Magnetic reconnection in the bow shock

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Space plasma

- Plasma is composed of charged particles
  - Solar wind and the magnetosphere
- Plasma movements are governed by electromagnetic fields
- It is very sensitive to externally applied fields
- Magnetic reconnection is the merging and rearranging of magnetic field lines in the plasma

Frozen-in condition

- A theory originating from Alfvén
- Highly conductive plasma
- Plasma and magnetic field lines move together
- Solar wind is frozen-in to the magnetic field

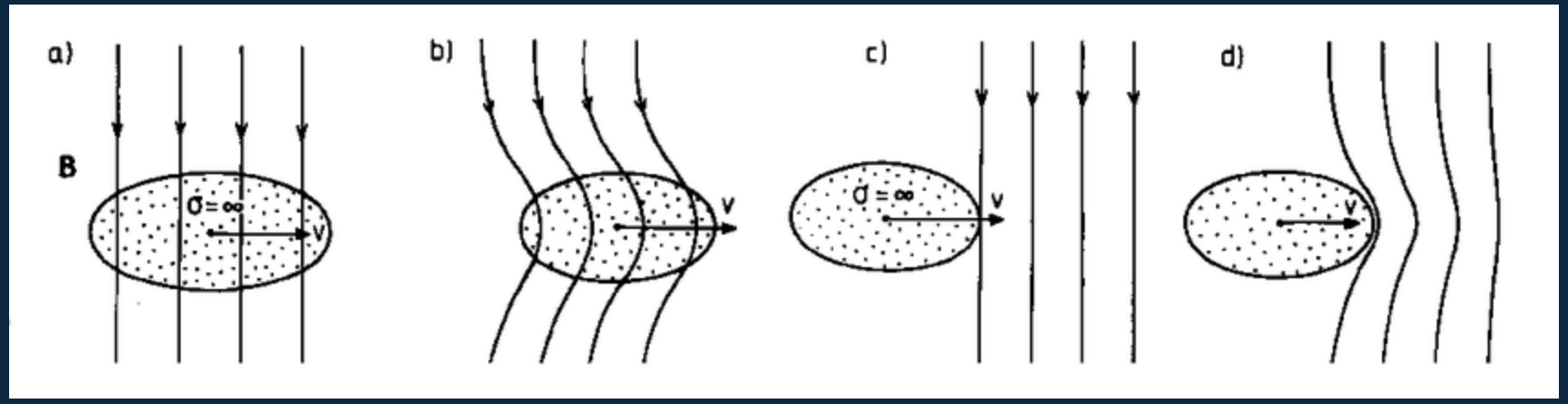
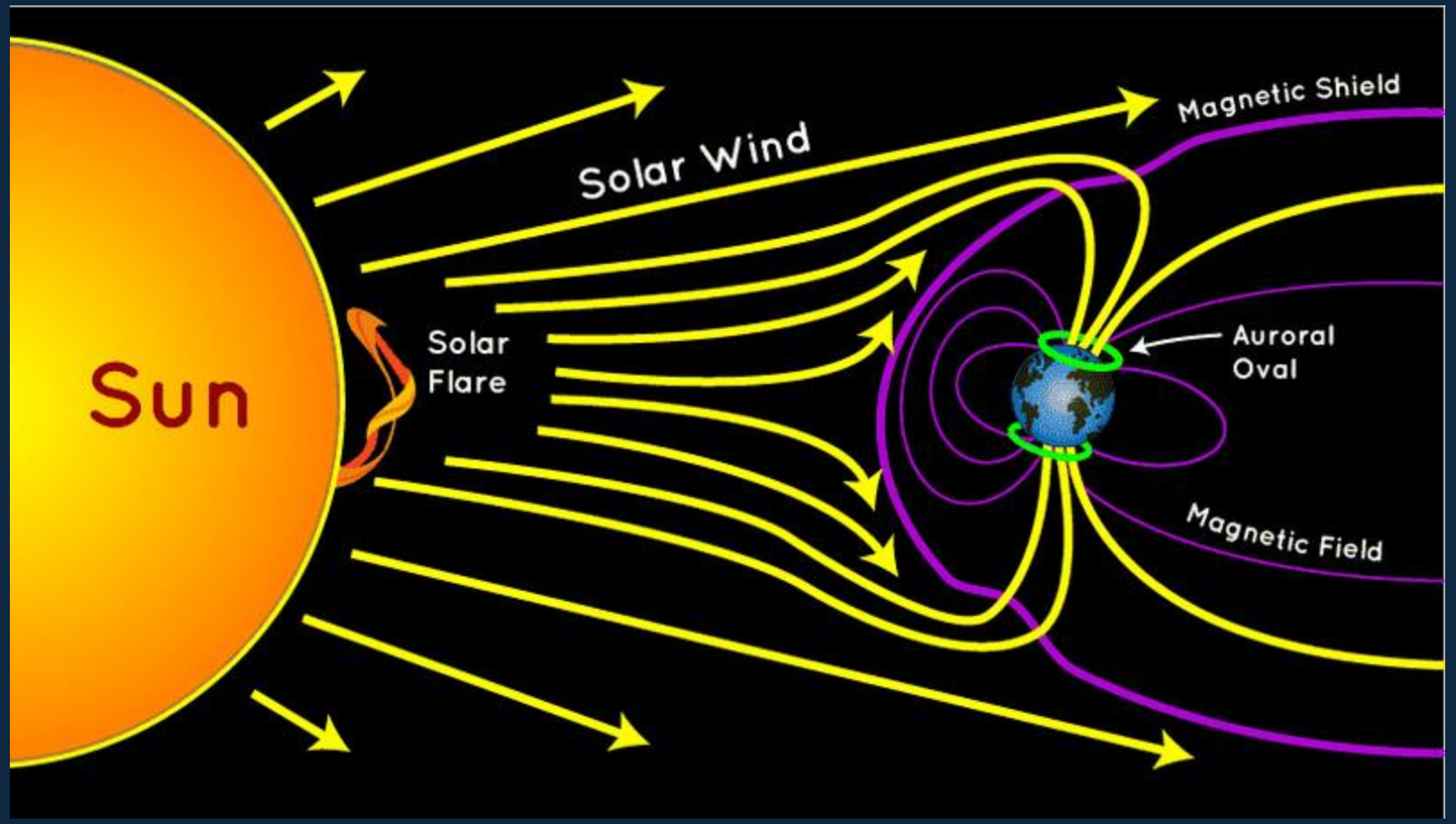


Image credit: Brekke (1997)

Solar wind

- Energetic particles from the Sun
- Fast and slow solar wind
  - Fast: v=800km/s
  - Slow: v=400km/s
- Low density
- Highly electrically conductive



Source: ResearchGate

Magnetosphere and the bow shock

- Bow shock
  - First part where the solar wind interacts with Earth's magnetosphere
  - Shock wave
  - Solar wind drops from supersonic to subsonic speeds
- Magnetosheath
  - Magnetosphere is weak and irregular due to interactions with the solar wind
  - Turbulent plasma motion

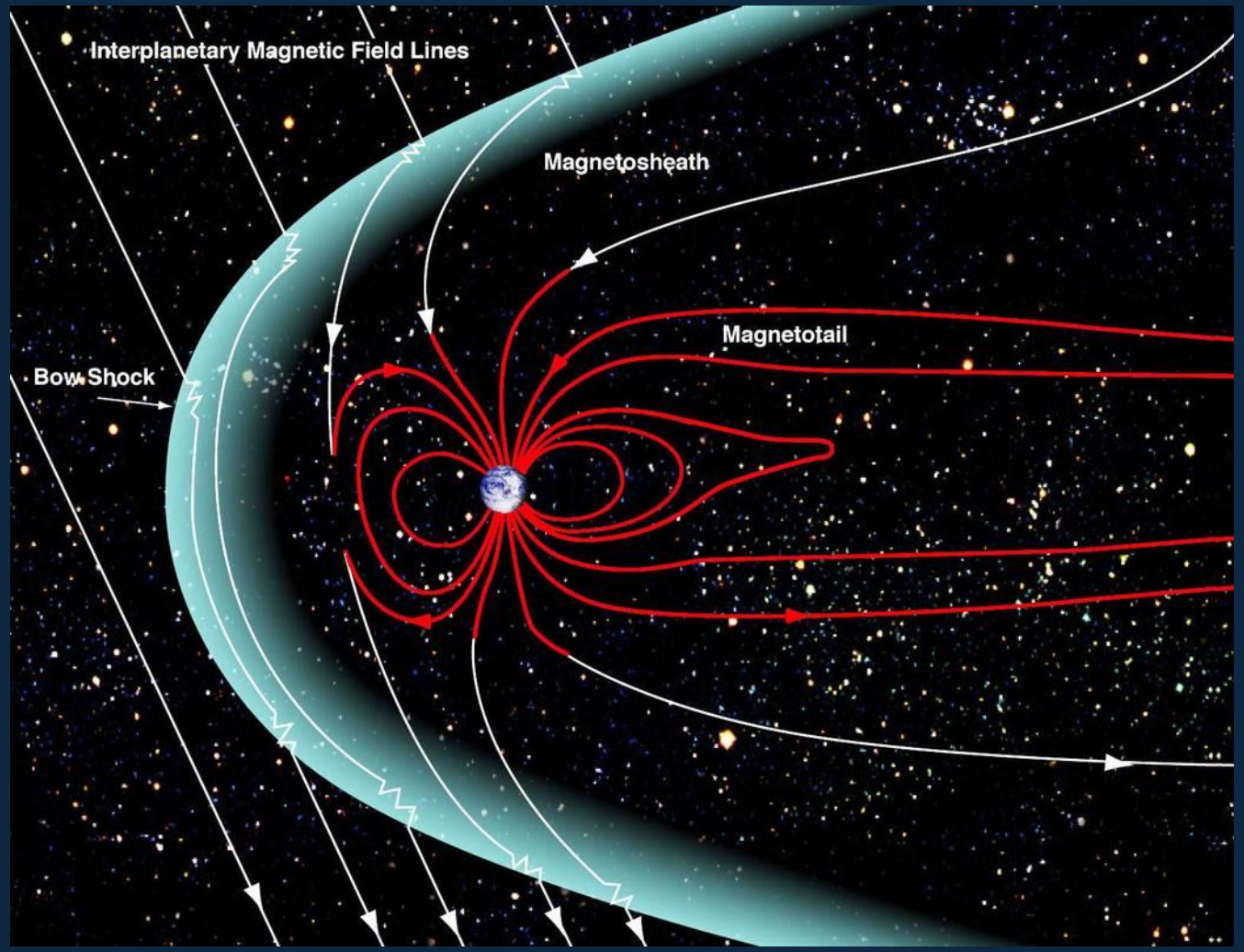


Image credit: NASA

Current sheets in magnetosheath

- Magnetosheath has turbulent plasma motion
- Current sheets are commonly formed in the magnetosheath
  - Forms between two magnetic fields of opposing directions
- Current sheets are a prerequisite for magnetic reconnection

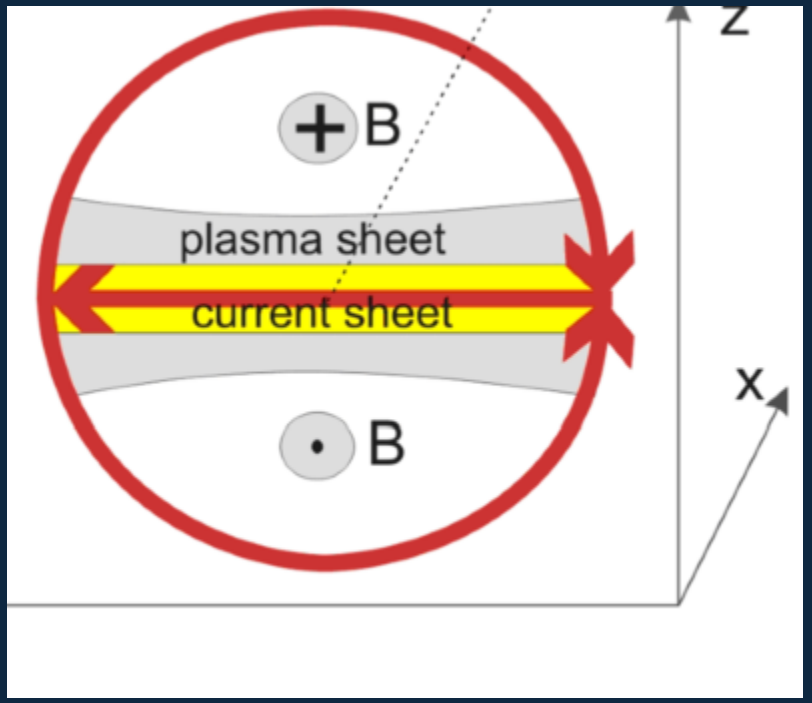


Image credit: Khabarova et al. 2021

Magnetic reconnection

- A process in which the magnetic field lines are rearranged
- Magnetic reconnection breaks the frozen-in condition in the diffusion region
  - Inflow and outflow regions follow the frozen-in theorem
- Can cause magnetic energy being converted to
  - Kinetic energy
  - Thermal energy
  - Particle acceleration

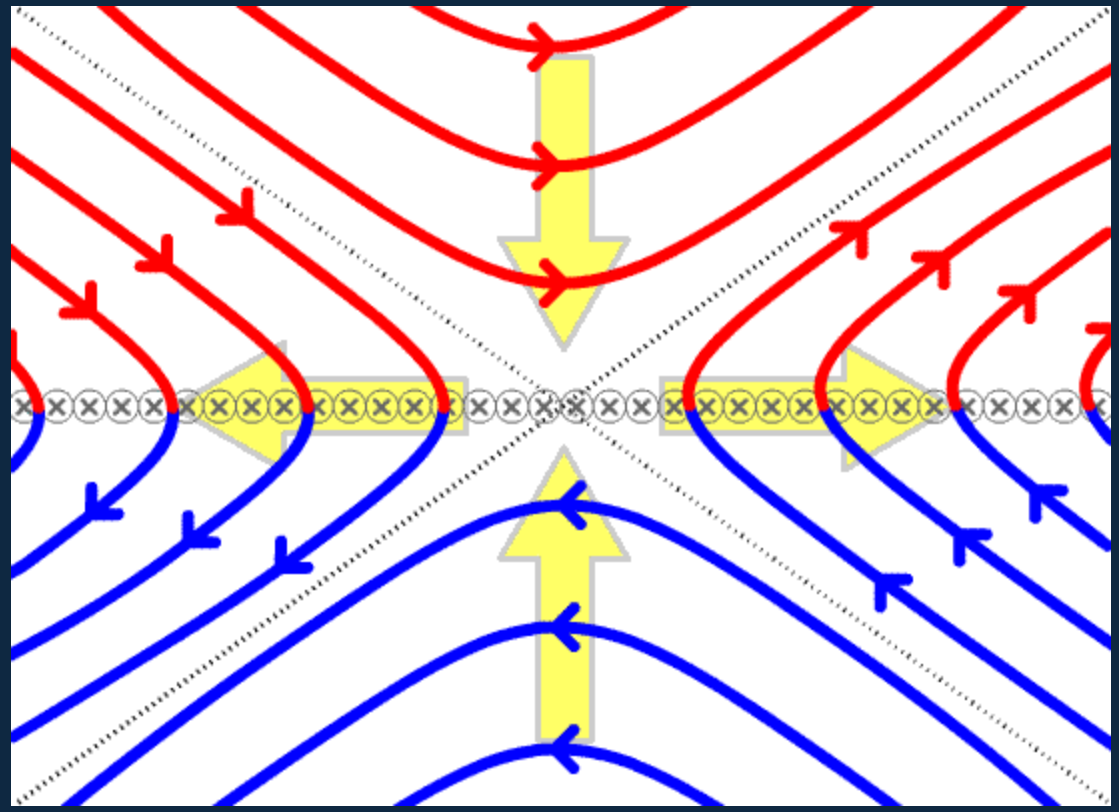


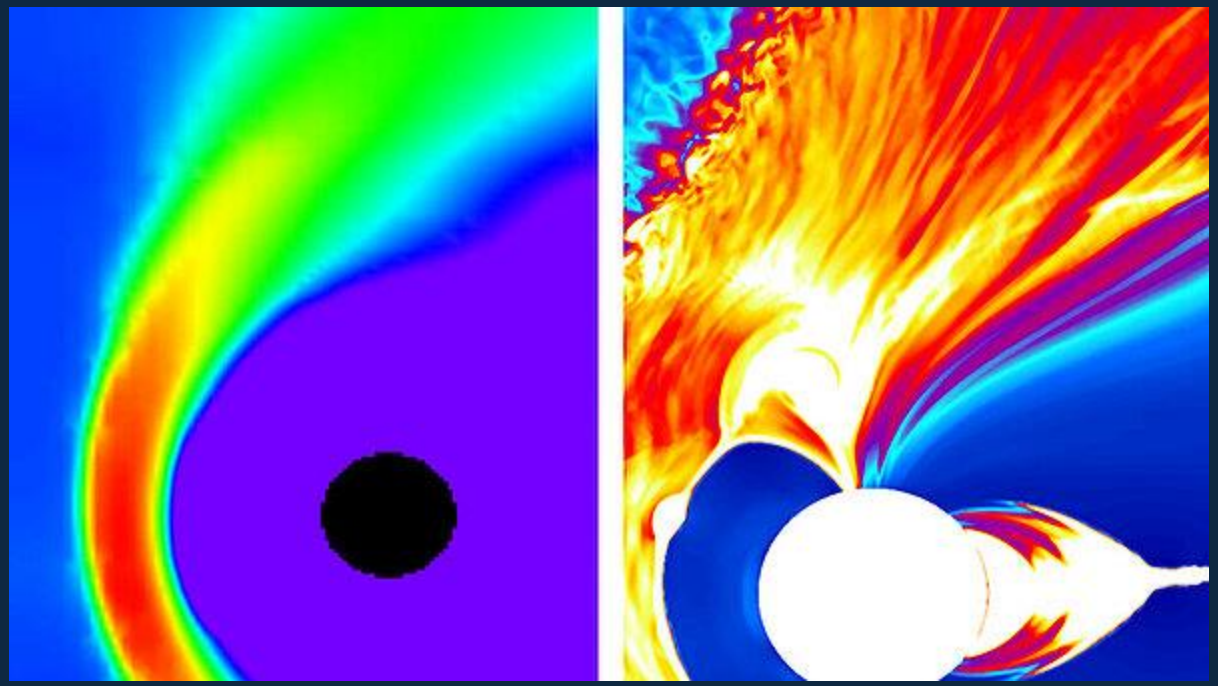
Image source: Wikipedia

Reconnection in the bow shock?

- There is not much knowledge of magnetic reconnection occurring in the bow shock
  - No knowledge of the nature or properties of it
- Observations have indicated that current sheets can exist in the transition region of the bow shock
  - Observations from Magnetospheric Multiscale mission have indicated magnetic reconnection in the current sheets

Vlasiator

- Vlasiator is a hybrid-Vlasov plasma model, run by the University of Helsinki
- Electrons are modeled as fluid
- Ions are modeled as kinetic velocity distribution functions
  - Can capture ion kinetic effects
- Simulates global near-Earth space



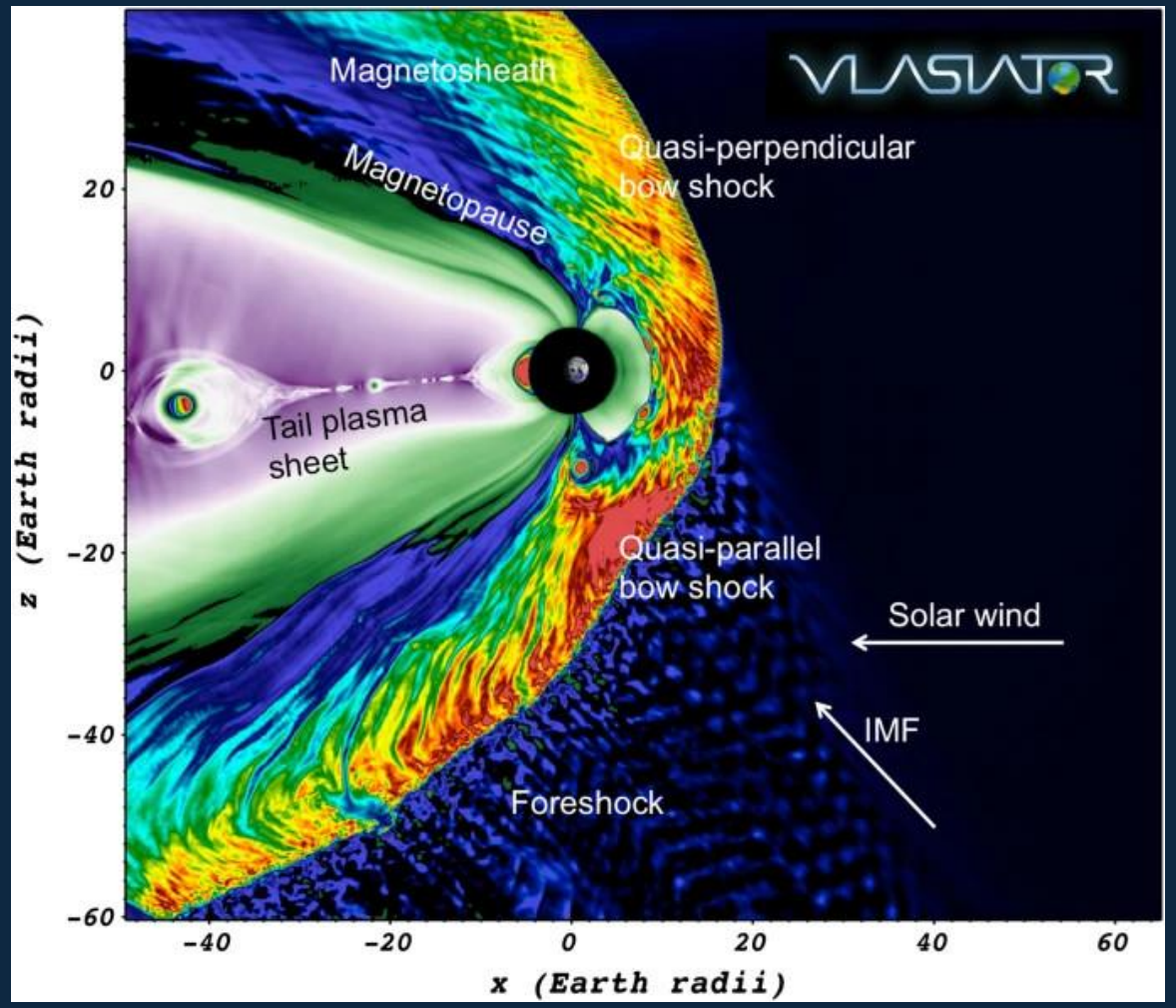
Comparison with MHD model (left) and Vlasiator (right). Image: University of Helsinki

Vlasiator

- Vlasiator can run 6D simulations
- Only one of its kind
- Because of the multi-dimensional approach at ion scales, Vlasiator is very computationally challenging
- Uses supercomputing to run the simulations

Reconnection in the bow shock in a Vlasiator run

- Two-dimensional run in Vlasiator
- Magnetic reconnection was observed in the bow shock
  - What caused the reconnection?
  - What is the nature of it?



Finding the reconnection points

- Plotting times from the run, and looking for the reconnection points
- Uses the Analysator tool – created specifically for analysing Vlasiator files
- Uses the flux function to find the null points, where reconnection might happen
- Not all null points are reconnection, only saddle points are
  - Uses Hessian matrix to determine the type of the null point

Reconnection in the dataset

- Reconnection can be found at the saddle points
- Hessian matrix to determine the type of the point
  - If det(H) < 0, it is a saddle point
- Reconnection points are called X-points
  - Another type of null points are the local maxima – magnetic O points
- Reconnection jets

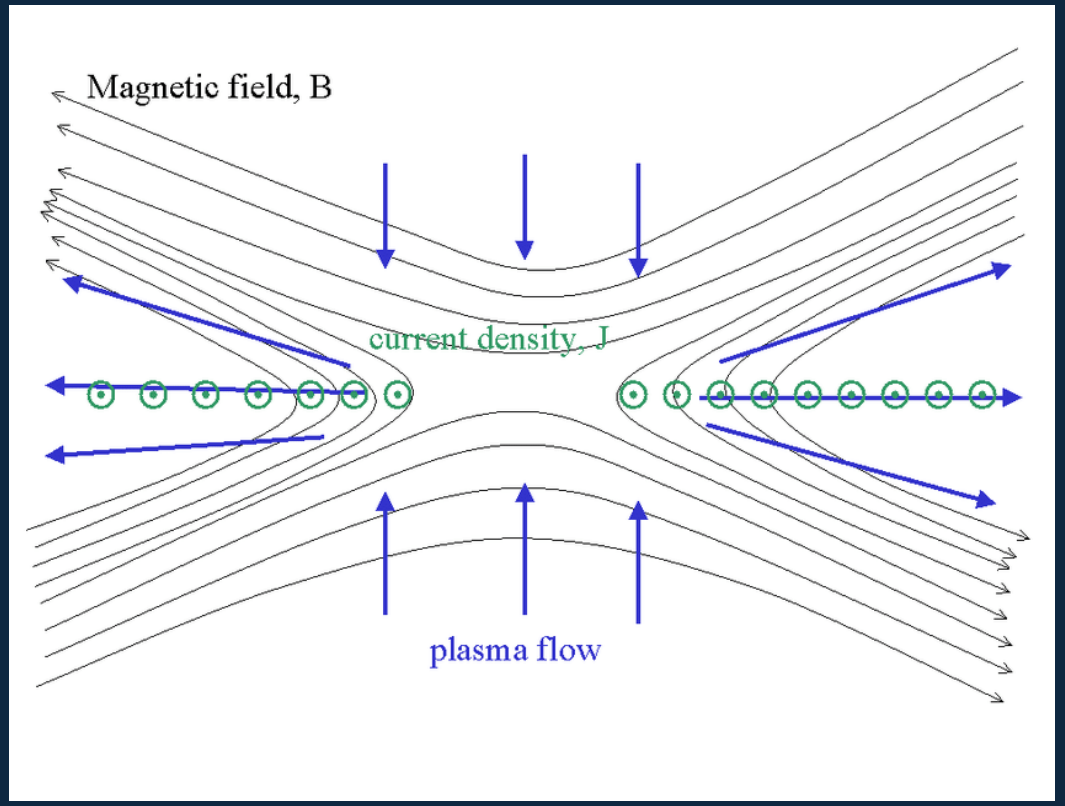


Image credit: Bárta et al.

Analysing the reconnection points

- Following the reconnection points
  - The evolution of the X-points
- Plasma dynamics that formed the current sheet in the bow shock
- The properties of the magnetic reconnection
  - Reconnection speed
  - Thickness of the outflow region
  - Reconnection rate
- The analysis has not been done yet

Expected results

- I don’t have results yet
- Hypothesis is that the reconnection could be turbulent
  - Does the data have properties that indicate turbulent reconnection?

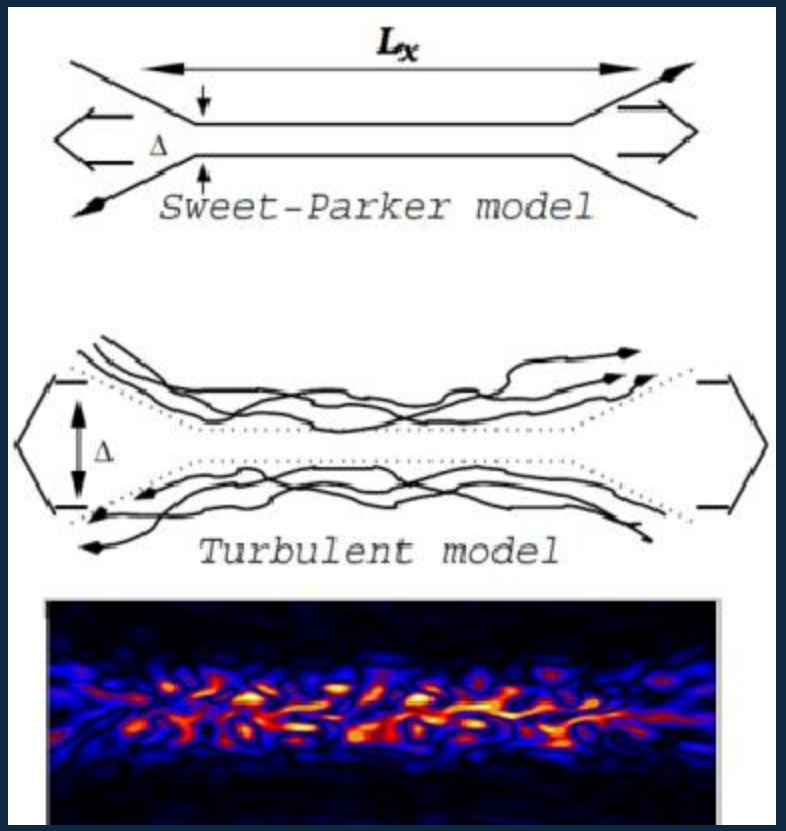


Image credit: Leão et al. 2012

Conclusions

- Bow shock is a shock wave that forms when the solar wind interacts with the Earth's magnetosphere
- Magnetic reconnection can happen in the current sheets in the bow shock and the magnetosheath
  - Common in the magnetosheath
- Vlasiator simulations can show the reconnection points
  - Simulation found unexpected reconnection at the bow shock
  - What caused the reconnection, and what is the nature of it?
- Analysis of the data will be done using the Analysator tool
- Hypothesis is turbulent reconnection
  - My thesis is not done, so I cannot yet tell if the hypothesis is correct

Thank you for listening!

Any questions?

References

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