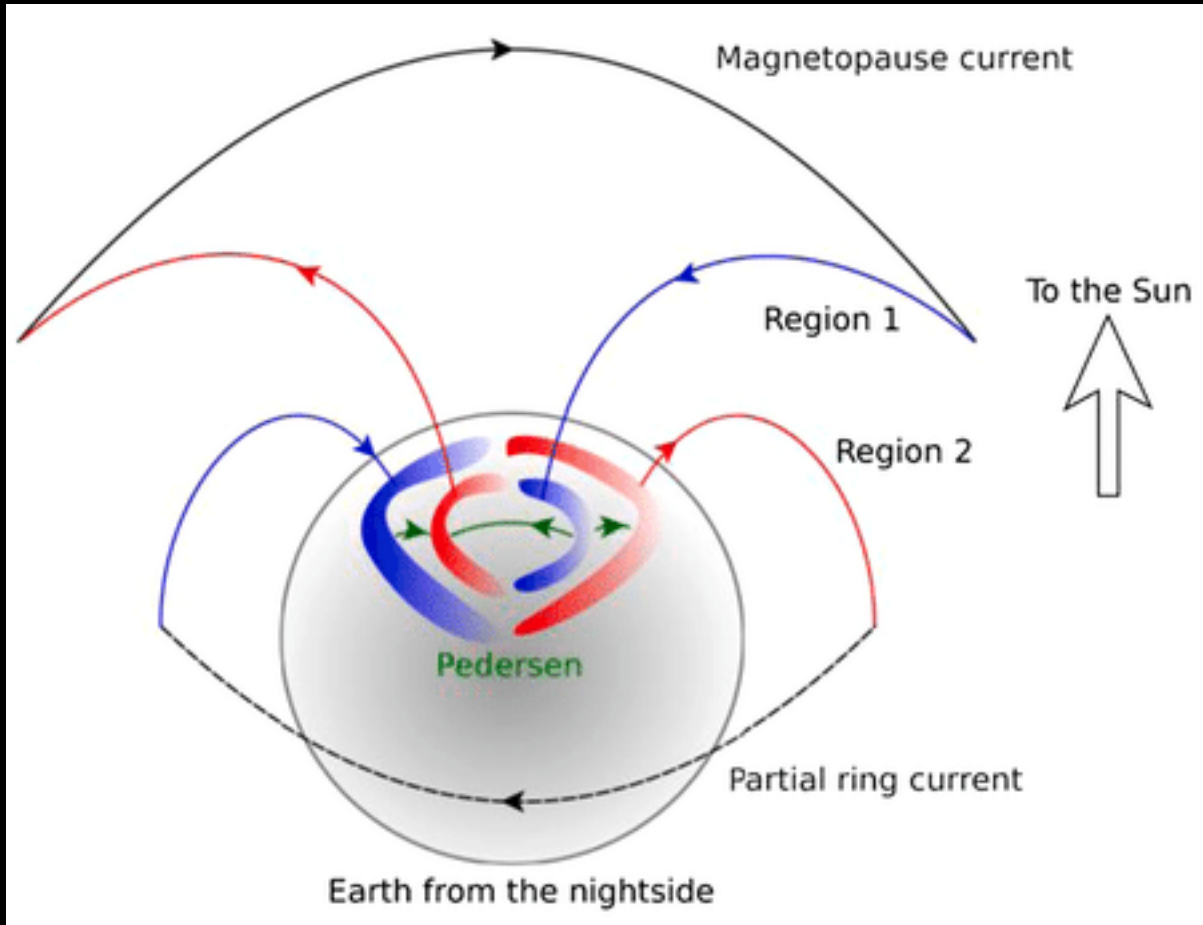


Particles gyrating around a curved field line experience a **centrifugal force** perpendicular to the field. **Curvature drift**.





# CURRENT SYSTEMS – THE MAGNETOSPHERE/IONOSPHERE FIELD ALIGNED/BIRKELAND CURRENTS



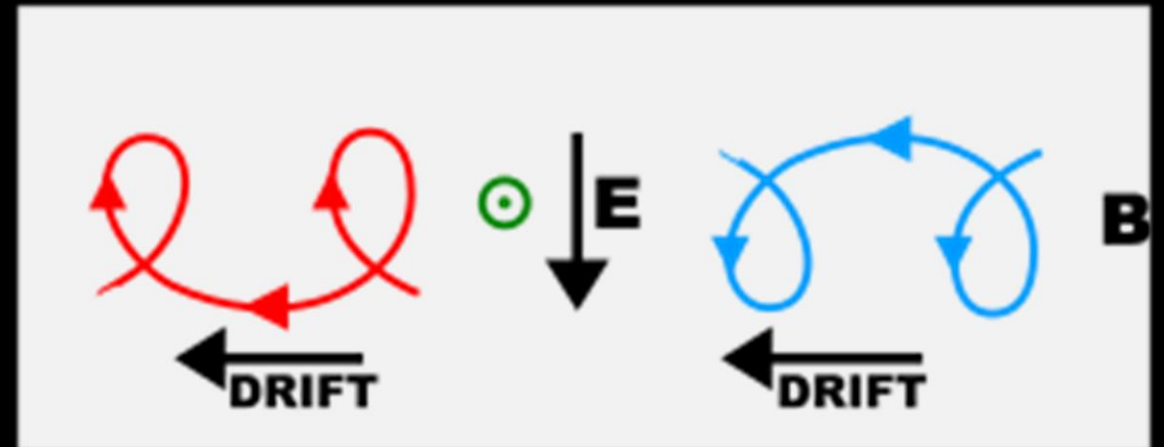


# CURRENT SYSTEMS – THE MAGNETOSPHERE/IONOSPHERE

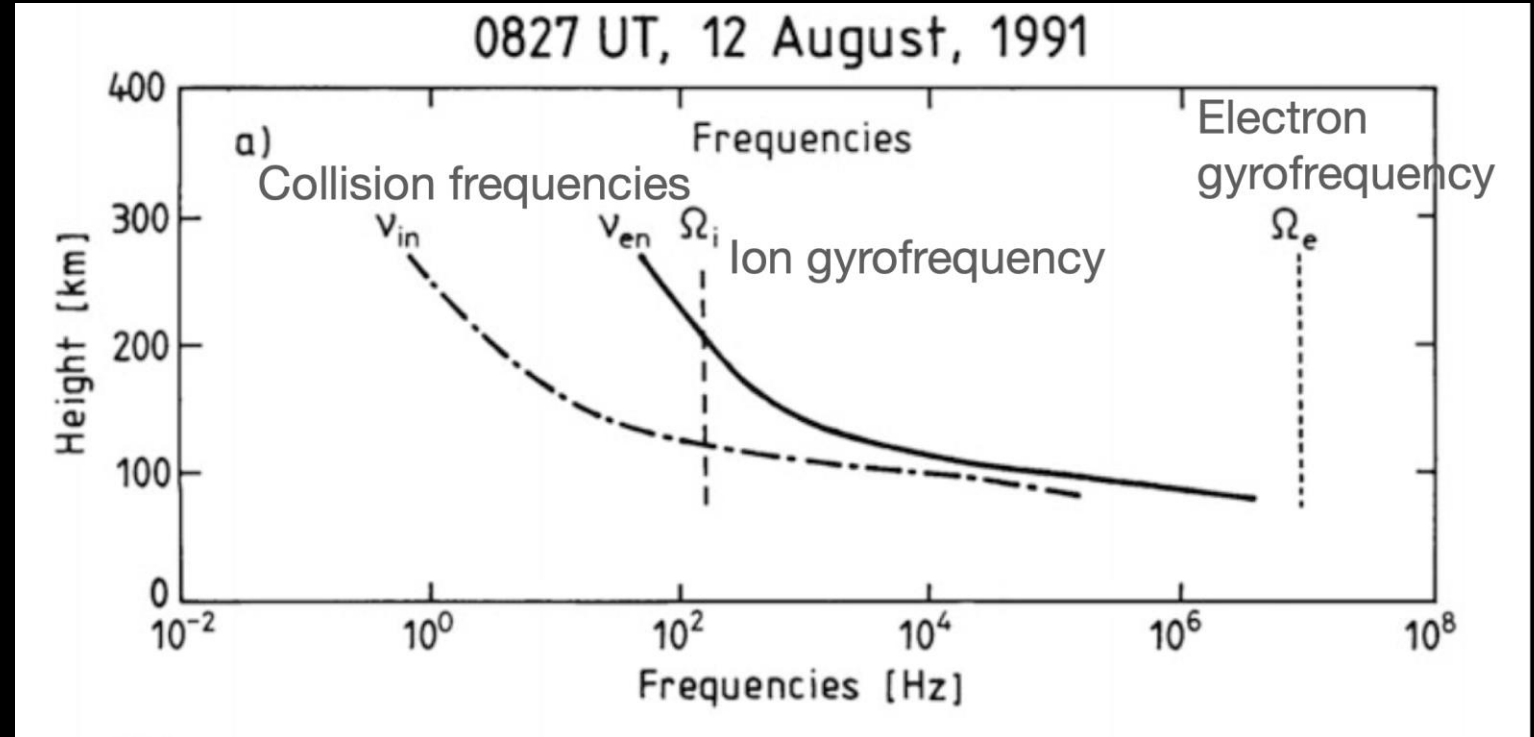
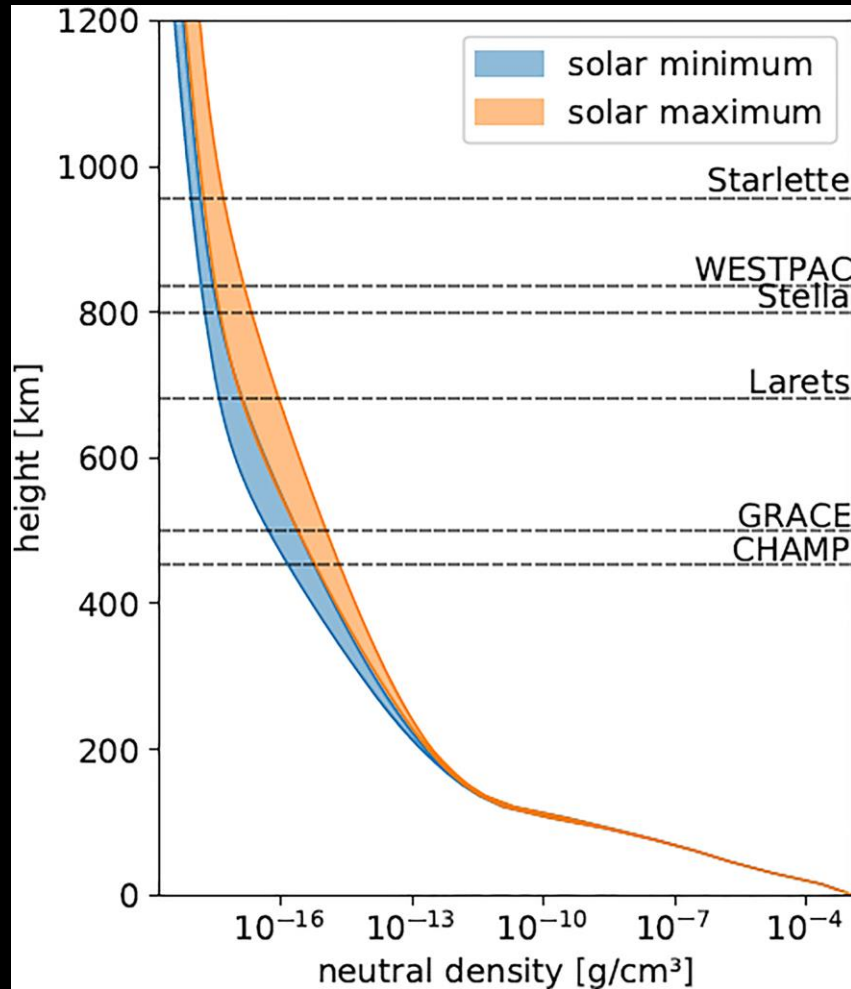


Both ions and electrons are frozen-in with the magnetic field, moving **perpendicular to the magnetic field**.

An electric field is set up because of this. Both ions and electrons are  **$E \times B$  drifting**.



# BUT! THE IONOSPHERE IS NOT COLLISIONLESS

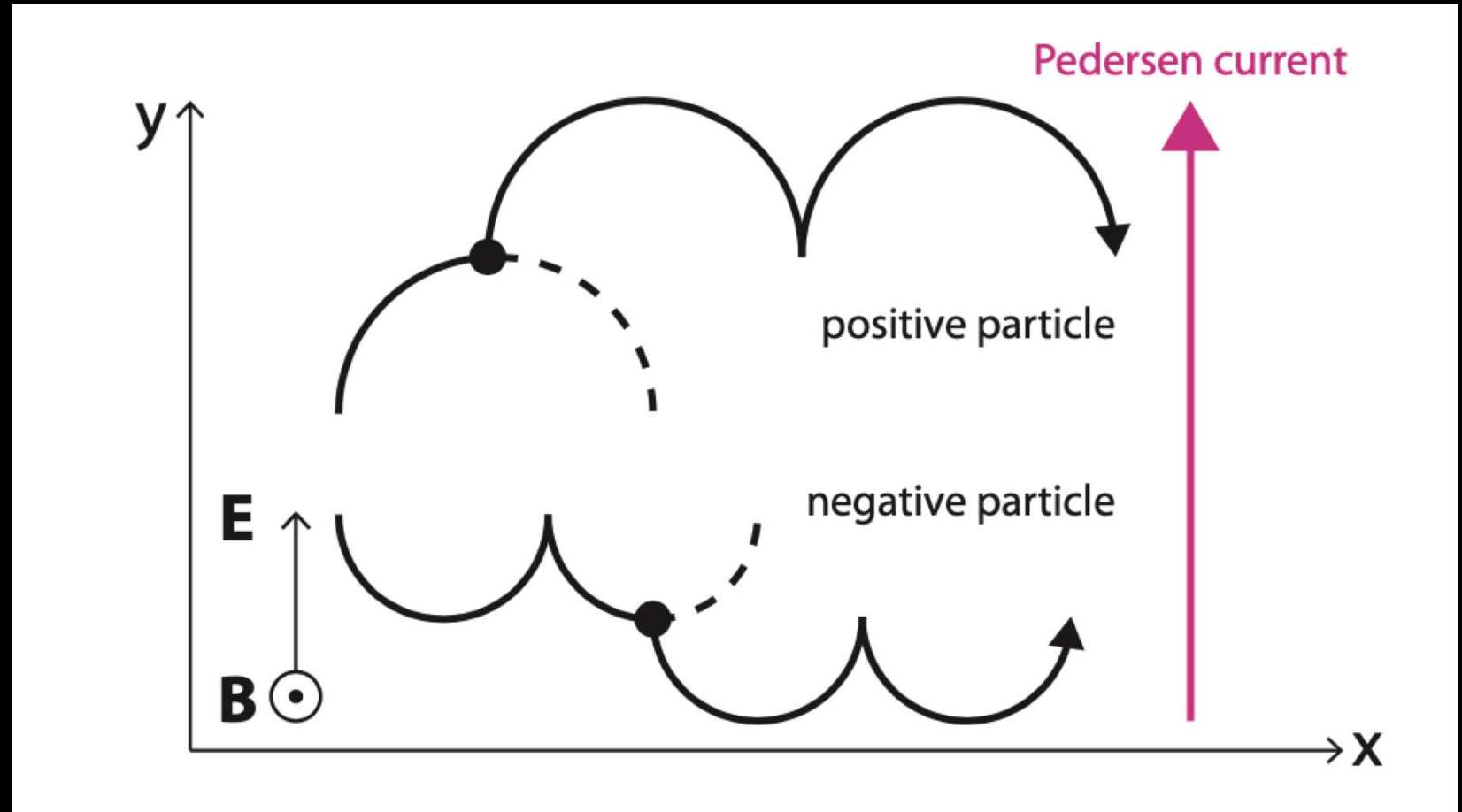


Ions are heavy, so their **gyrofrequency** is much lower than electrons. At ~125km altitude, every ion gyration is met with a **neutral collision**.

# AN IONOSPHERIC CURRENT IN THE ELECTRIC FIELD DIRECTION – PEDERSEN CURRENT

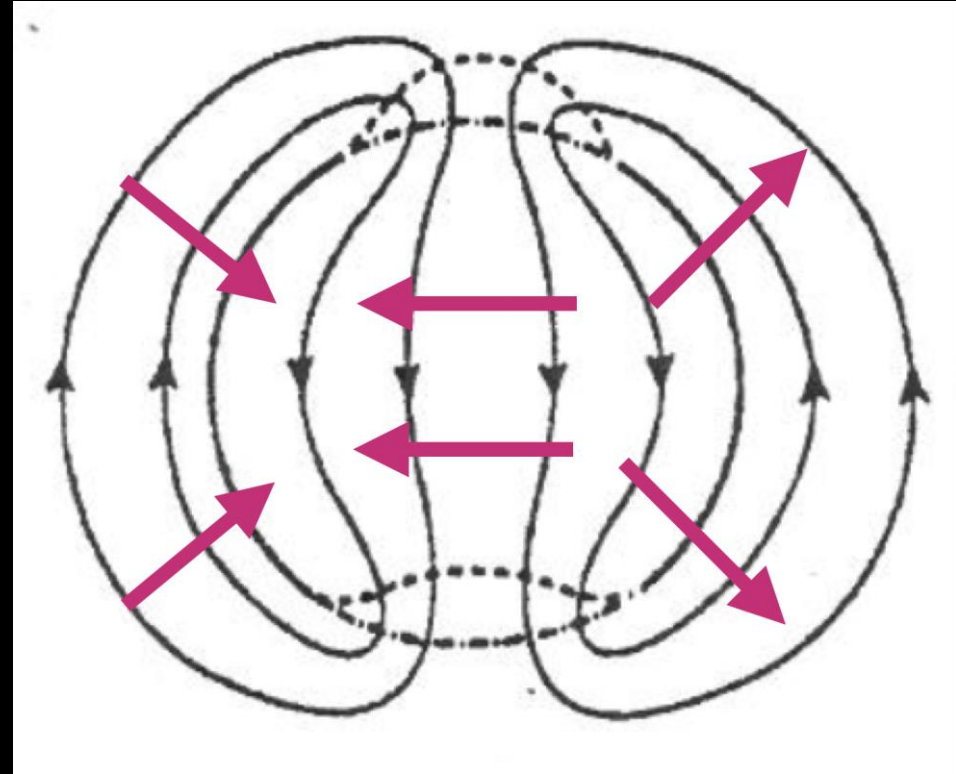
Ion with **low** gyrofrequency:

Electron with **high** gyrofrequency:





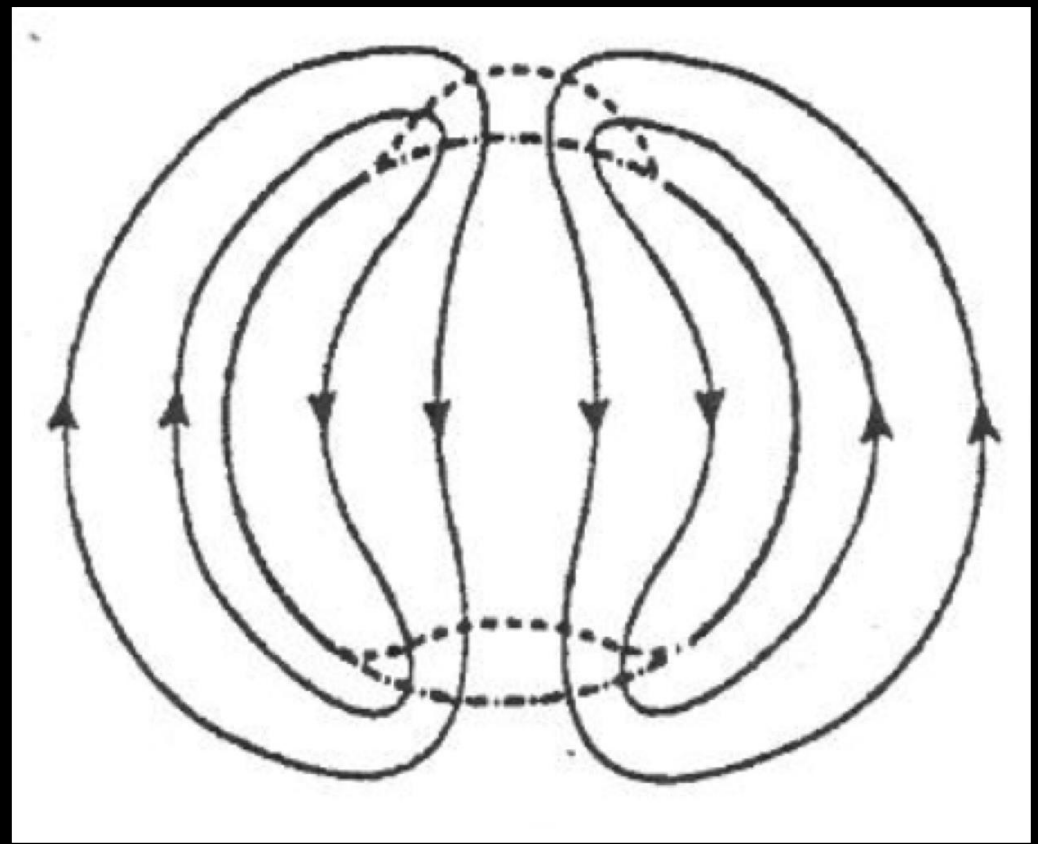
# AN IONOSPHERIC CURRENT IN THE ELECTRIC FIELD DIRECTION – PEDERSEN CURRENT



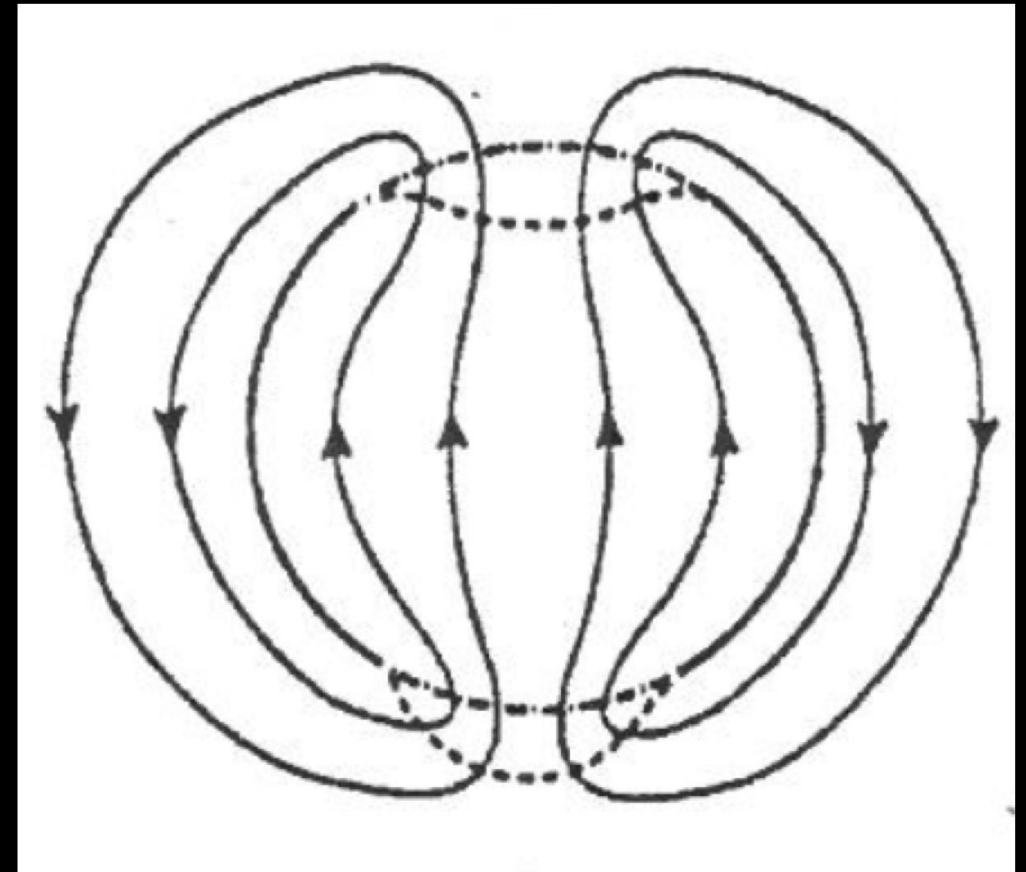


# OH, AND THERE IS ALSO THE **HALL CURRENT/** **ELECTROJET**

Plasma convection



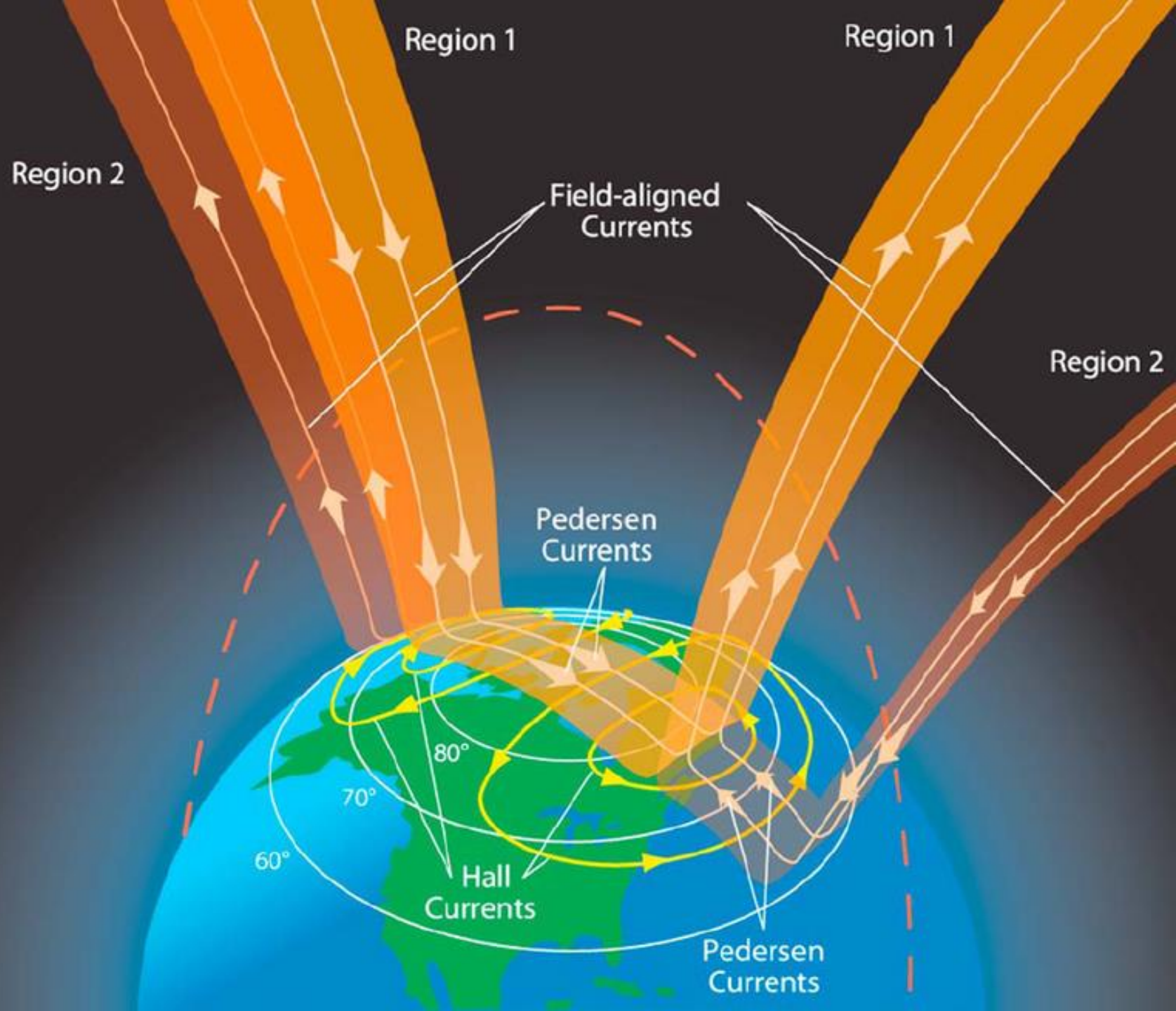
Parallel Hall current – due to neutral collisions slowing down  $E \times B$  drifting ions



**Hall currents** are self contained and close on their own.

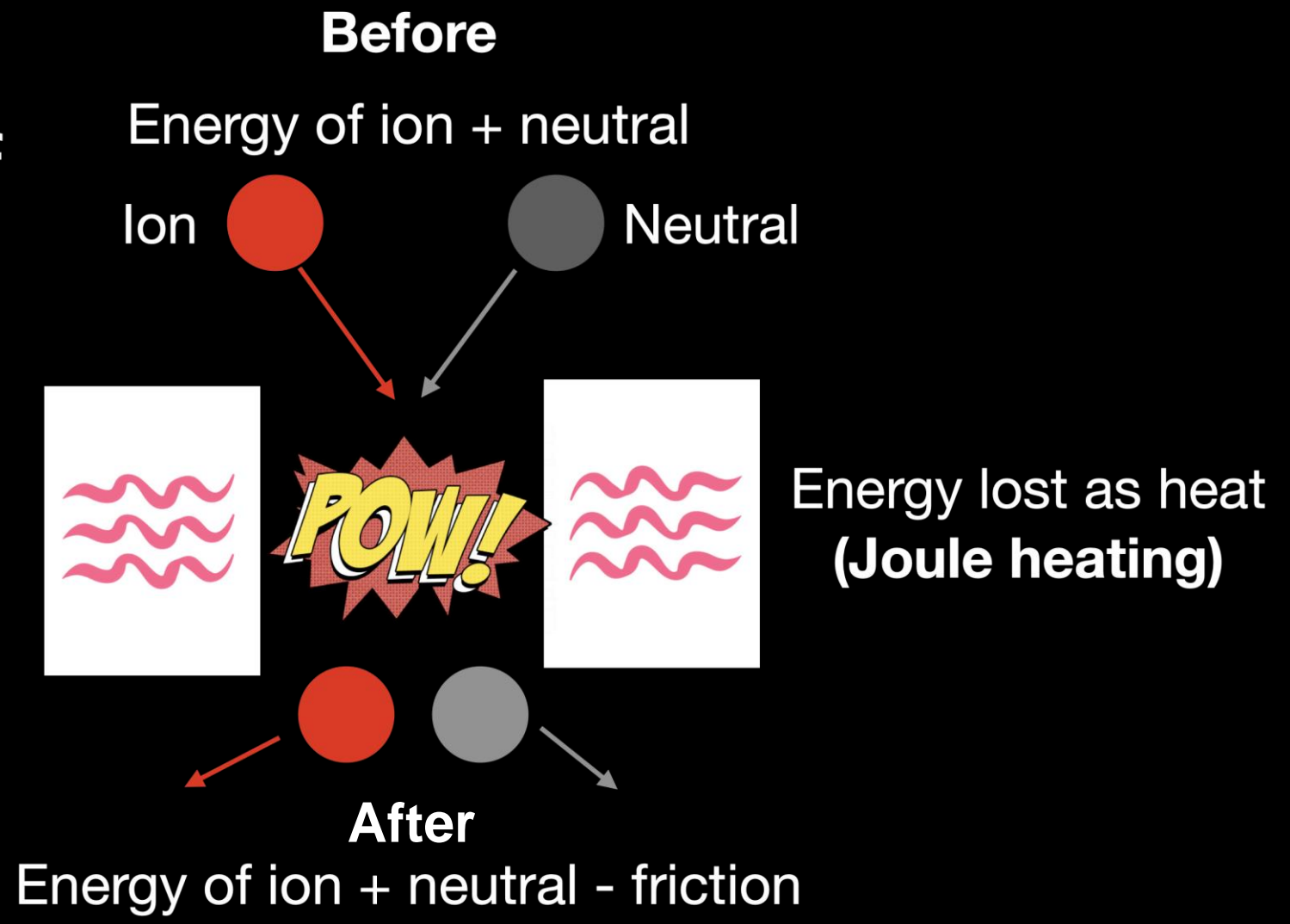
**Pedersen currents** arise due to the difference in ion and electron gyrofrequencies/ collision frequencies.

**Field-aligned currents** are necessary to close Pedersen currents – connecting the ionosphere to the magnetosphere.



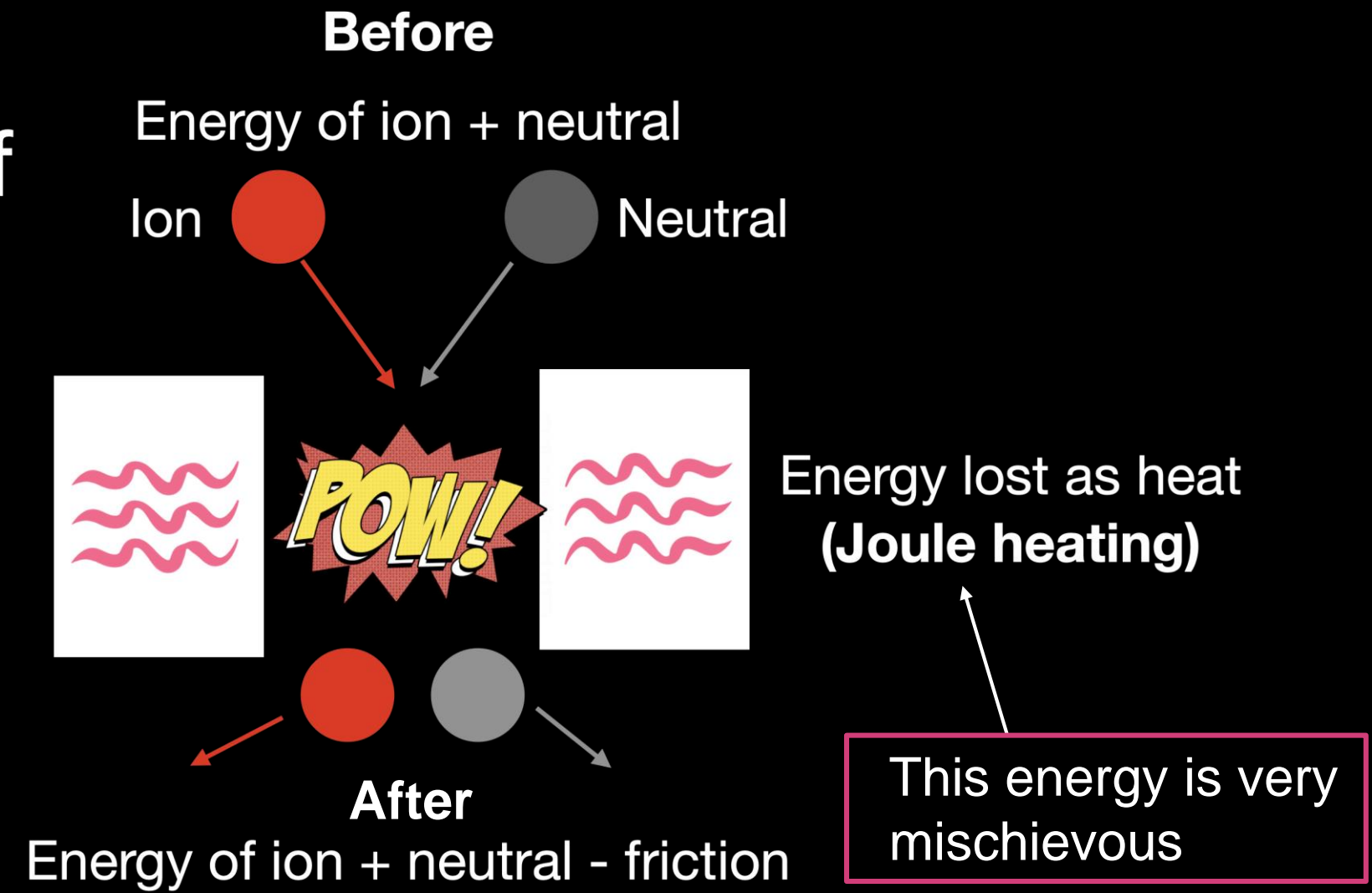
# SPACE ENERGY TO EARTH ENERGY

The collision of ions and neutrals



# SPACE ENERGY TO EARTH ENERGY

The collision of ions and neutrals

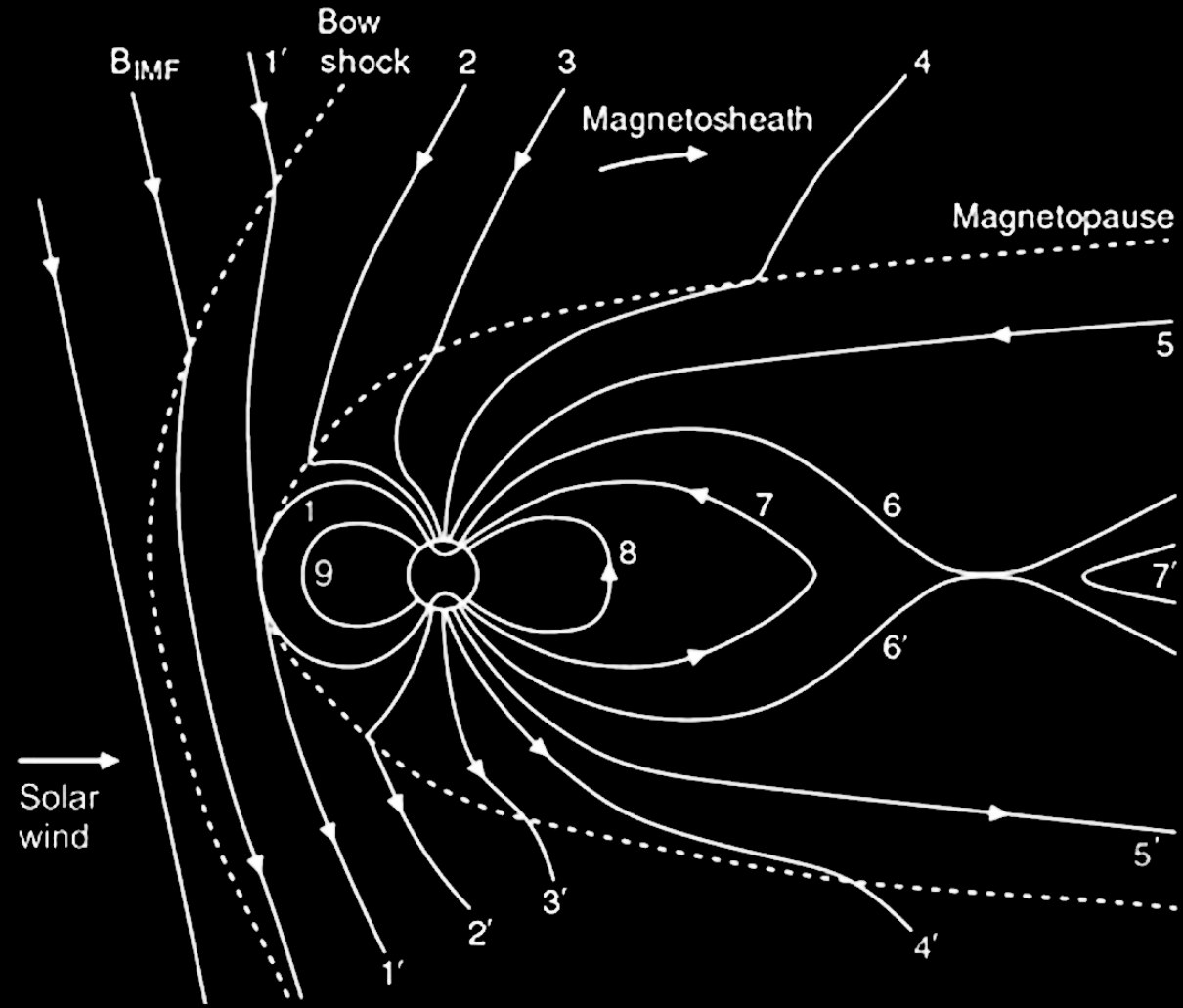




# AURORA BOREALIS: AT THIS TIME OF THE SOLAR CYCLE? LOCATED ENTIRELY WITHIN THE POLAR CAP?

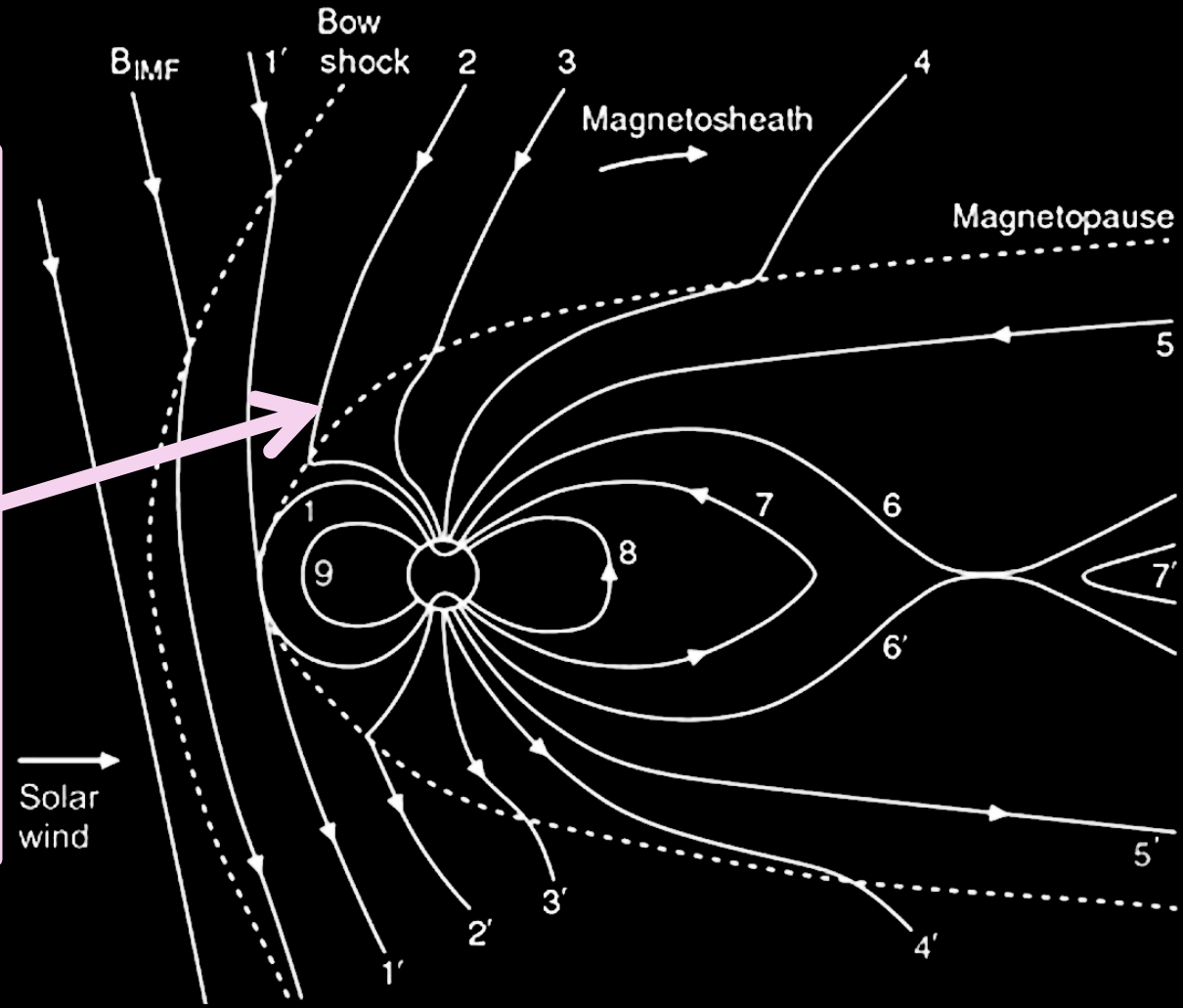


# AURORA



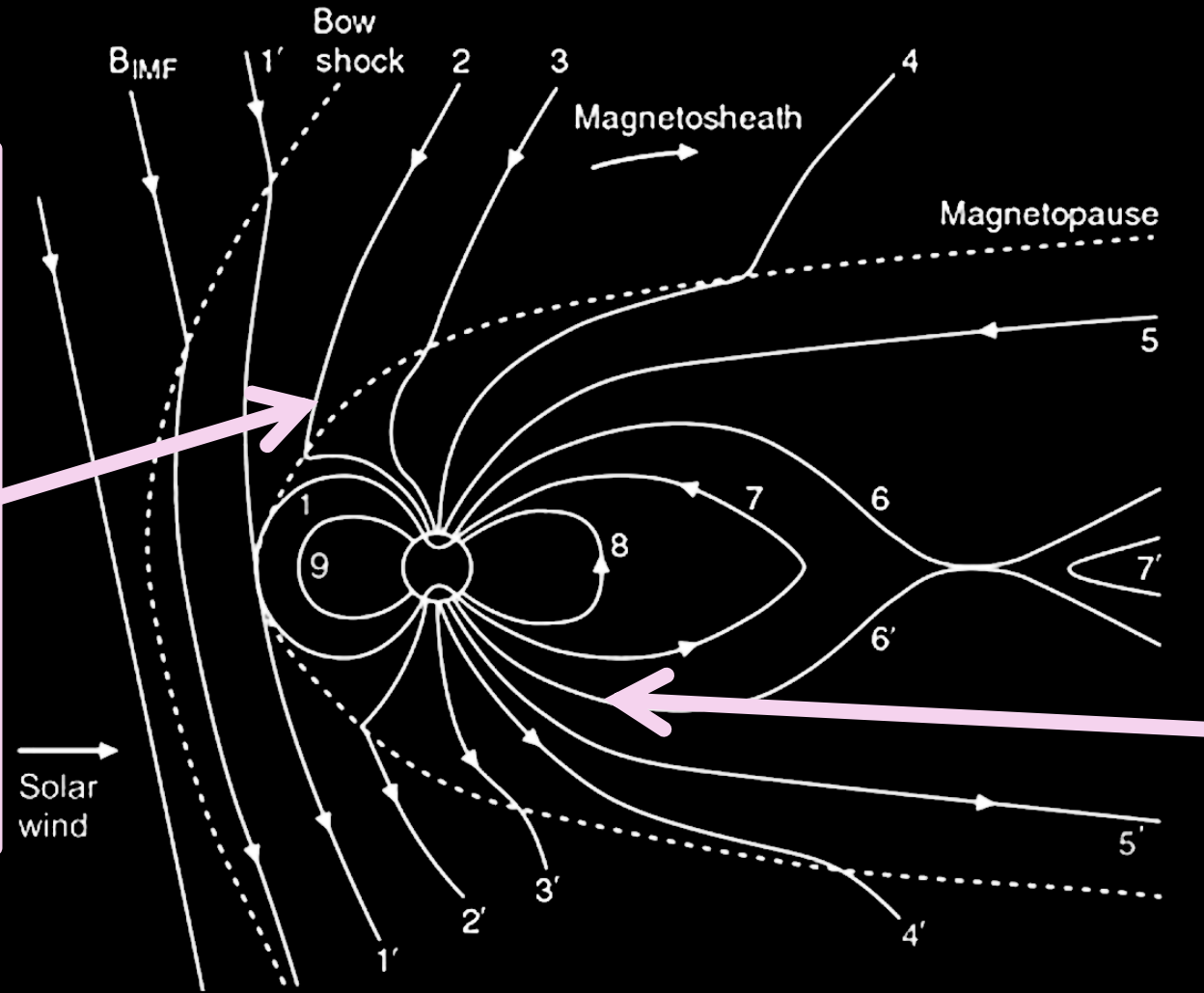
# AURORA

After **dayside reconnection** energetic particles from the solar wind travel down into the atmosphere: 'CUSP'



# AURORA

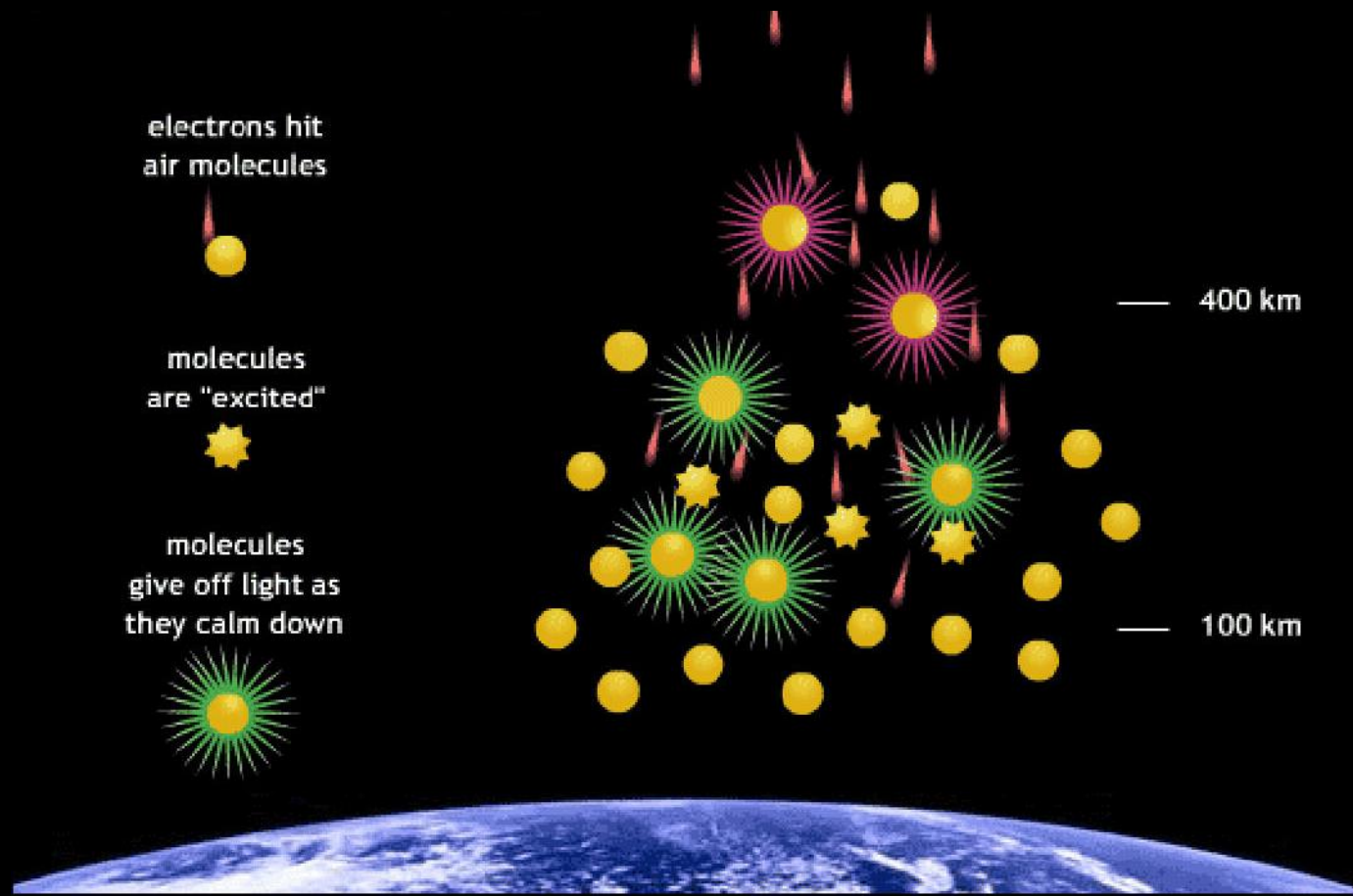
After **dayside reconnection** energetic particles from the solar wind travel down into the atmosphere: 'CUSP'



After **tail reconnection** energetic particles travel down to the atmosphere again and continue to travel down the field lines as they move back around to the dayside

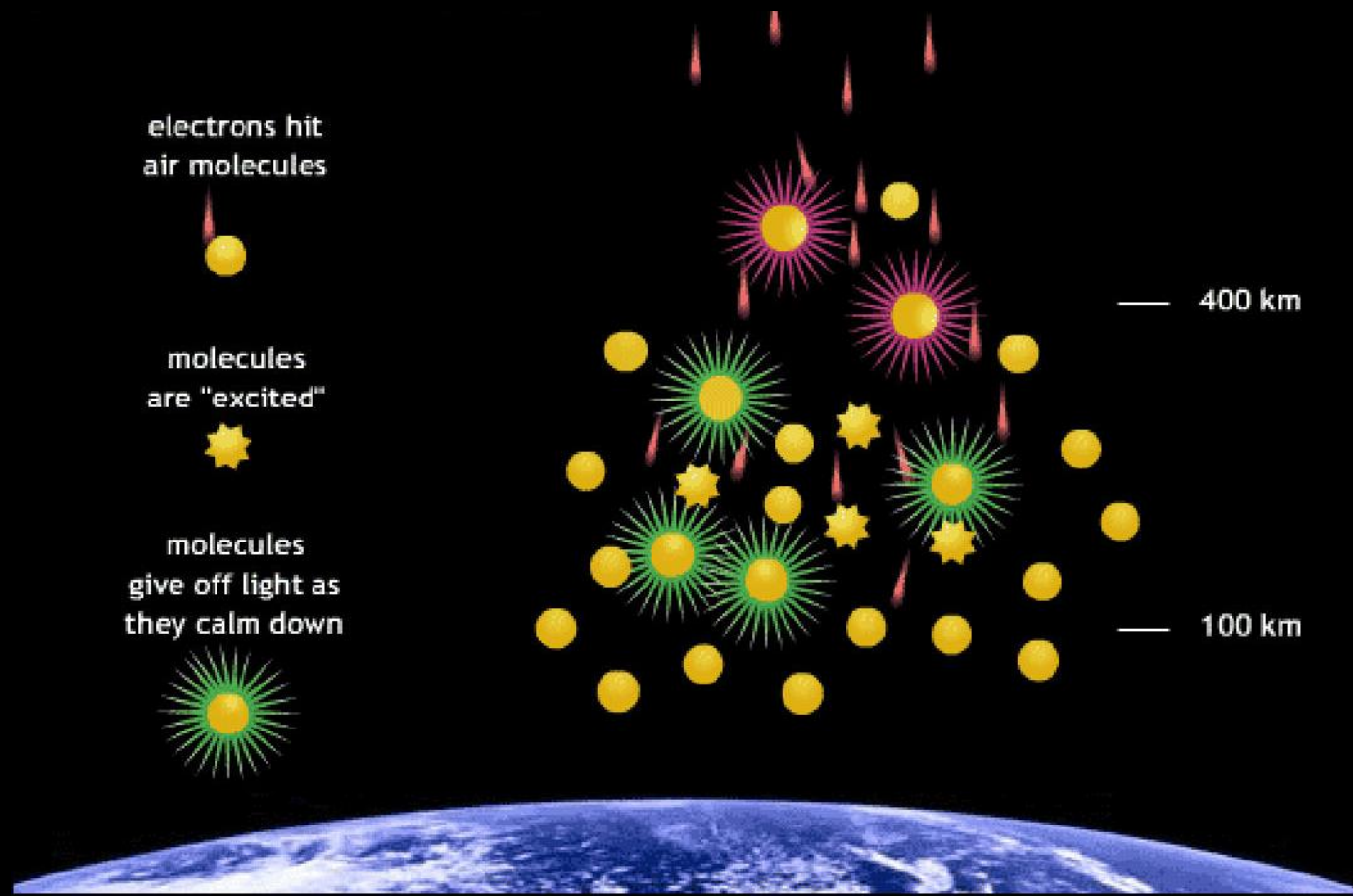


# AURORA BOREALIS



# AURORA BOREALIS

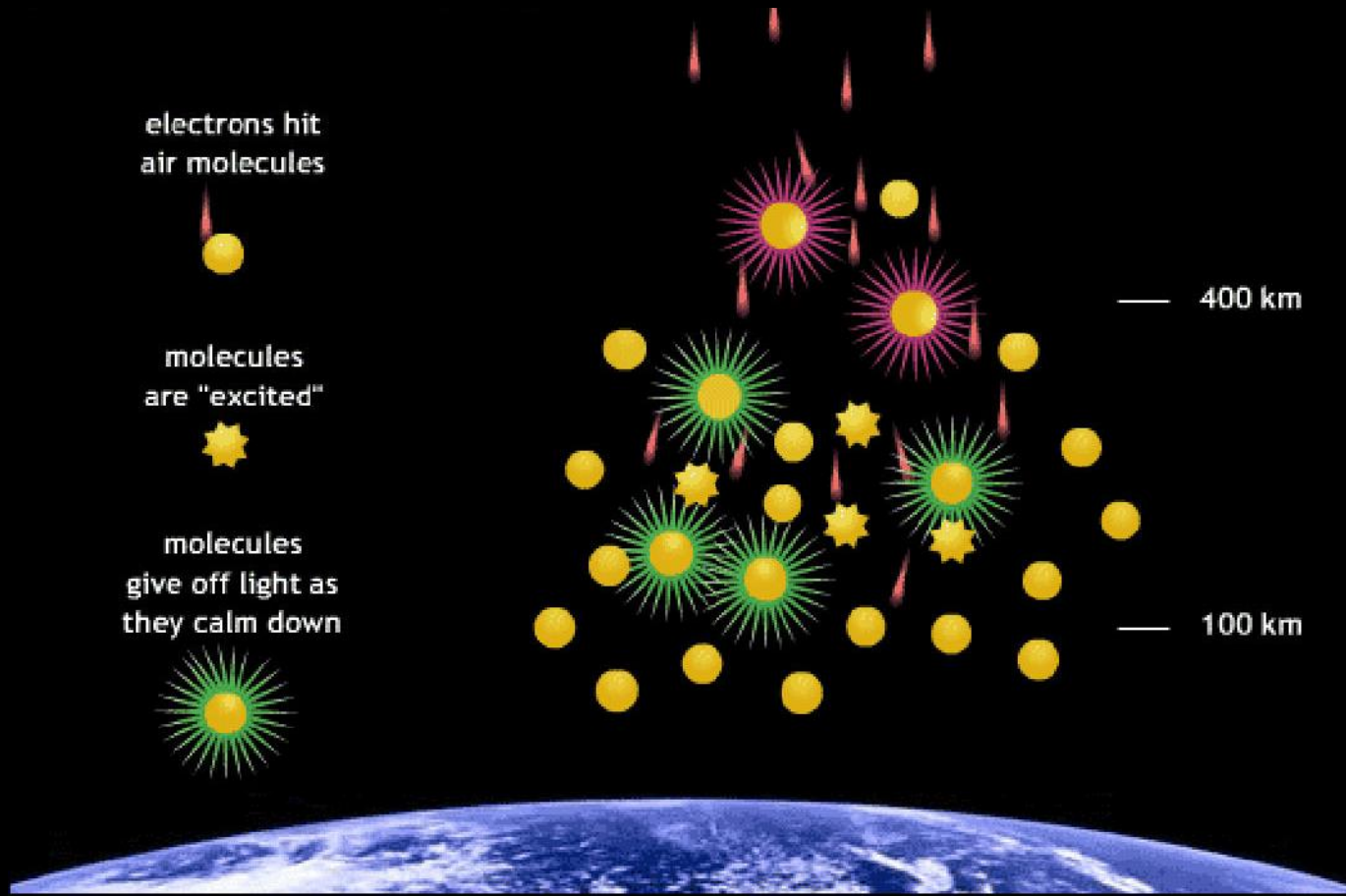
SW electrons 'bump' into particles in the atmosphere and energy is transferred to the atmospheric particles



# AURORA BOREALIS

SW electrons 'bump' into particles in the atmosphere and energy is transferred to the atmospheric particles

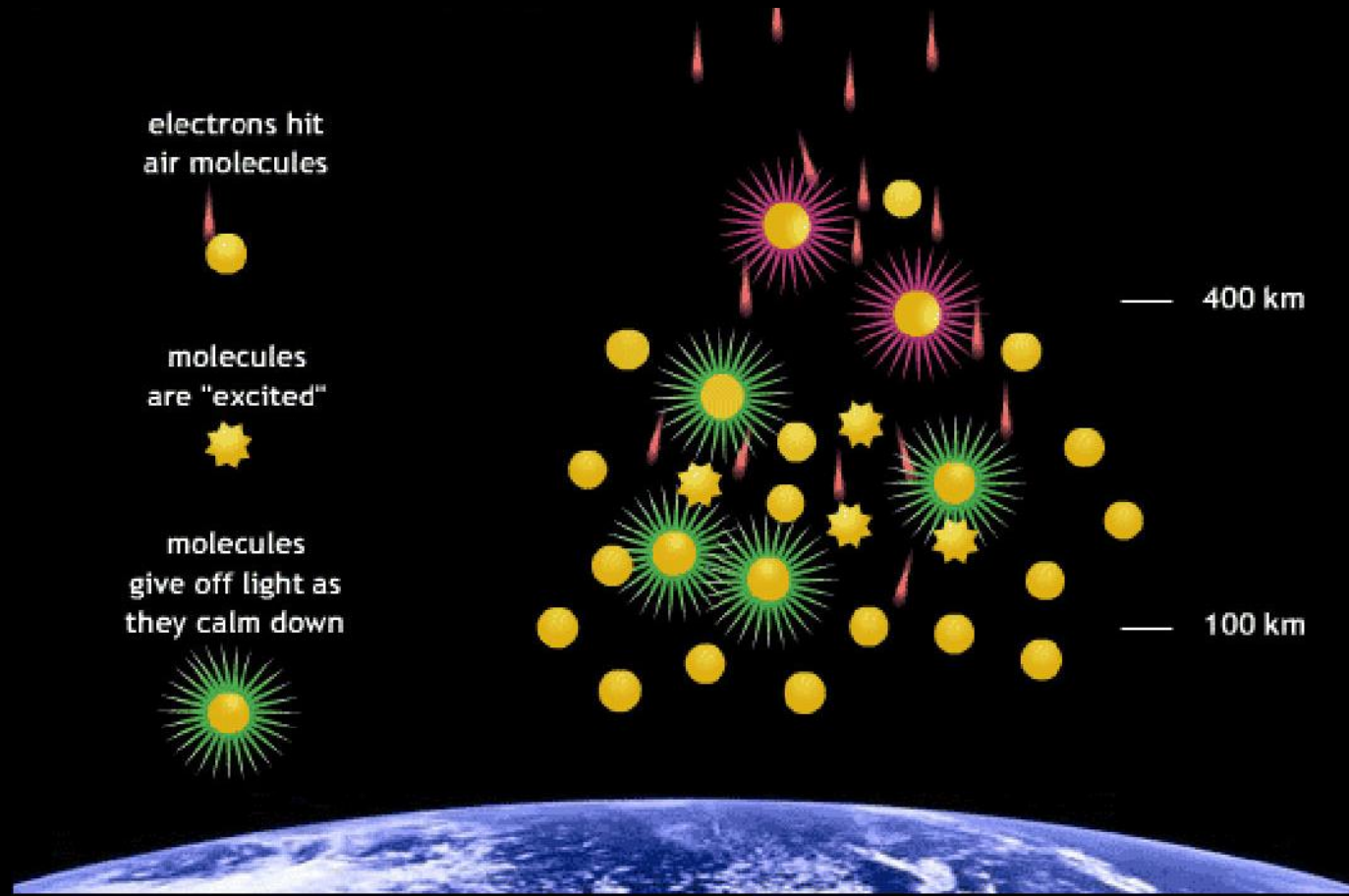
When atmospheric particles relax back to their original state, they emit light: the aurora



# AURORA BOREALIS

SW electrons 'bump' into particles in the atmosphere and energy is transferred to the atmospheric particles

When atmospheric particles relax back to their original state, they emit light: the aurora



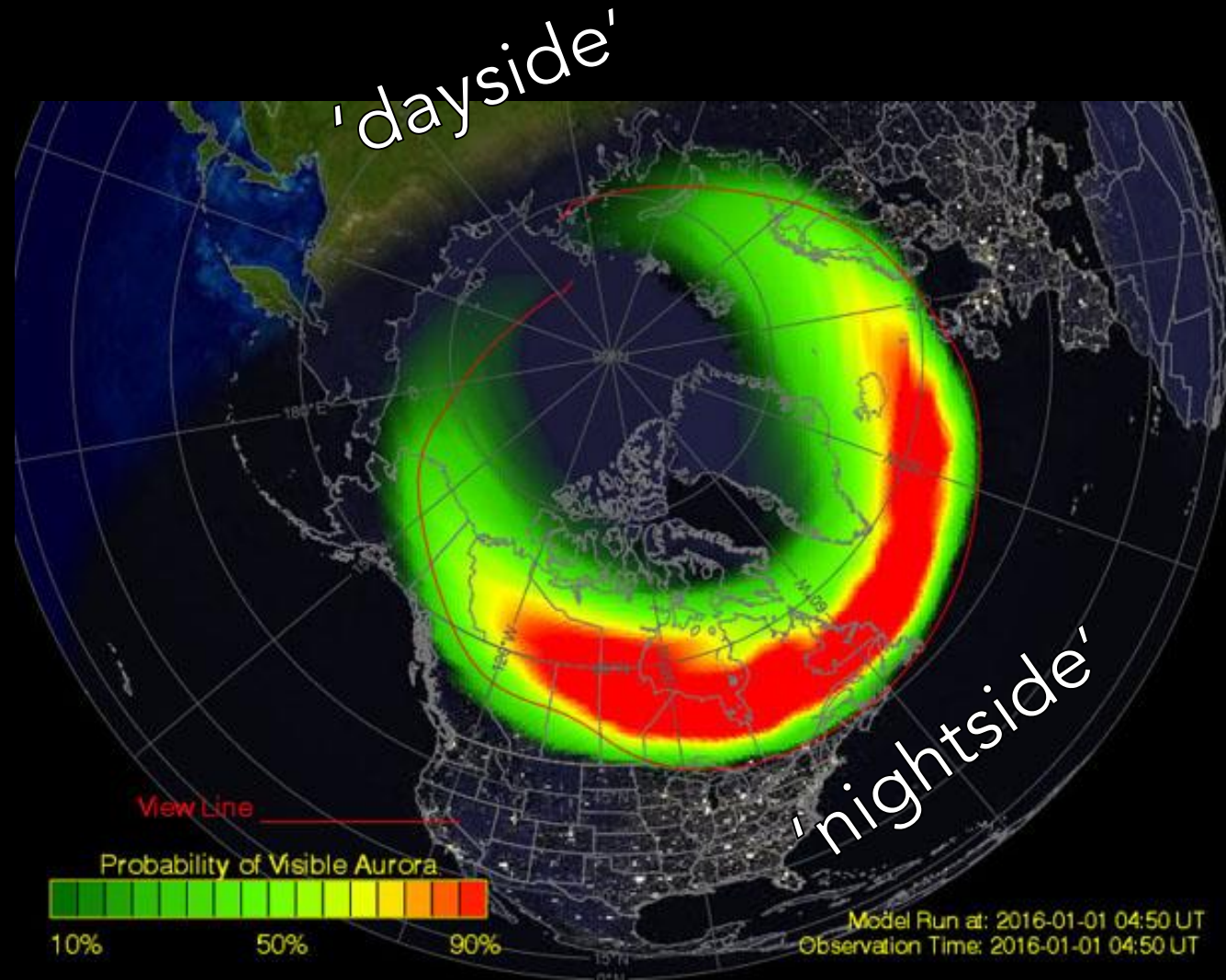
Specific particles release light at specific wavelengths  
**GREEN/RED:** Oxygen  
**BLUE/ PURPLE:** Nitrogen

Yellow/ pink are just a mix of one of these

Yellow is also likely light pollution



# AURORAL OVAL



# Further Reading

All info generally from "Introduction to Space Physics", Kivelson and Russell  
and "Physics of the Upper Polar Atmosphere", Asgeir Brekke



Things we didn't cover but do exist if you come across them:

- Plasma waves
- Magnetohydrodynamics and kinetic theory
- Current sheets/neutral sheets
- The million different types of aurora
- Magnetic fields and aurora of other planets (not the same process)

TOP TIP:

TOP TIP:

Be dumb.