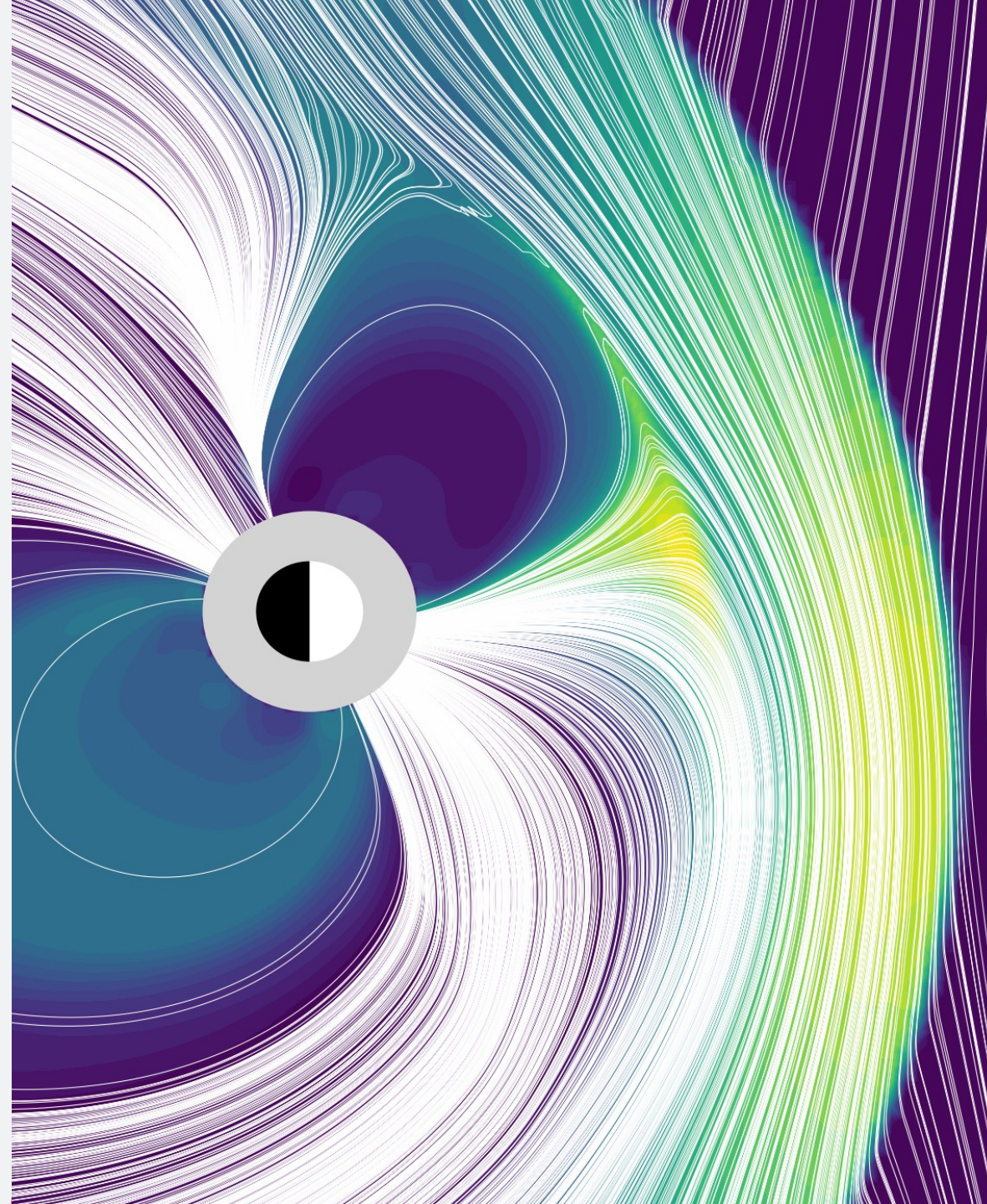


# *RAPID AURORAL WANDERING DURING THE LASCHAMPS EVENT*

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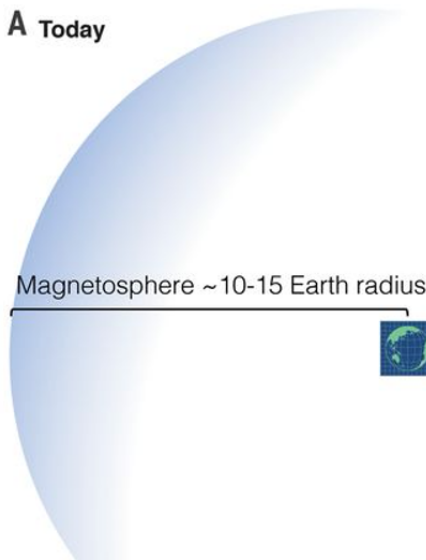


# *BACKGROUND*

- The Laschamp Geomagnetic Excursion occurred between 42k and 40k years, over an approximate span of ~1300 years.
  - Named for Laschamp lava flows in France, where it was first discovered.
  - Studied extensively in academia, most recently using ancient *kauri* trees from New Zealand
- The geomagnetic low was seen during 42,200–41,500 years ago (Adams Event). The geomagnetic dipole strength dropped to ~4% of present values.
- Estimates range from the magnetosphere completely disappearing to diminished dayside. No specific space weather evaluation of this study exists until now.
- Could have had severe consequences on environmental and anthropological factors in paleo-Earth.



A Today



Magnetosphere  
~5 Earth radius



**Depleted geomagnetic field strength**

~28% modern levels (reversed polarity phase),  
~6.3% during Adams Event.  
Rigidity cut-off at Equator 1GV.

**B Laschamps Excursion  
(Active Sun)**

# Present Guesstimates...

+ A recent study estimated that due to the drastic reduction in strength, the magnetosphere would be severely diminished, and the aurora would extend down to 40 degrees latitude.

**Aurora down to 68° latitude**

**14 GV GCR rigidity  
cut-off at equator**  
(modulation potential  
400-1400 MV)



**Aurora down to ~40° latitude**

**Low latitude stratosphere (10-20 km)**

Increased ionization (x17 sunspot min.; x7.5 sunspot max.)

**Low latitude troposphere (0-10 km)**

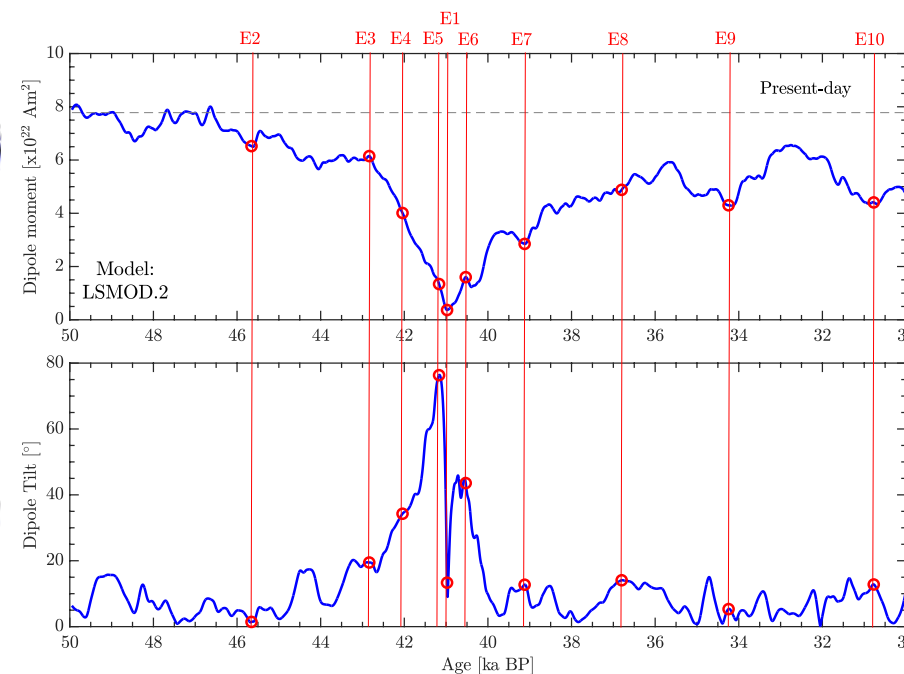
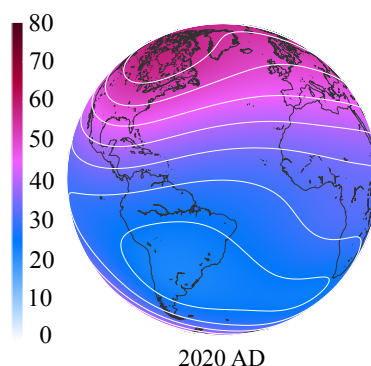
Increased ionization (x7 sunspot min.; x4 sunspot max.)

Potential increase in cloudiness and lightning.

*Cooper et al. (2021), Science*

# Terrestrial B-Field: LSMOD.2 Paleomagnetic Field Model

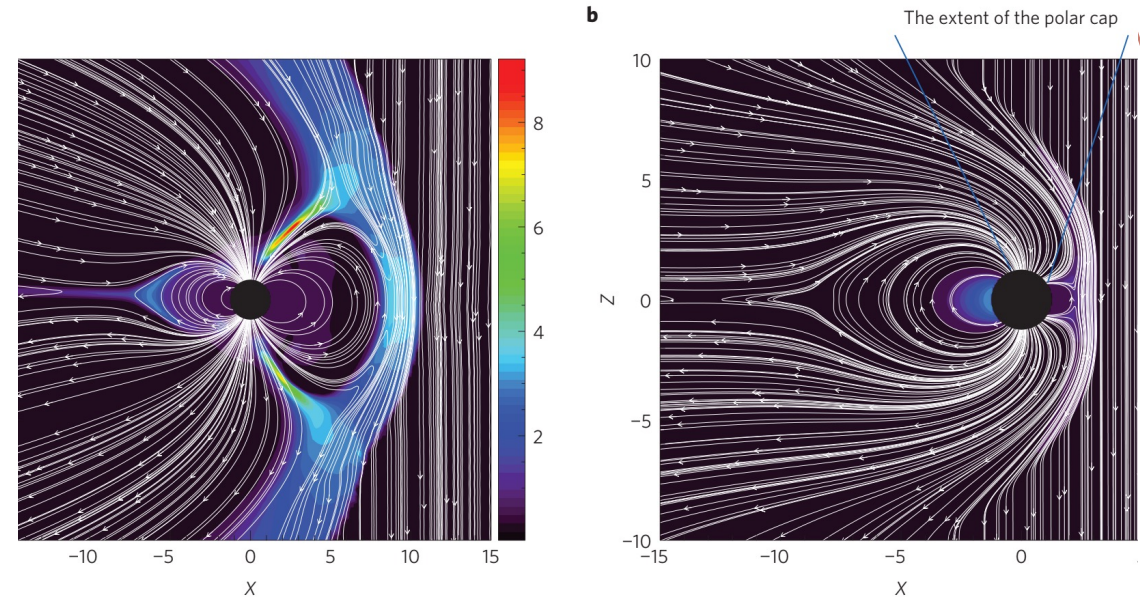
- + LSMOD.2 is a terrestrial paleomagnetic field model that predicts the geomagnetic field parameters like IGRF. We have used this model (up till now) for simulations.
- + The model is built on a global data set of paleomagnetic sediment records and volcanic data. The mathematical representation of the model is spherical harmonics in space and B-splines in time.
- + The model also computes the virtual geomagnetic dipole strength and tilt for reference.





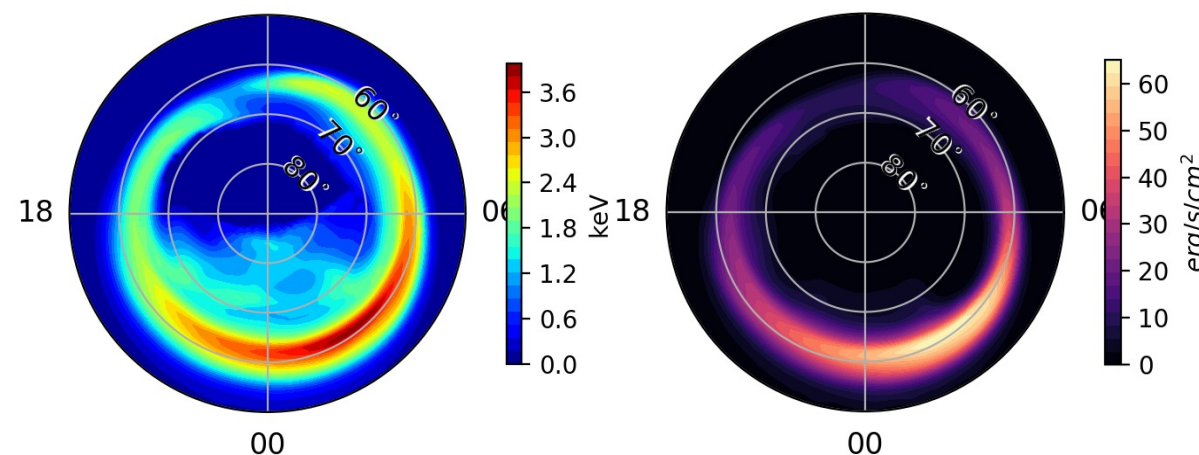
# Global Magnetosphere: BATS-R-US Global MHD Model

- + The global geomagnetic field has been simulated using the Block-Adaptive-Tree-Solar Wind-Roe-Upwind-Scheme magneto-hydrodynamic (MHD) model.
- + The geospace version of BATS-R-US solves for the ideal MHD equations for a near-Earth space environment domain spanning  $25 R_E$  to  $-225 R_E$  in the x-direction,  $-128 R_E$  to  $128 R_E$  in the y and z-directions, and  $2.5 R_E$  from the surface of the Earth.
- + BATS-R-US is a dominant component of the Space Weather Modeling Framework, which is used in forecasting space weather in the near-Earth space environment.



# Auroral Dynamics: MAGNIT Auroral Precipitation Model

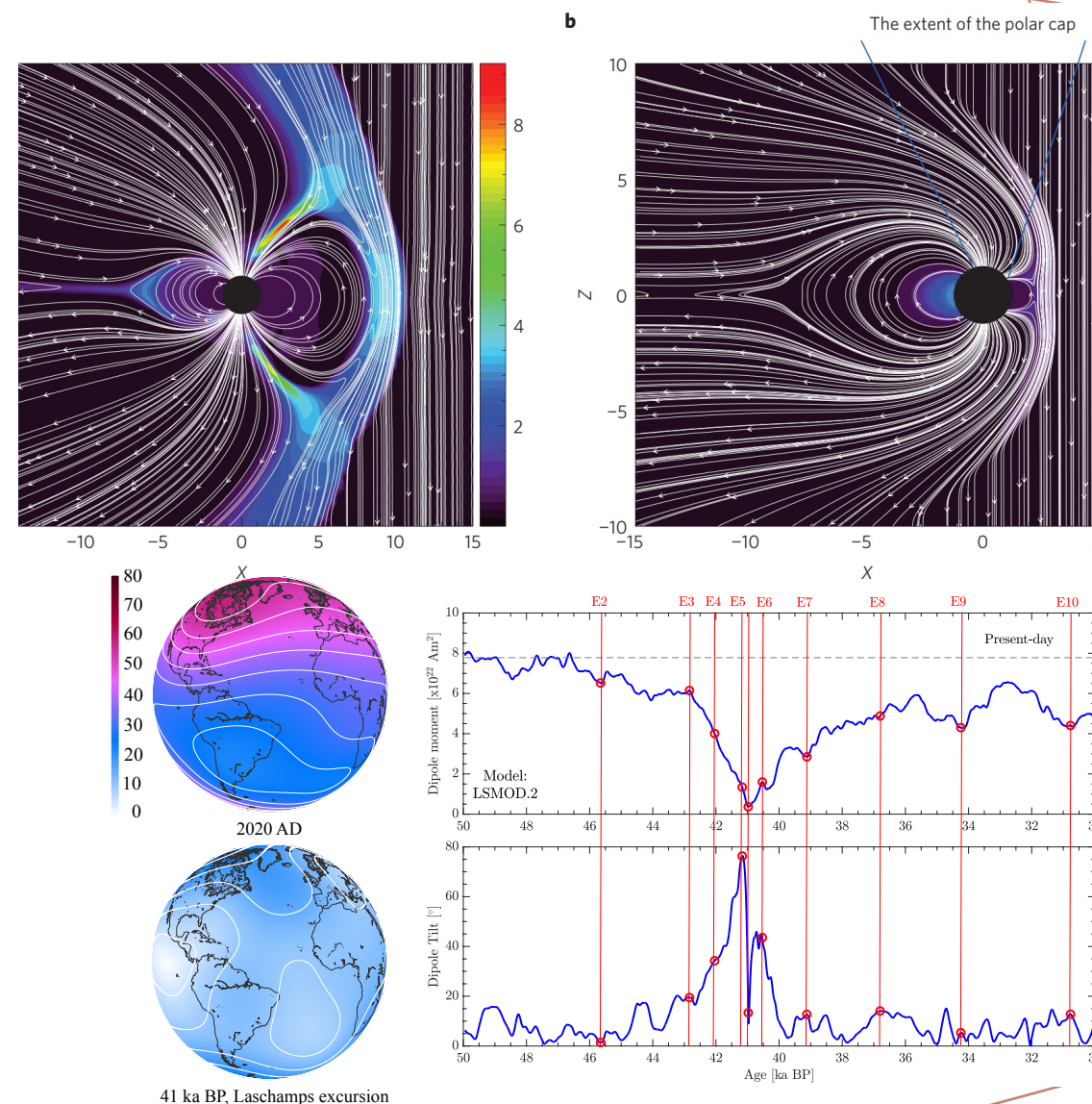
- + The MAGNetosphere-Ionosphere-Thermosphere (MAGNIT) Auroral Conductance Model is a physics-based model of the aurora that determines its strength, location and shape for a given magnetospheric configuration.
- + MAGNIT uses inputs from BATS-R-US quantities like plasma pressure, density, currents to estimate multiple sources of aurora.
- + MAGNIT is a relatively new model. Development was completed in December 2020, and initial simulations of this model with the SWMF show promising results.





# Methods

- + The global terrestrial magnetic field is generated using the LSMOD.2 model that provides us with the spherical harmonics of the terrestrial magnetic field up to a degree of 10 (similar to IGRF).
- + Near-Earth space environment is simulated using the Space Weather Modeling Framework's global MHD module BATS-R-US. BATS-R-US reads multipolar B-fields from LSMOD.2 output.
- + BATS-R-US outputs are then used by paleoMAGNIT to predict the aurora's strength, location and shape.



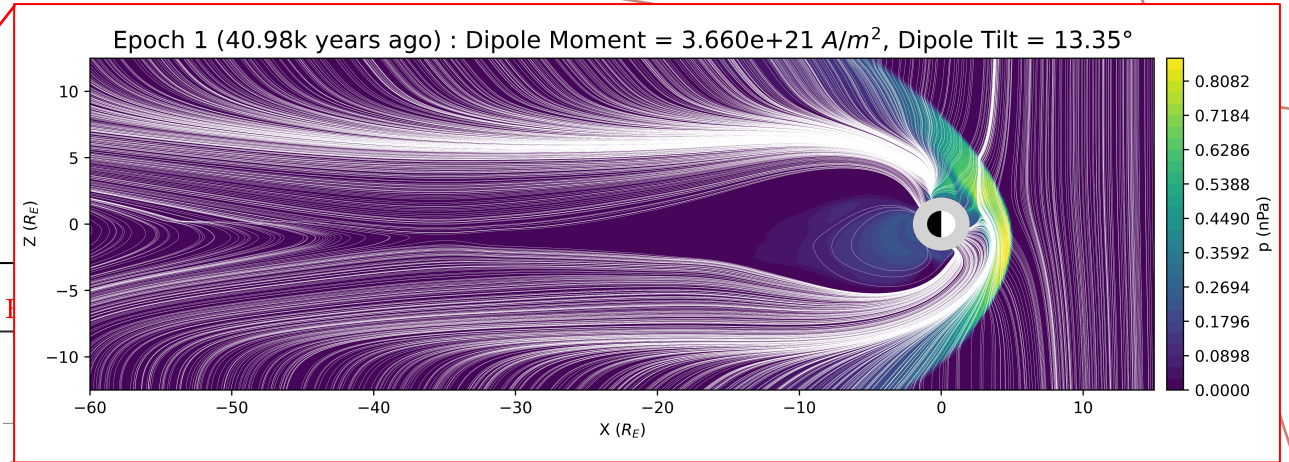
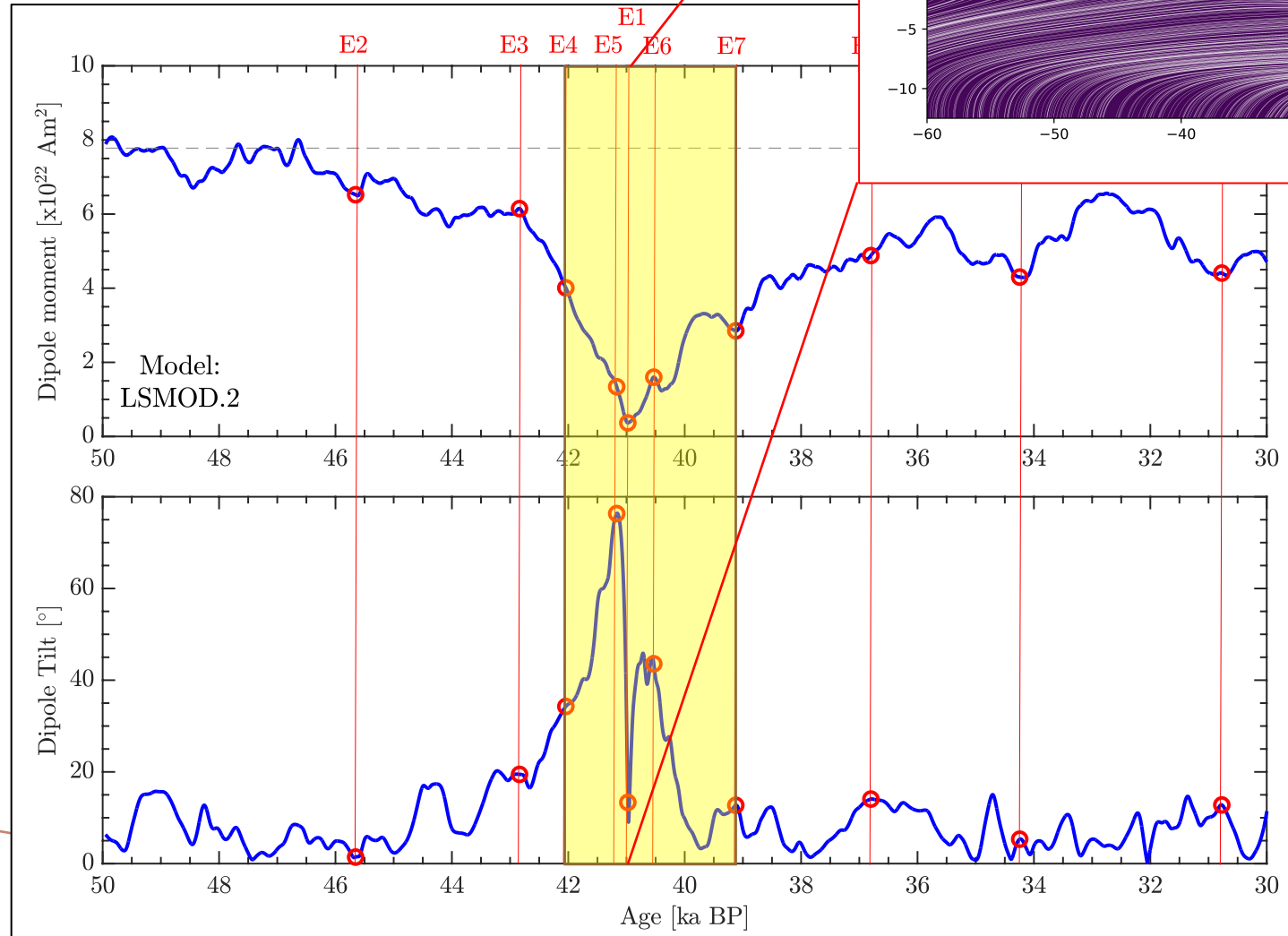
*Powell et al. (1999), Elsevier*

*Toth et al. (2005), JGR Space Physics*

*Korte et al. (2019), Frontiers*

*Mukhopadhyay et al. (2021), JGR Space Physics (in prep)*

# Results

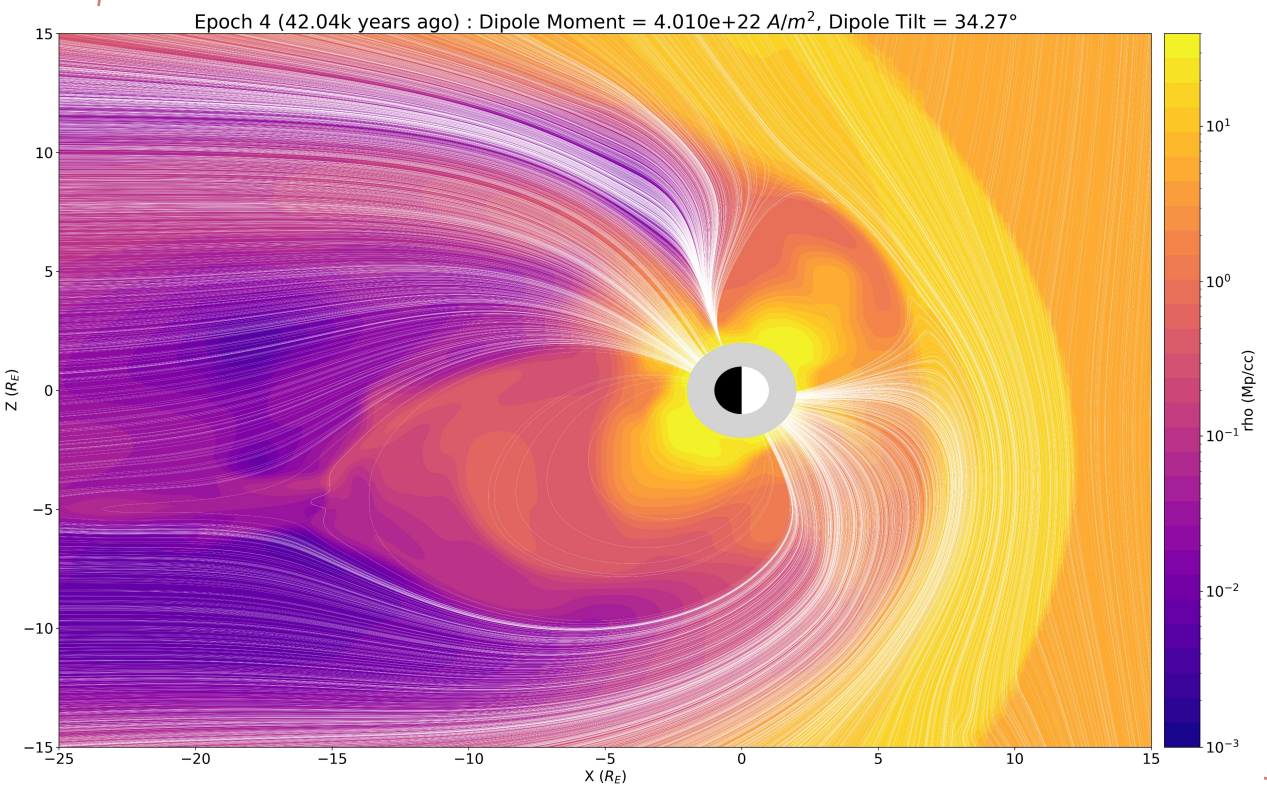




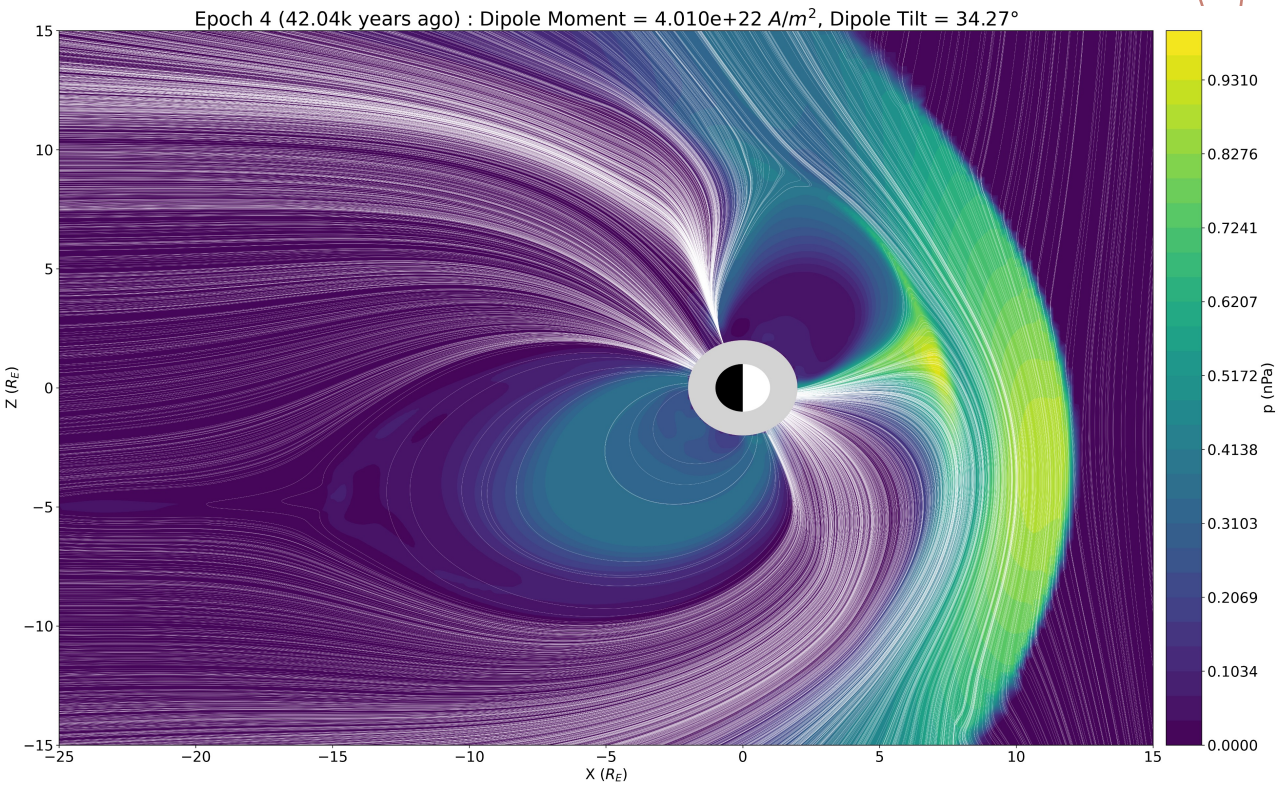
# *EPOCH 4 (42.04K Years ago)*

Dipole moment =  $4.010\text{e}+22 \text{ a/m}^2$ , Dipole tilt =  $34.27^\circ$

Log density on the  $y=0$  plane with  $B_x$  and  $B_z$  field lines



Pressure on the  $y=0$  plane with  $B_x$  and  $B_z$  field lines

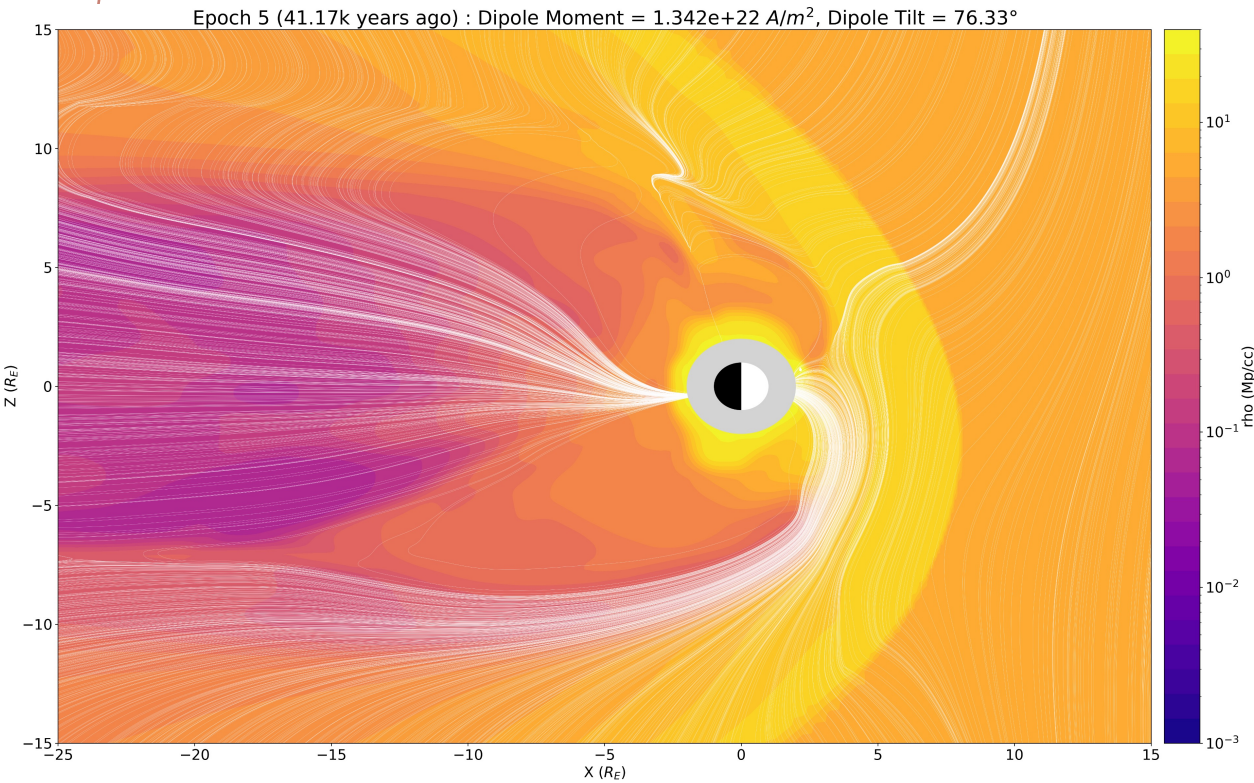




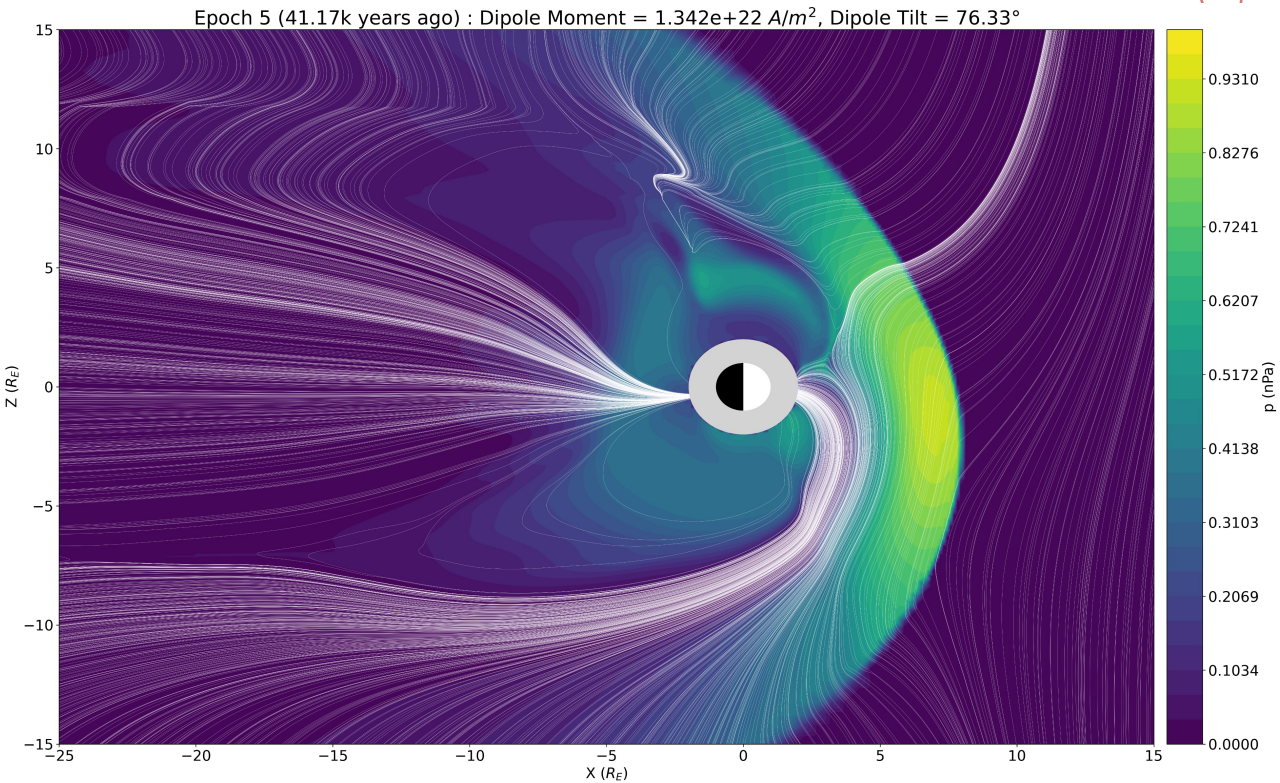
# *EPOCH 5 (41.17K Years ago)*

Dipole moment =  $1.342\text{e}+22 \text{ a/m}^2$ , Dipole tilt =  $76.33^\circ$

Log density on the  $y=0$  plane with  $B_x$  and  $B_z$  field lines



Pressure on the  $y=0$  plane with  $B_x$  and  $B_z$  field lines

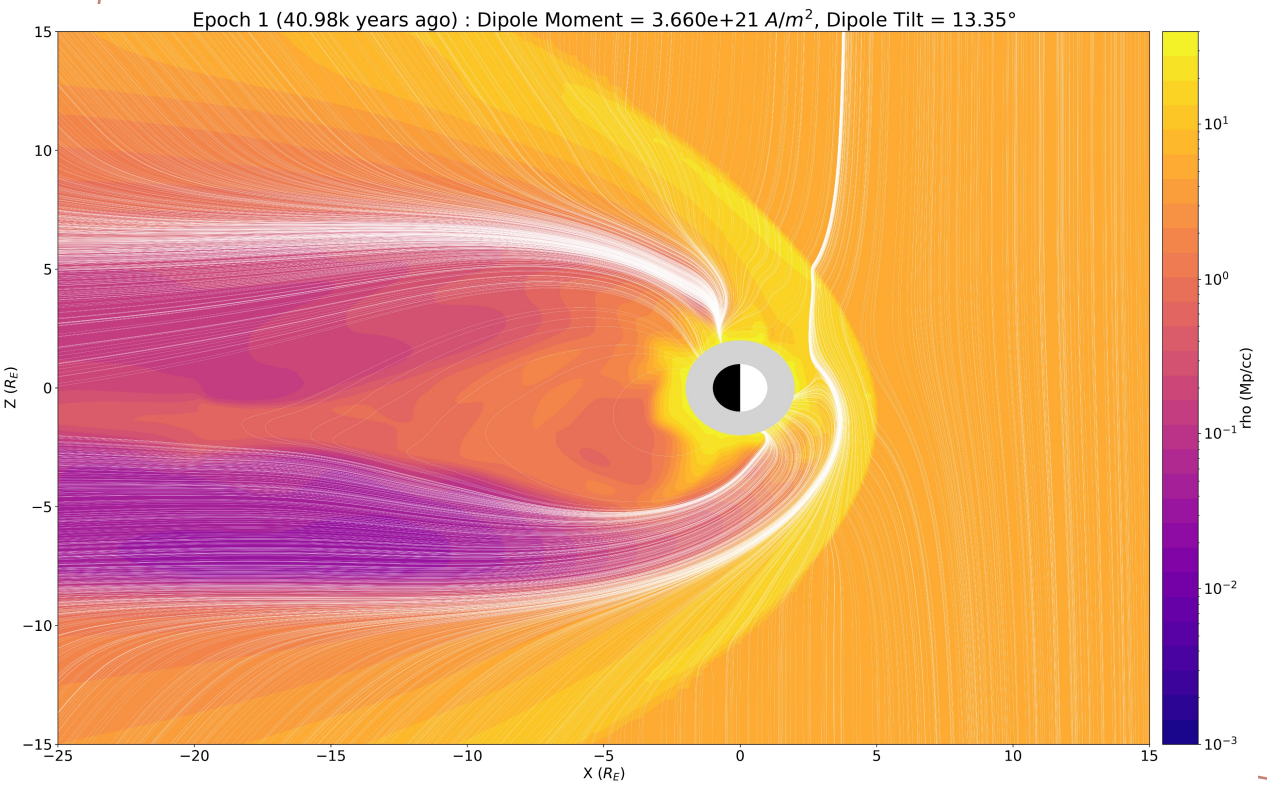




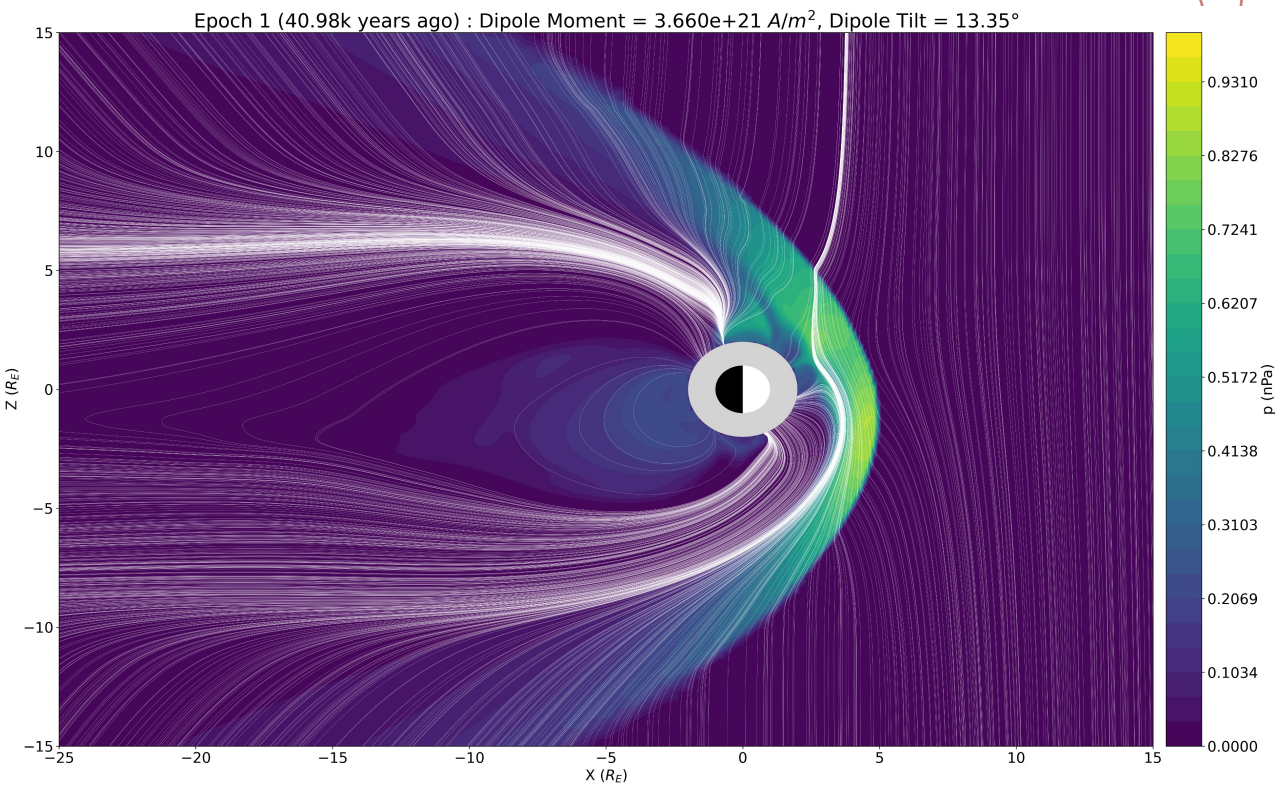
# *EPOCH 1 (40.98K Years ago)*

Dipole moment =  $3.660\text{e}+21 \text{ a/m}^2$ , Dipole tilt =  $13.35^\circ$

Log density on the  $y=0$  plane with  $B_x$  and  $B_z$  field lines



Pressure on the  $y=0$  plane with  $B_x$  and  $B_z$  field lines

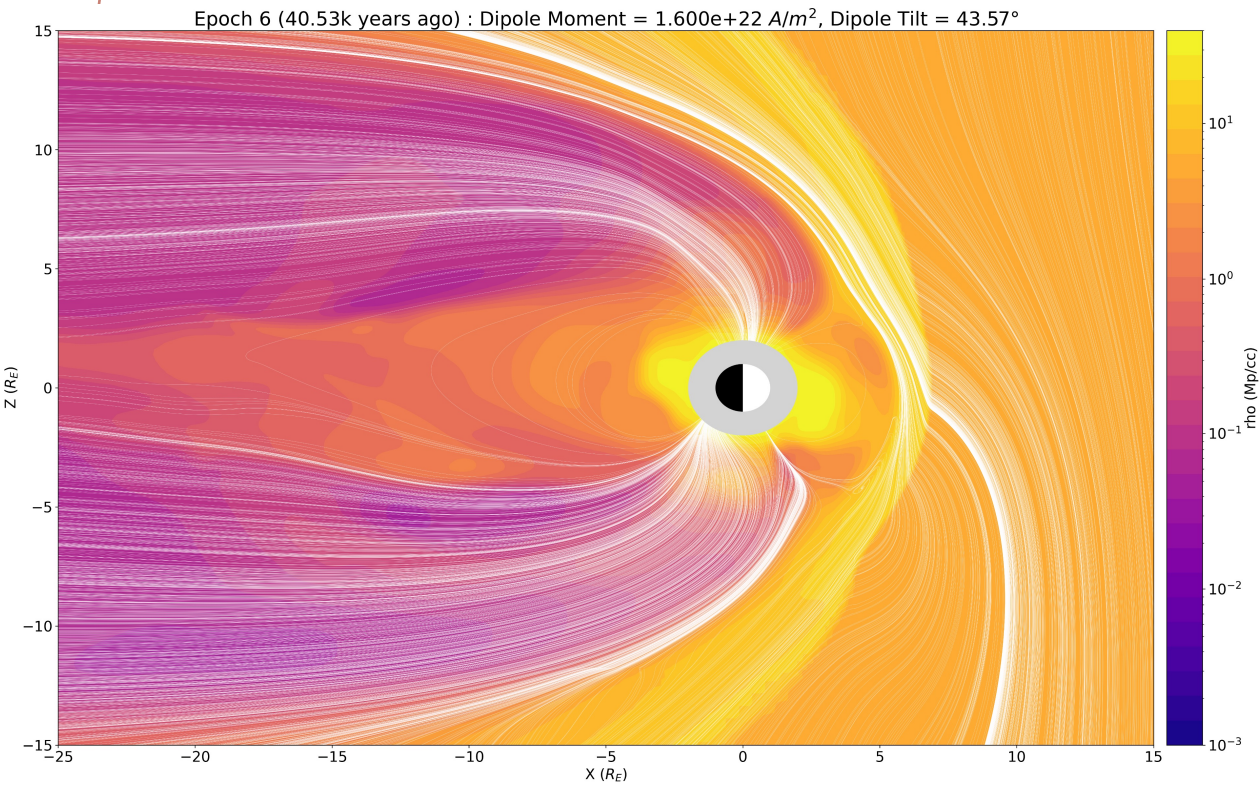




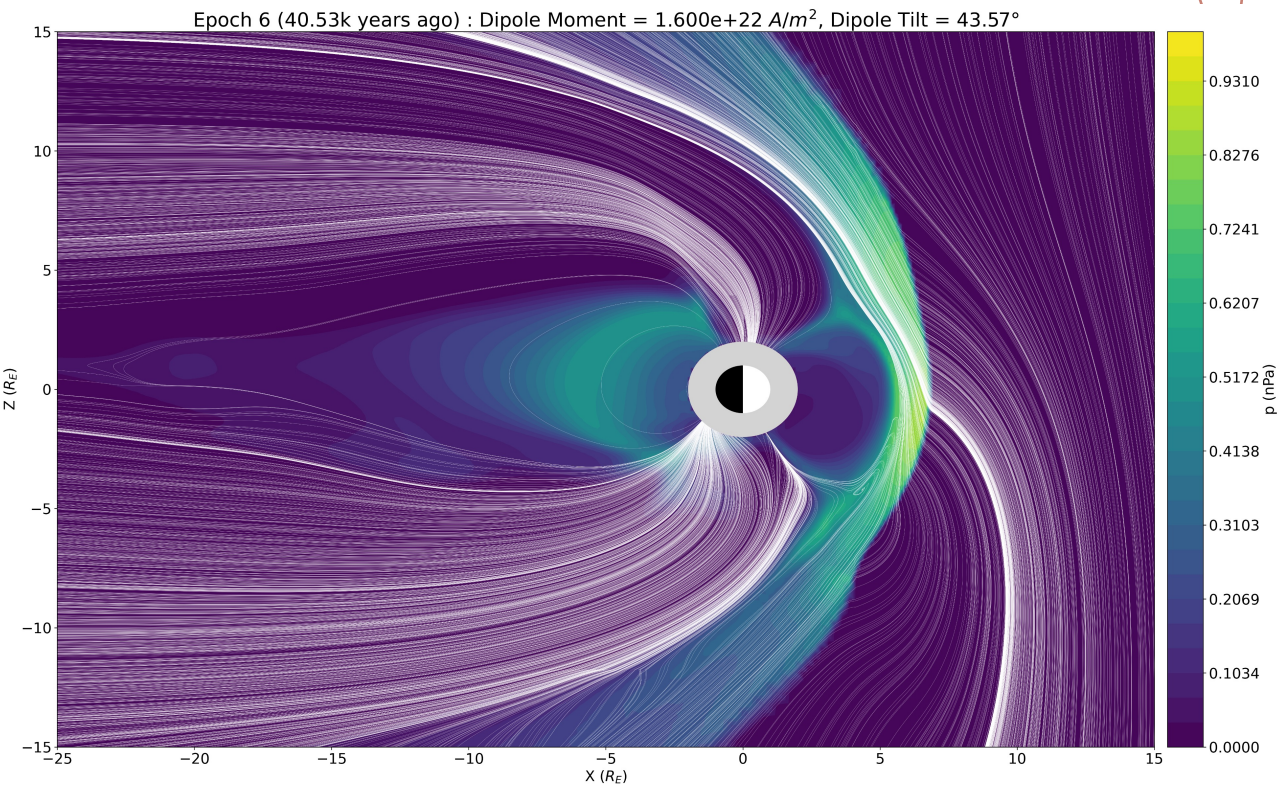
*EPOCH 6 (40.53K Years ago)*

Dipole moment =  $1.600\text{e}+22$  a/m<sup>2</sup>, Dipole tilt =  $43.57^\circ$

Log density on the y=0 plane with Bx and Bz field lines



Pressure on the y=0 plane with Bx and Bz field lines

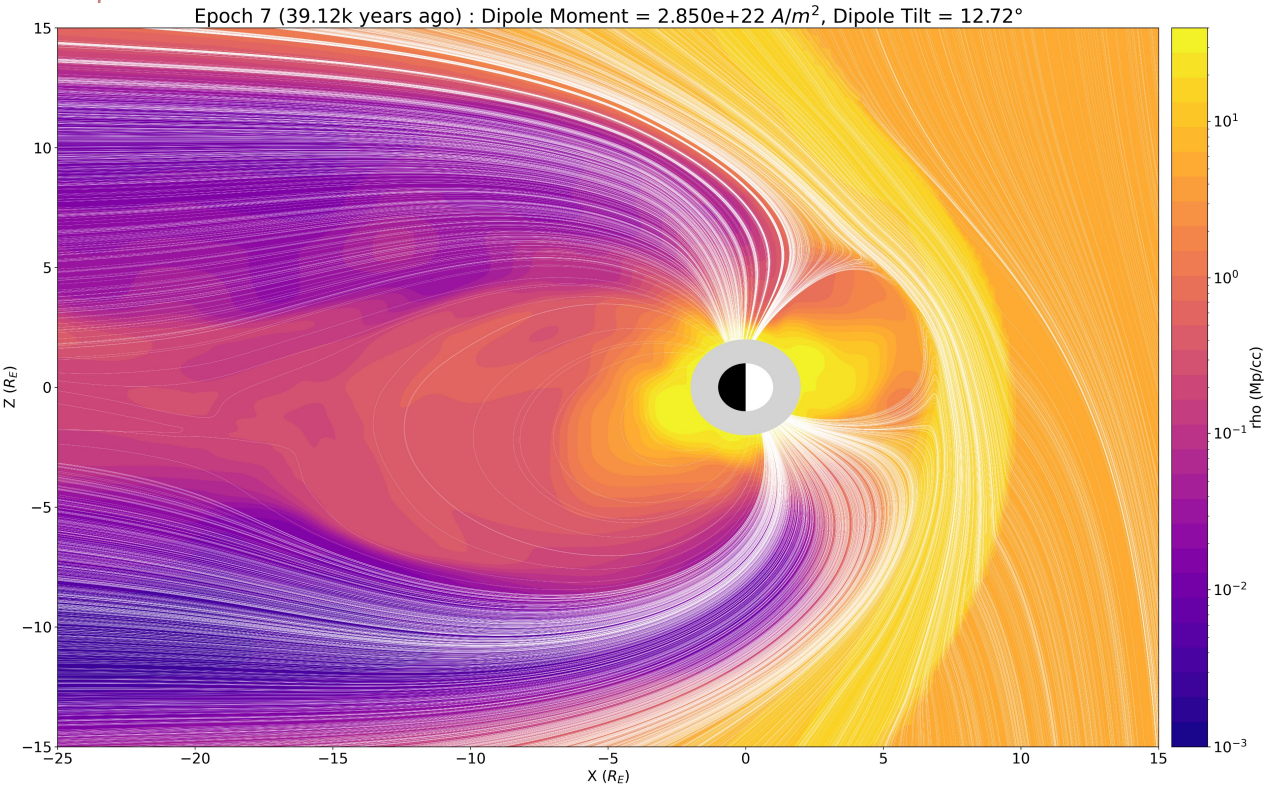




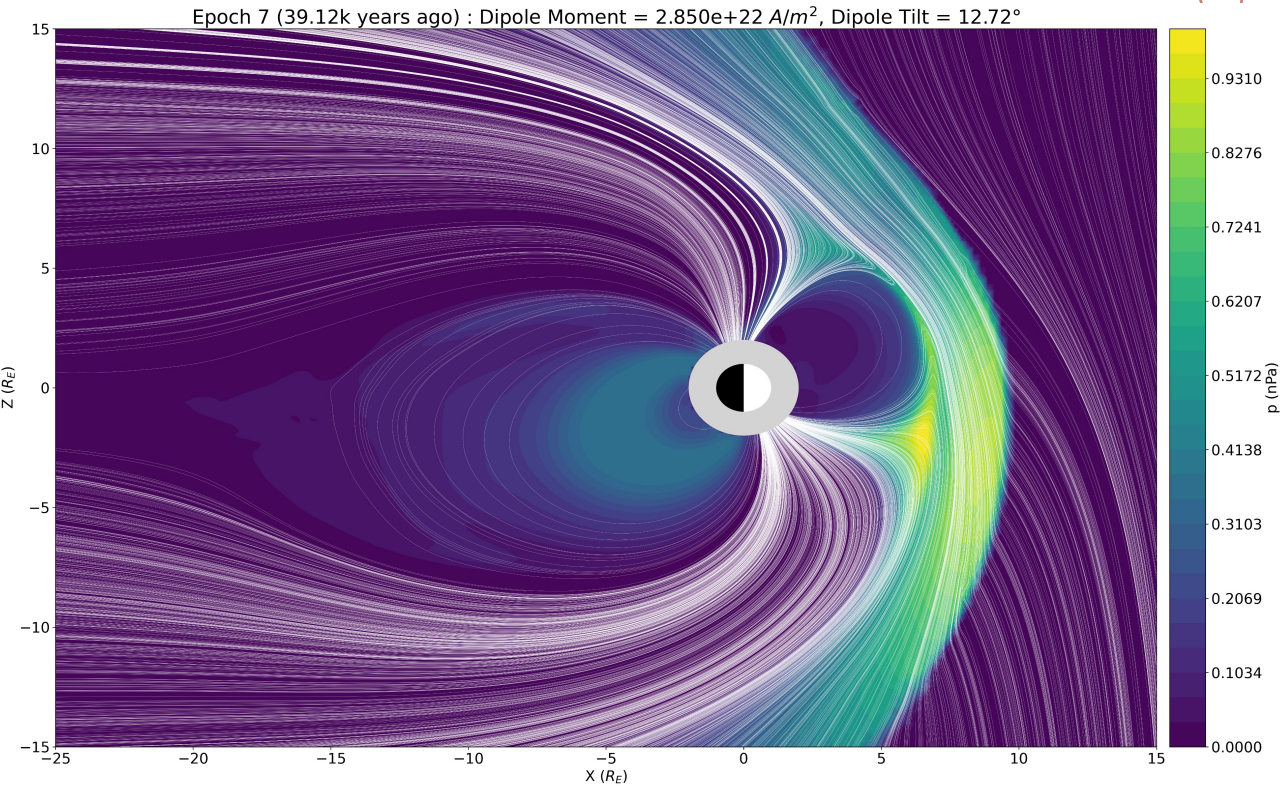
*EPOCH 7 (39.12K Years ago)*

Dipole moment =  $2.850\text{e}+22 \text{ a/m}^2$ , Dipole tilt =  $12.72^\circ$

Log density on the  $y=0$  plane with  $B_x$  and  $B_z$  field lines



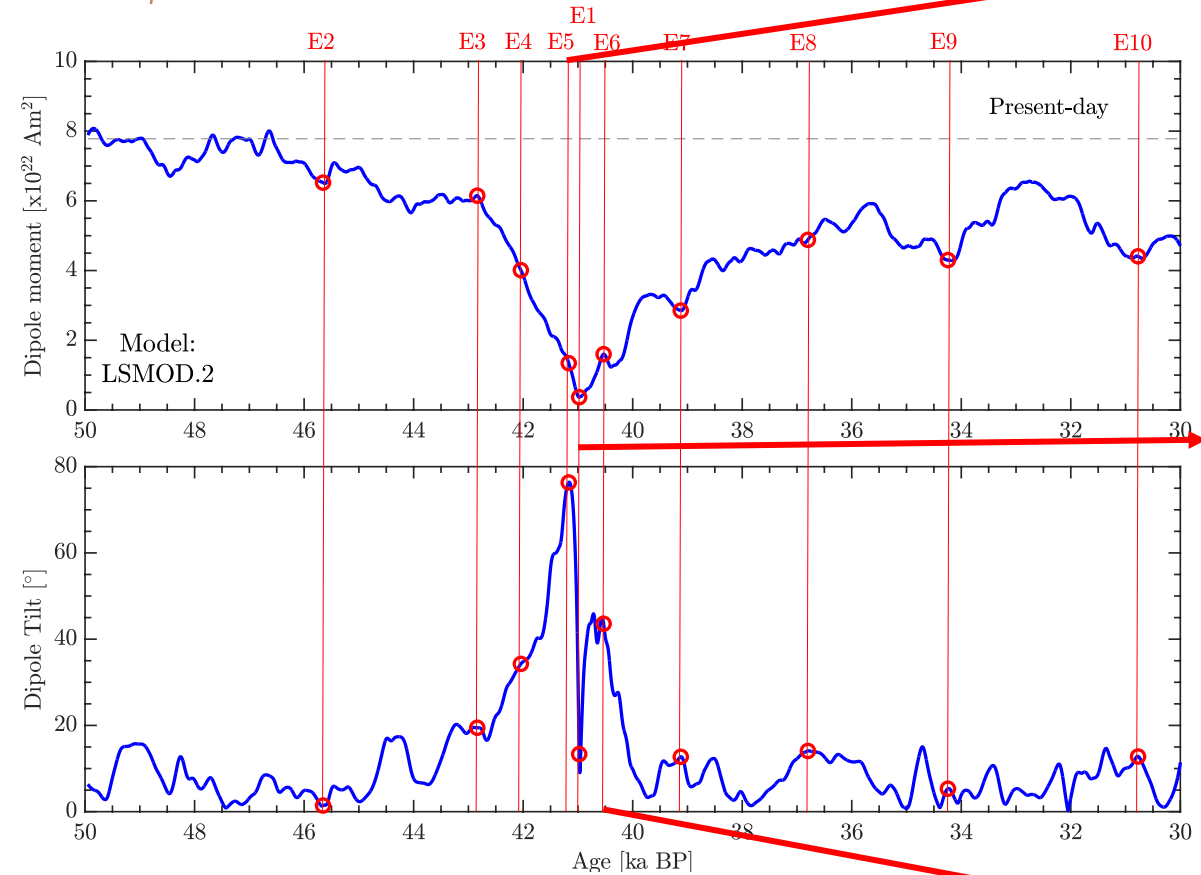
Pressure on the  $y=0$  plane with  $B_x$  and  $B_z$  field lines





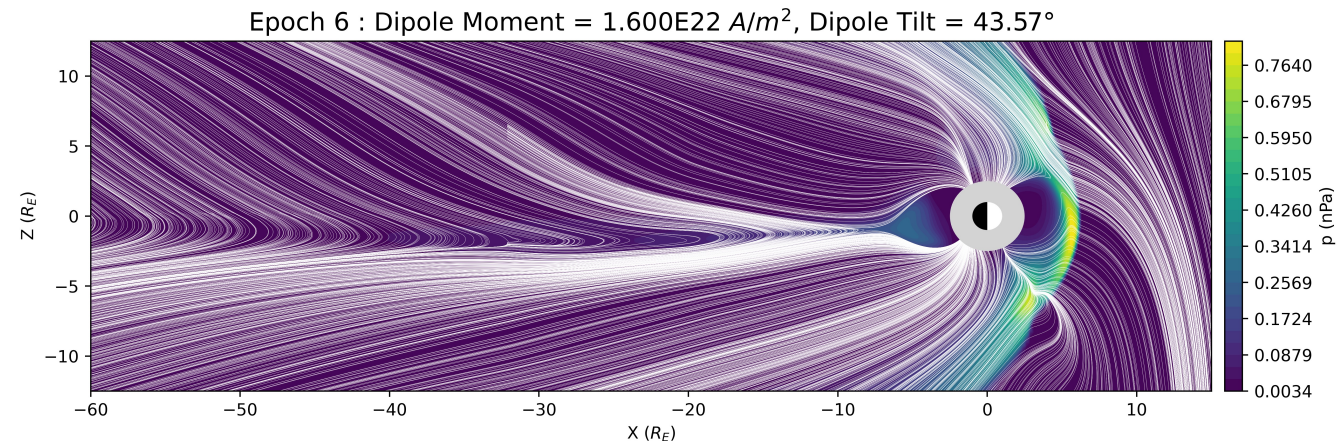
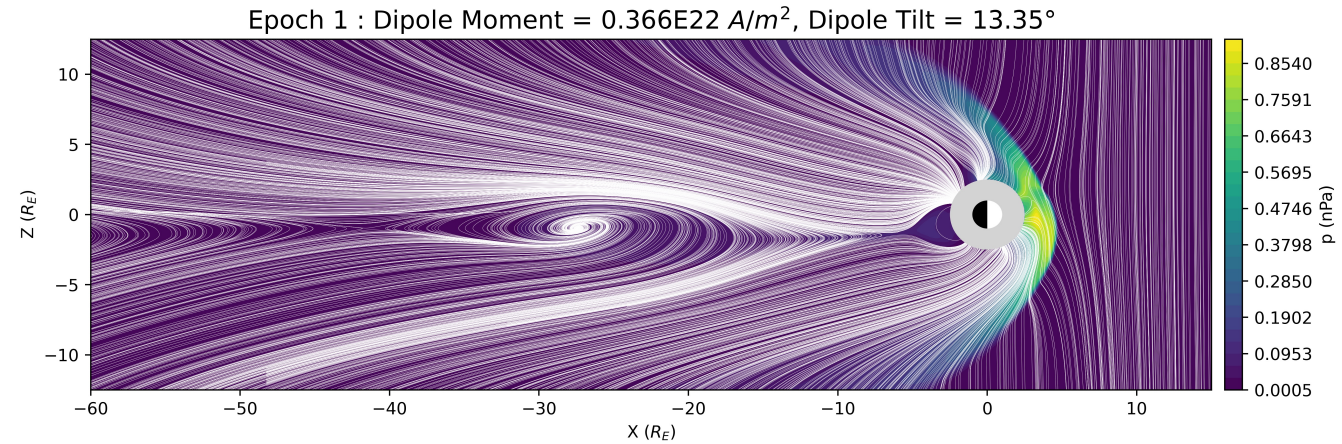
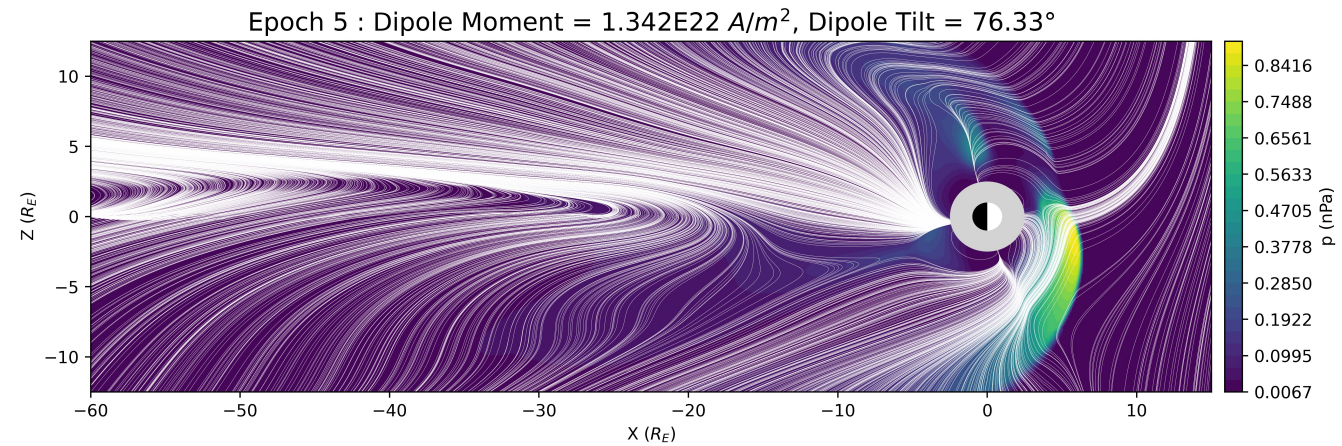
## Q1. How realistic are these results?

A. Magnetopause distance reduces to  $<4 R_E$ , validating the results found through lit. survey.



## Q2. How significant are these results?

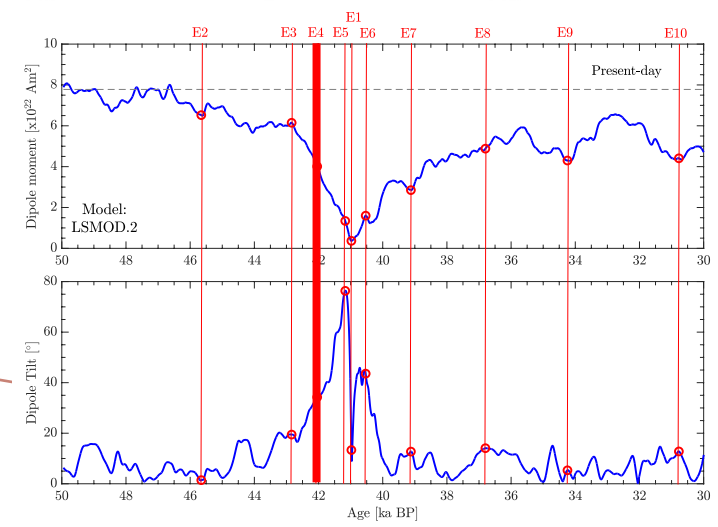
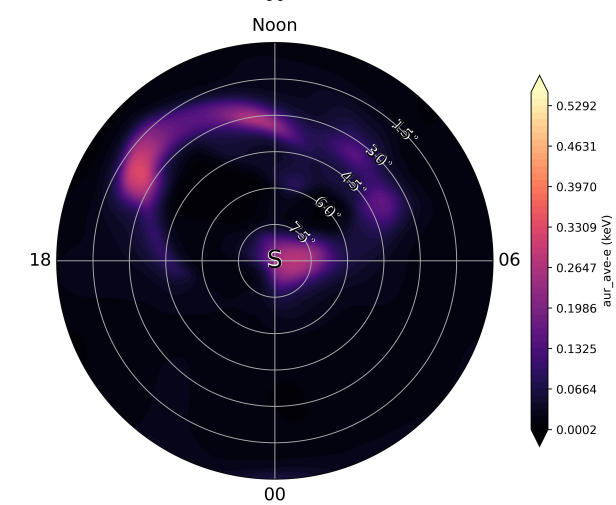
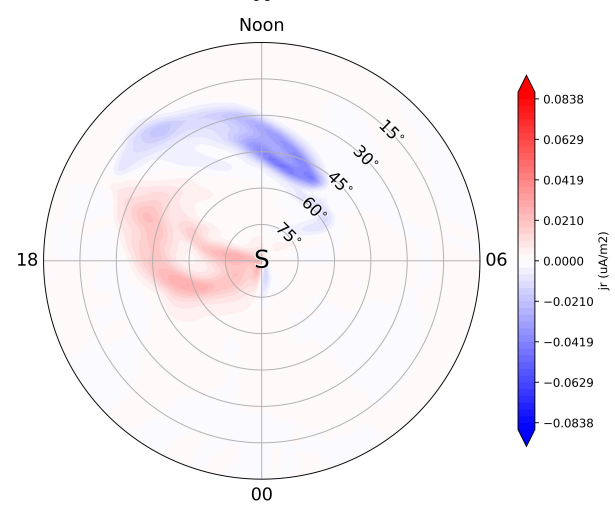
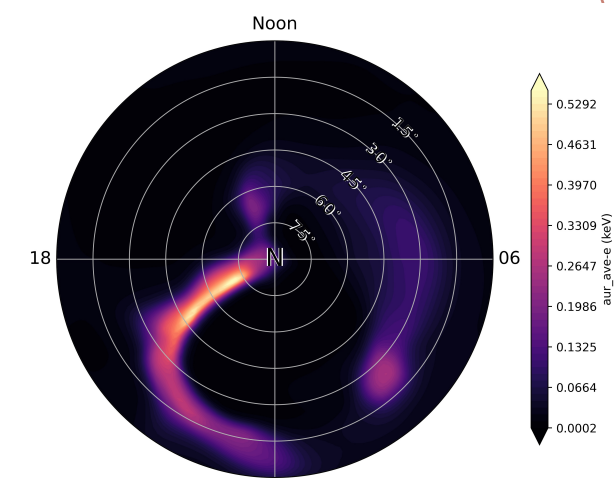
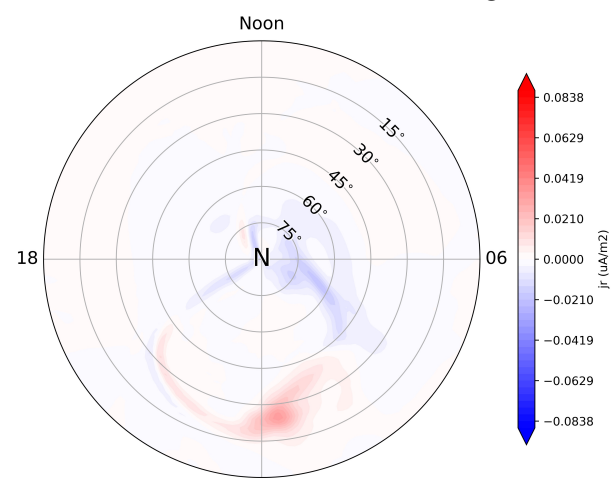
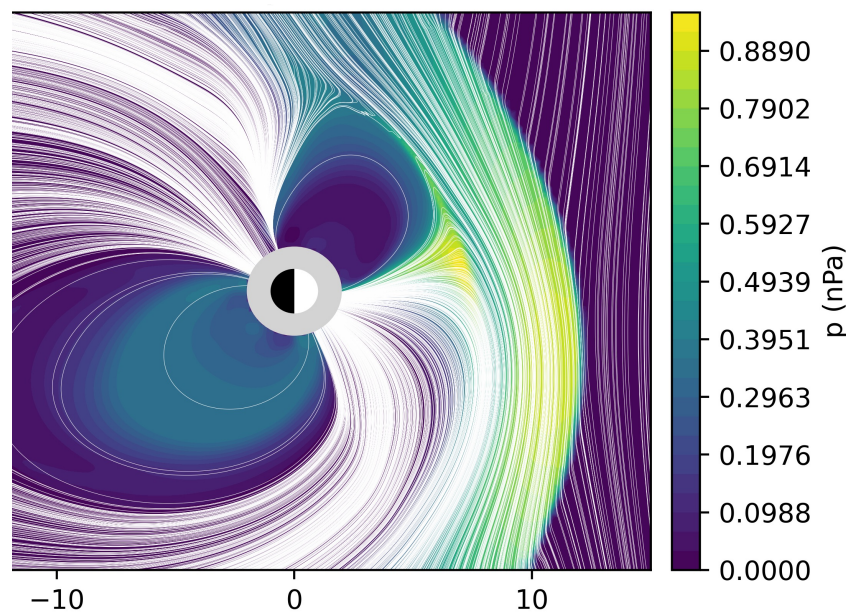
A. We are looking at a detailed study of the change in the magnetosphere over the peak of the event (from 42k to 39k years).





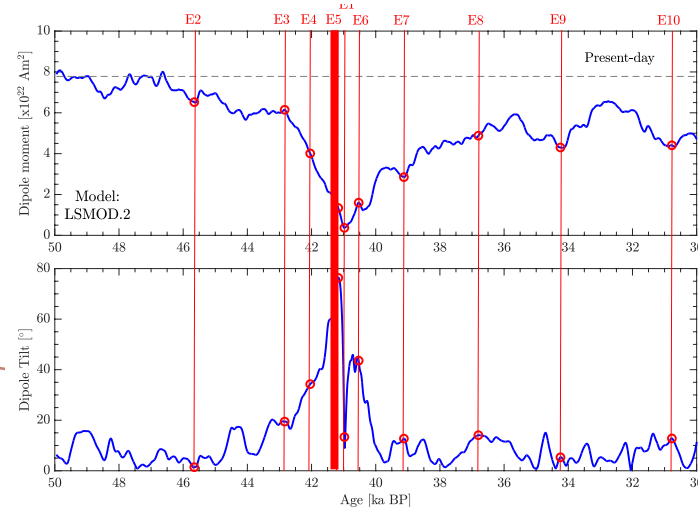
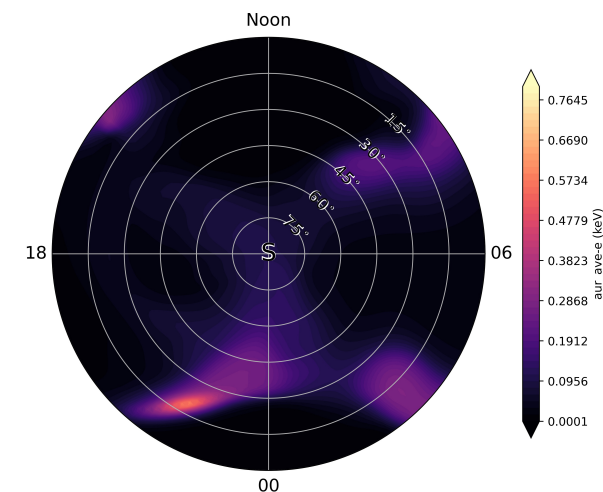
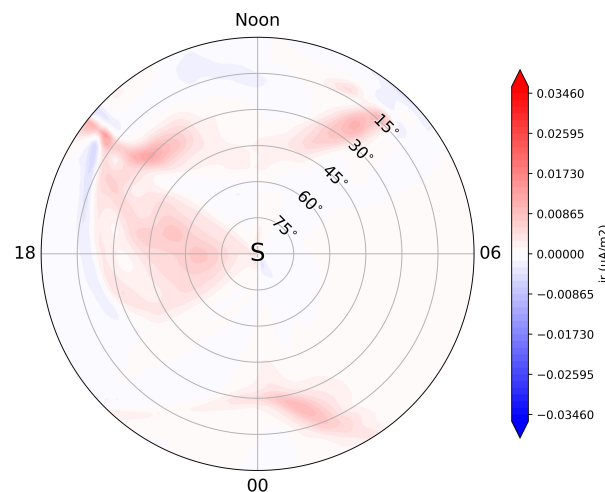
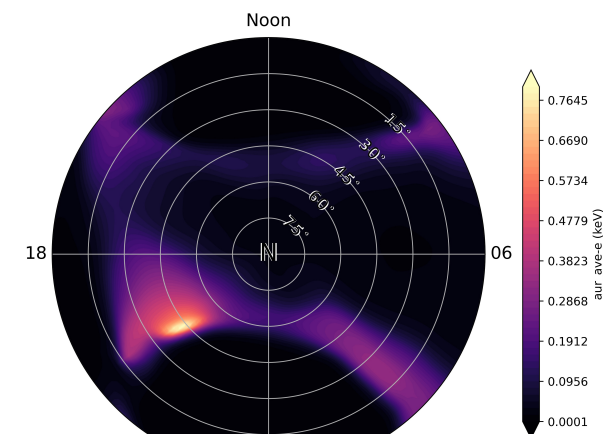
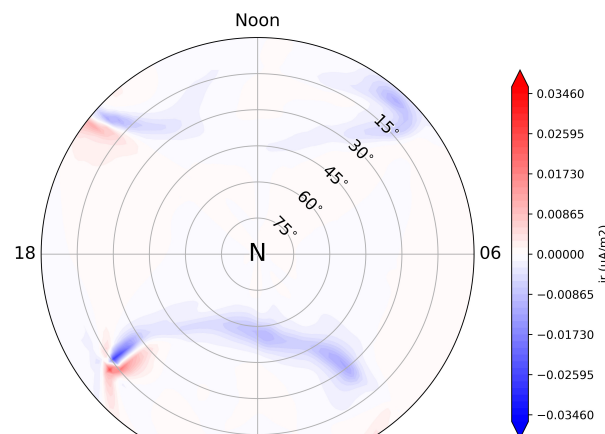
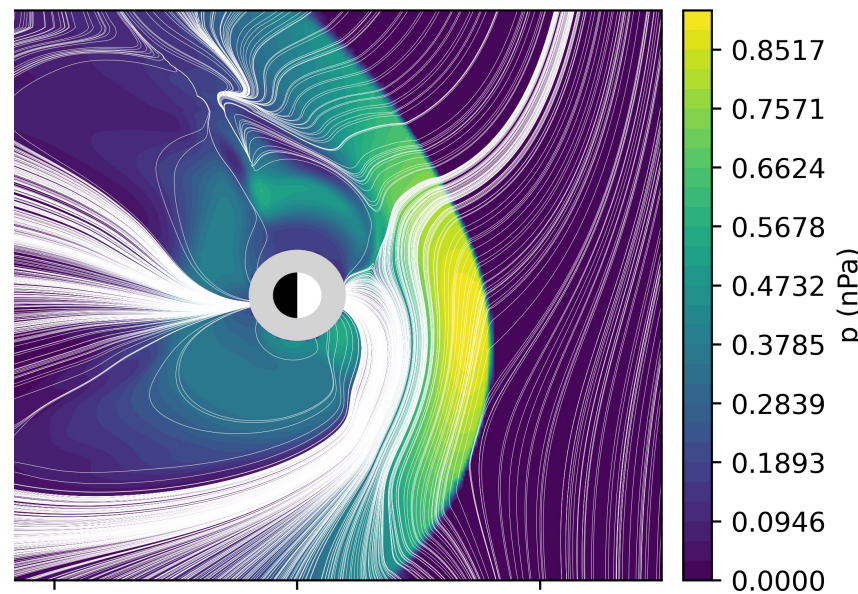
# Epoch 4

42.04k years ago | Dipole Strength = 50%, Dipole Tilt = 34.27 deg



# Epoch 5

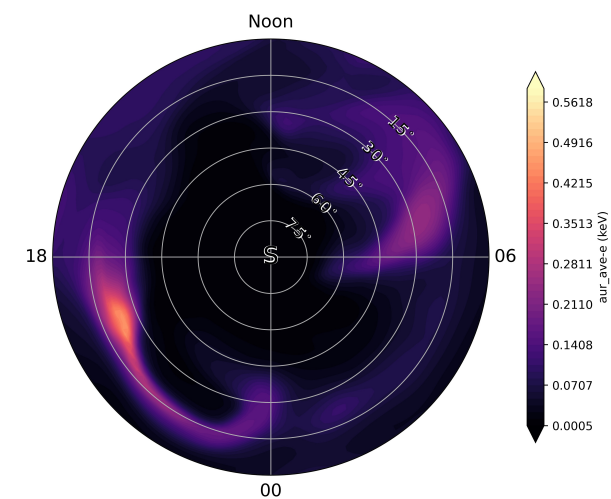
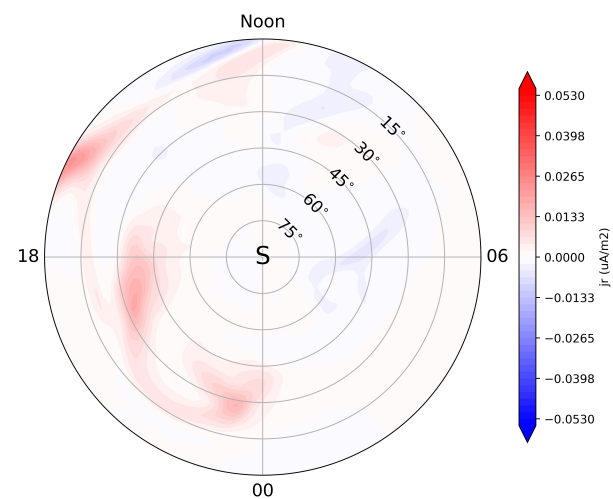
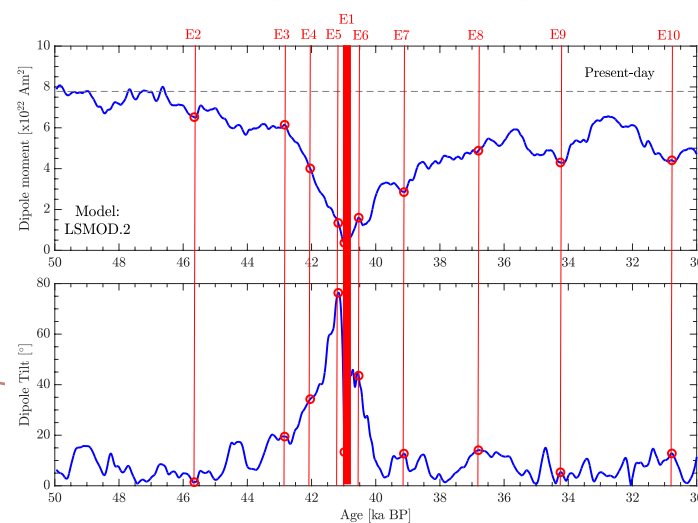
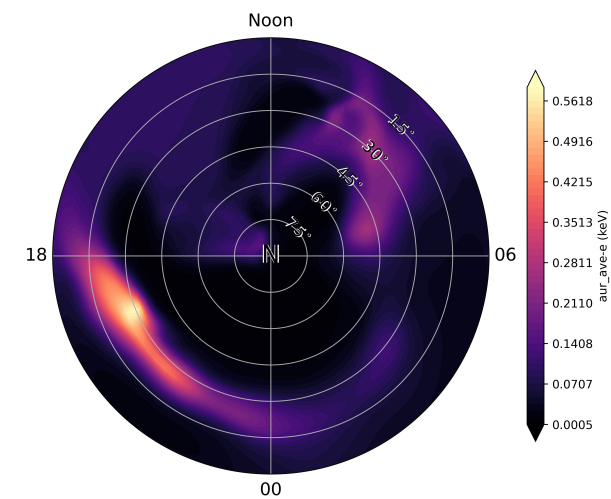
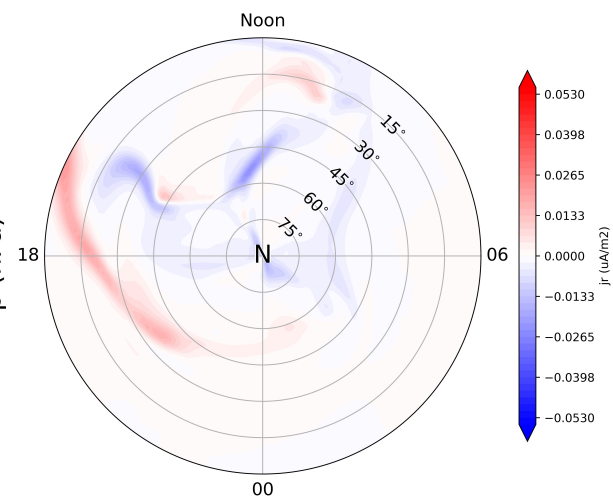
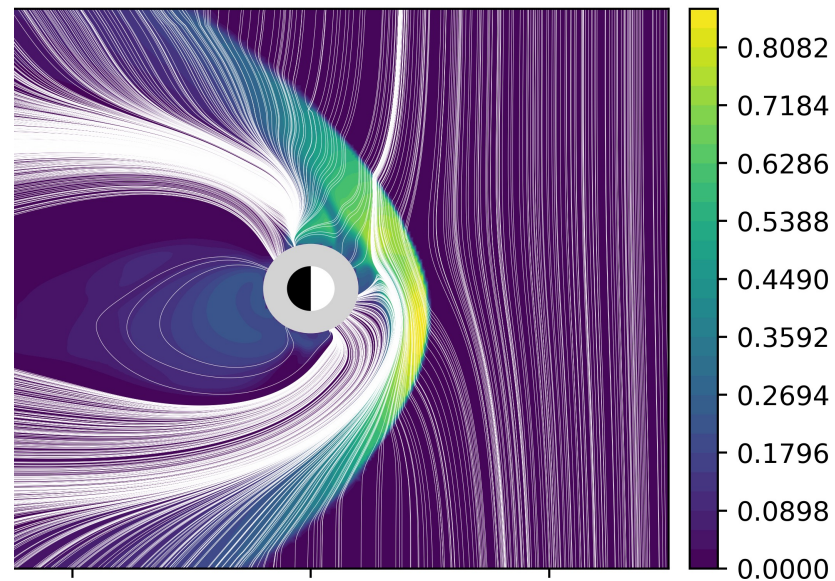
41.17k years ago | Dipole Strength = 17%, Dipole Tilt = 76.33 deg





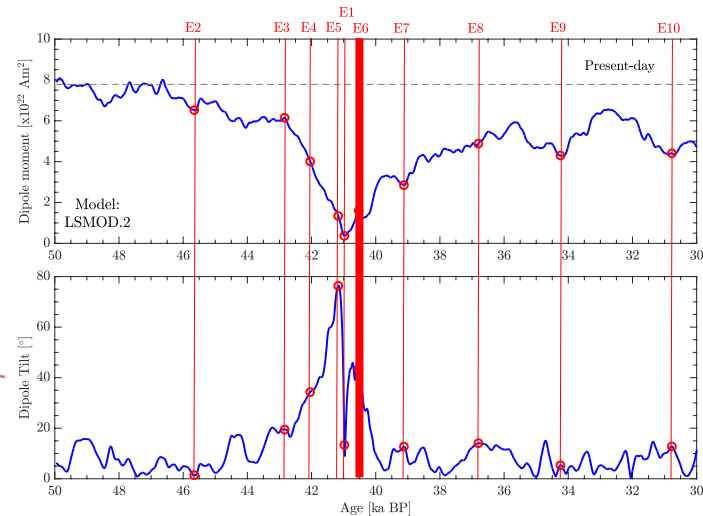
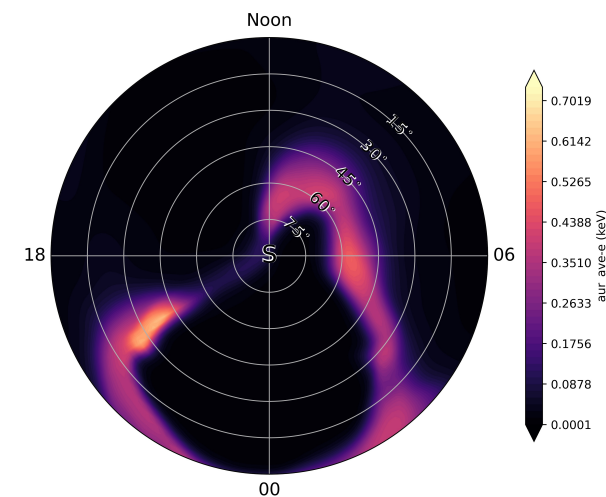
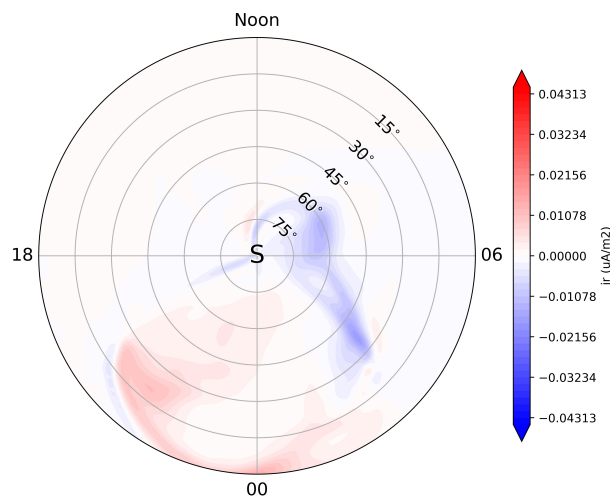
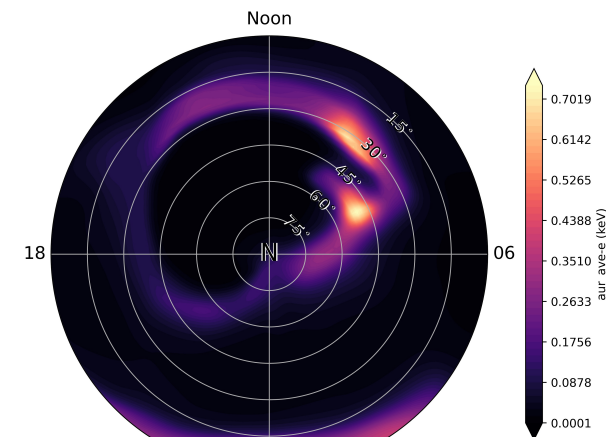
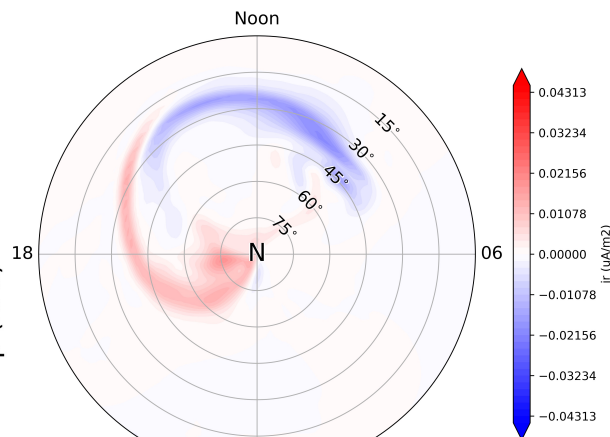
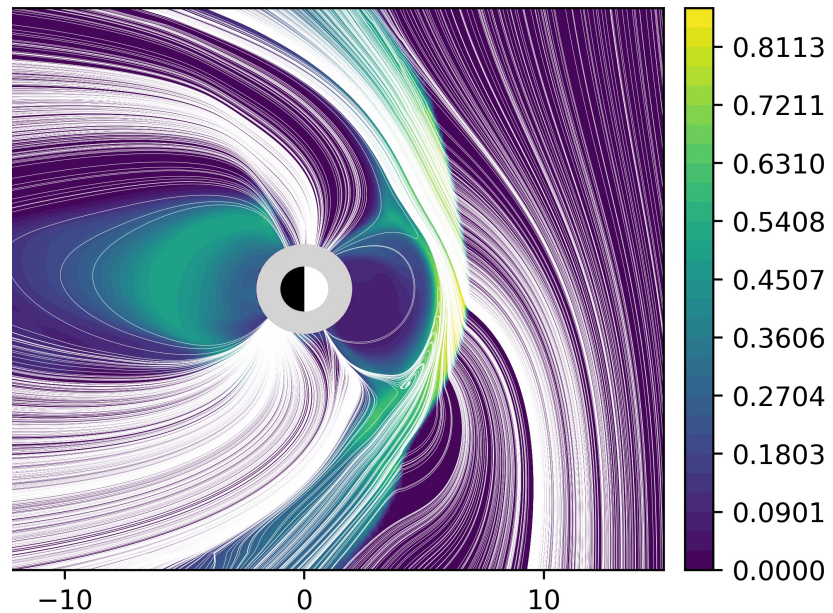
# Epoch 1

40.98k years ago | Dipole Strength = 4.6%, Dipole Tilt = 13.35 deg



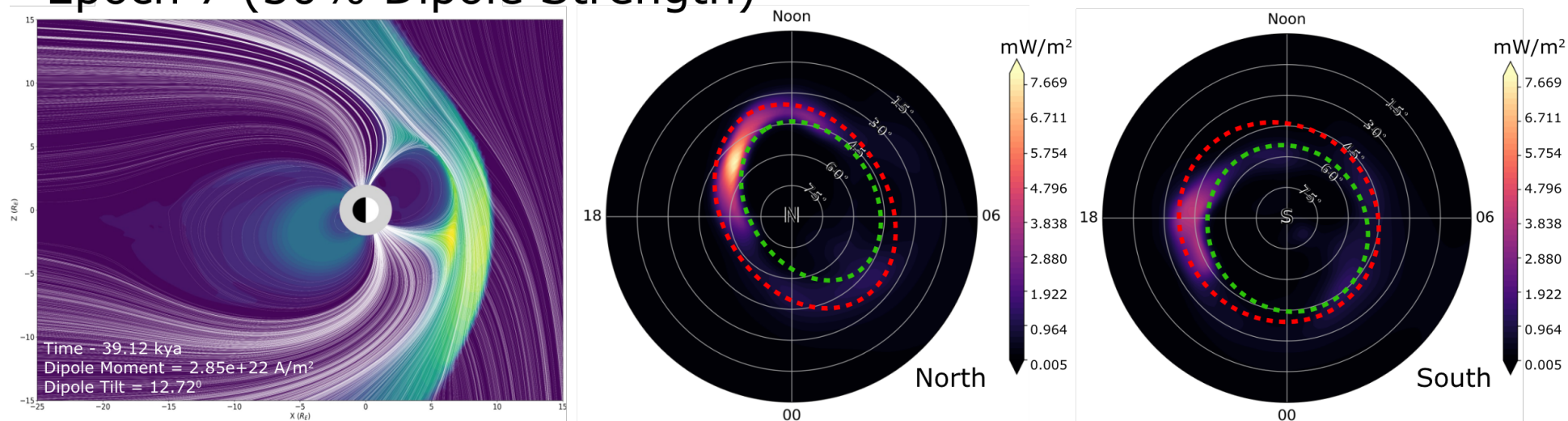
# Epoch 6

40.53k years ago | Dipole Strength = 20%, Dipole Tilt = 43.57 deg

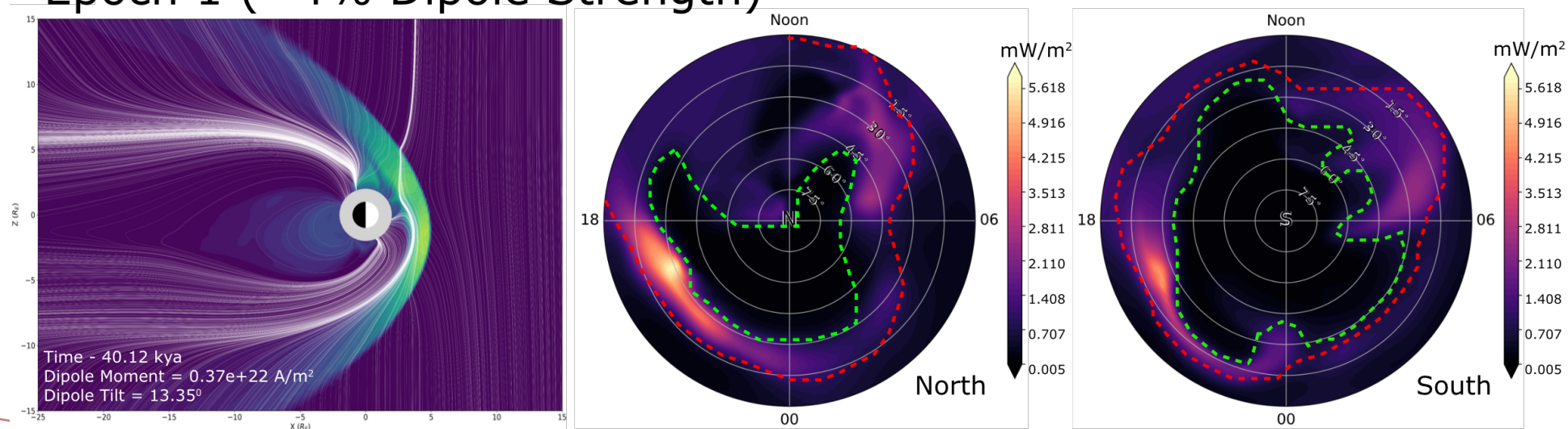




## Epoch 7 (30% Dipole Strength)

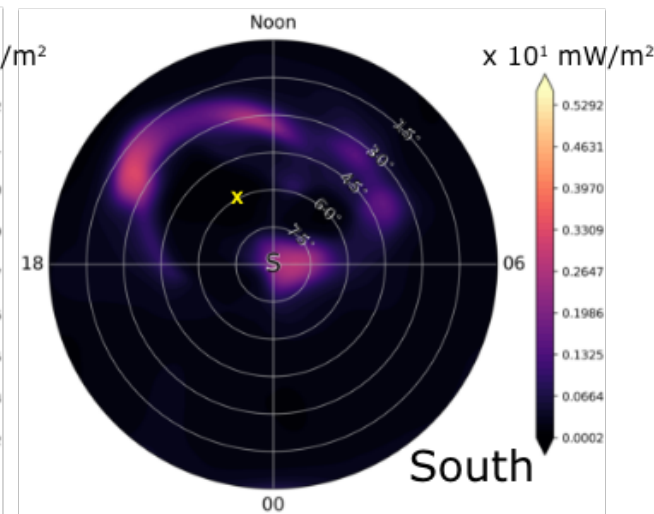
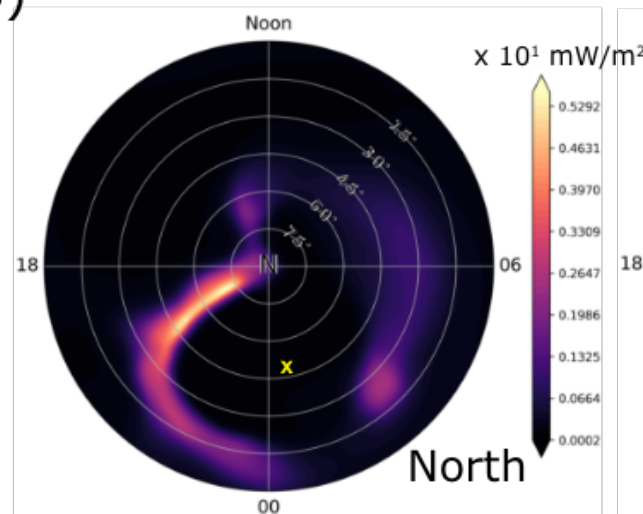
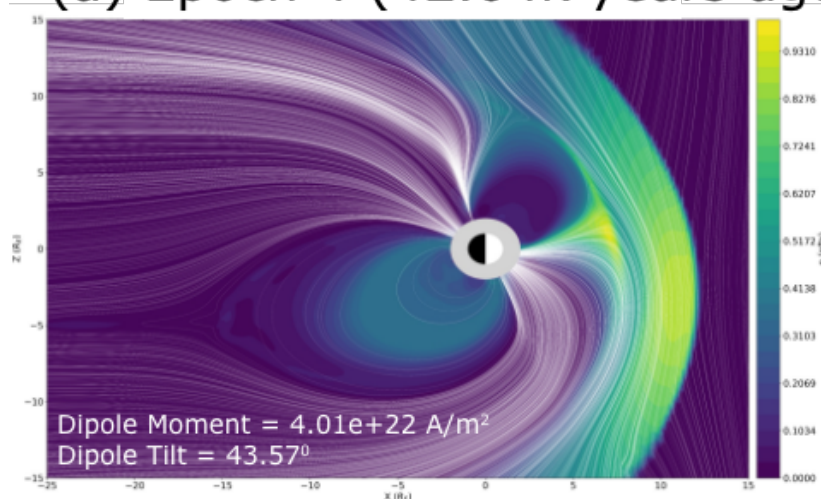


## Epoch 1 (~4% Dipole Strength)

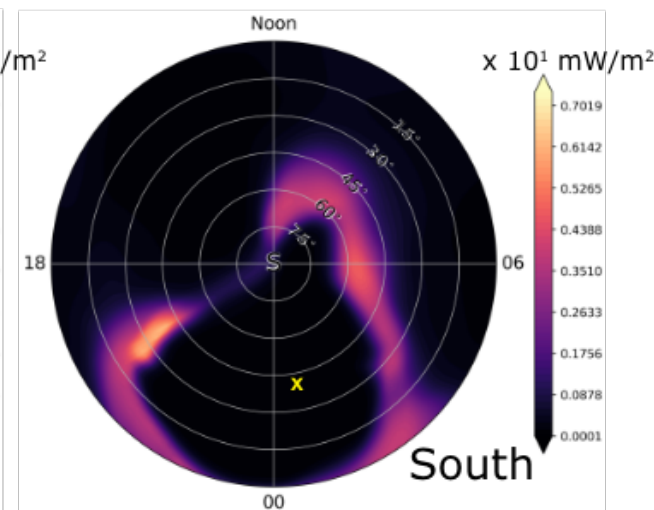
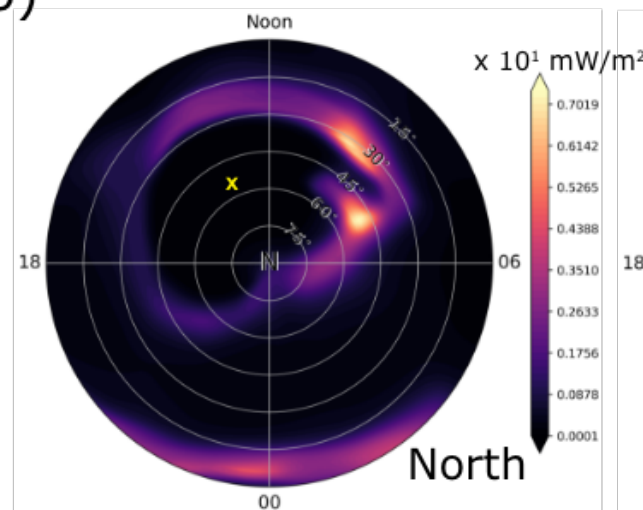
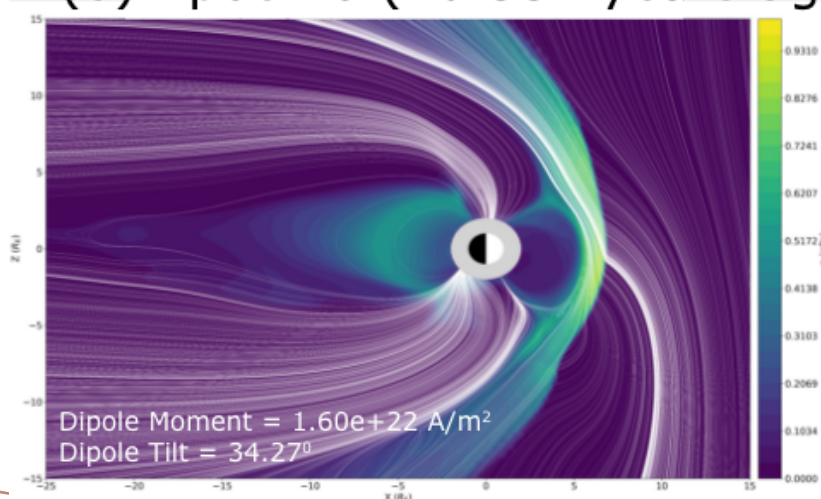




(a) Epoch 4 (42.04k years ago)



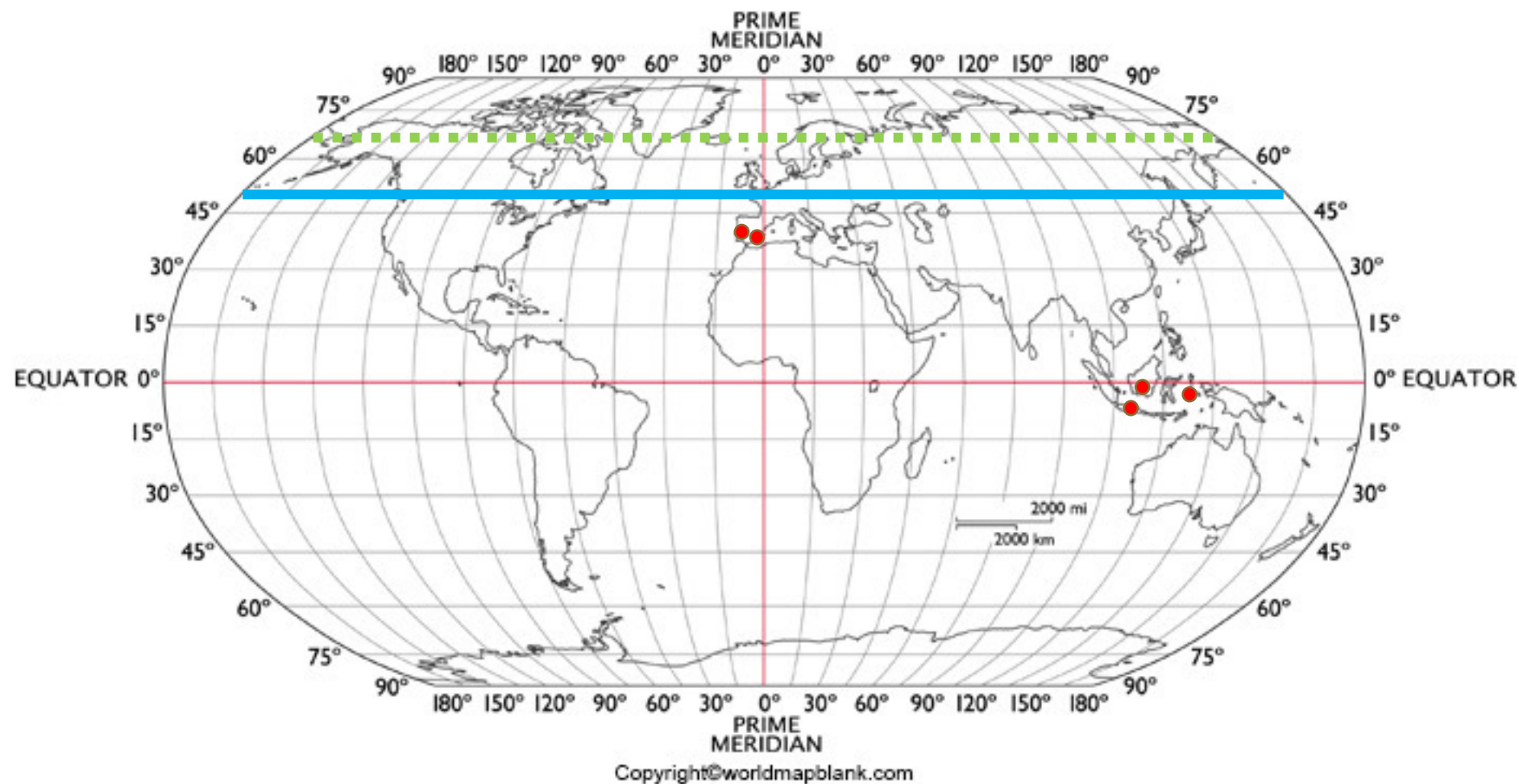
(b) Epoch 6 (40.35k years ago)



# *WIDER IMPLICATIONS*

- The recent study by *Cooper et al. (2021)*, while propagating glaring flaws in their geomagnetic estimations, does create a timeline comparing the geophysical changes on Earth with human migration and activities.
- However, many of these activities are located at latitudes far lower than 40 degrees, which is the study's estimate of where the aurora would have been visible.
- Our study can potentially explain why in places like Indonesia (*Aubert et al. 2019*) or the Iberian Peninsula (*Pike et al. 2018*), there would have been a decent possibility of seeing the aurora which might have affected human behaviour.

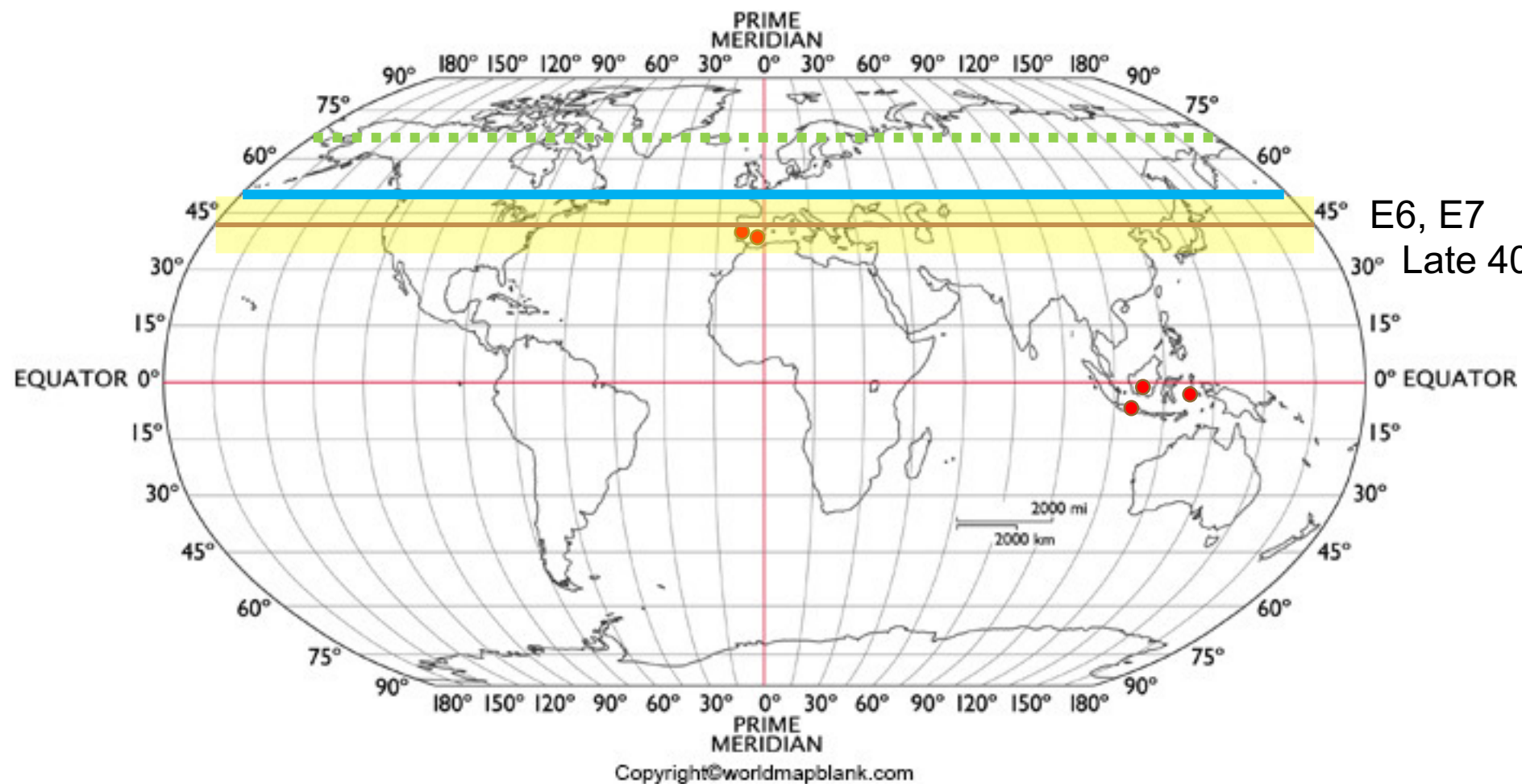




----- Auroral Boundary  
 (Modern Values; Moderate  
 Solar Driving)

— Auroral Boundary  
 (as suggested in Cooper+ 2021)

• Traces of Human Civilization during  
 the Laschamp Period



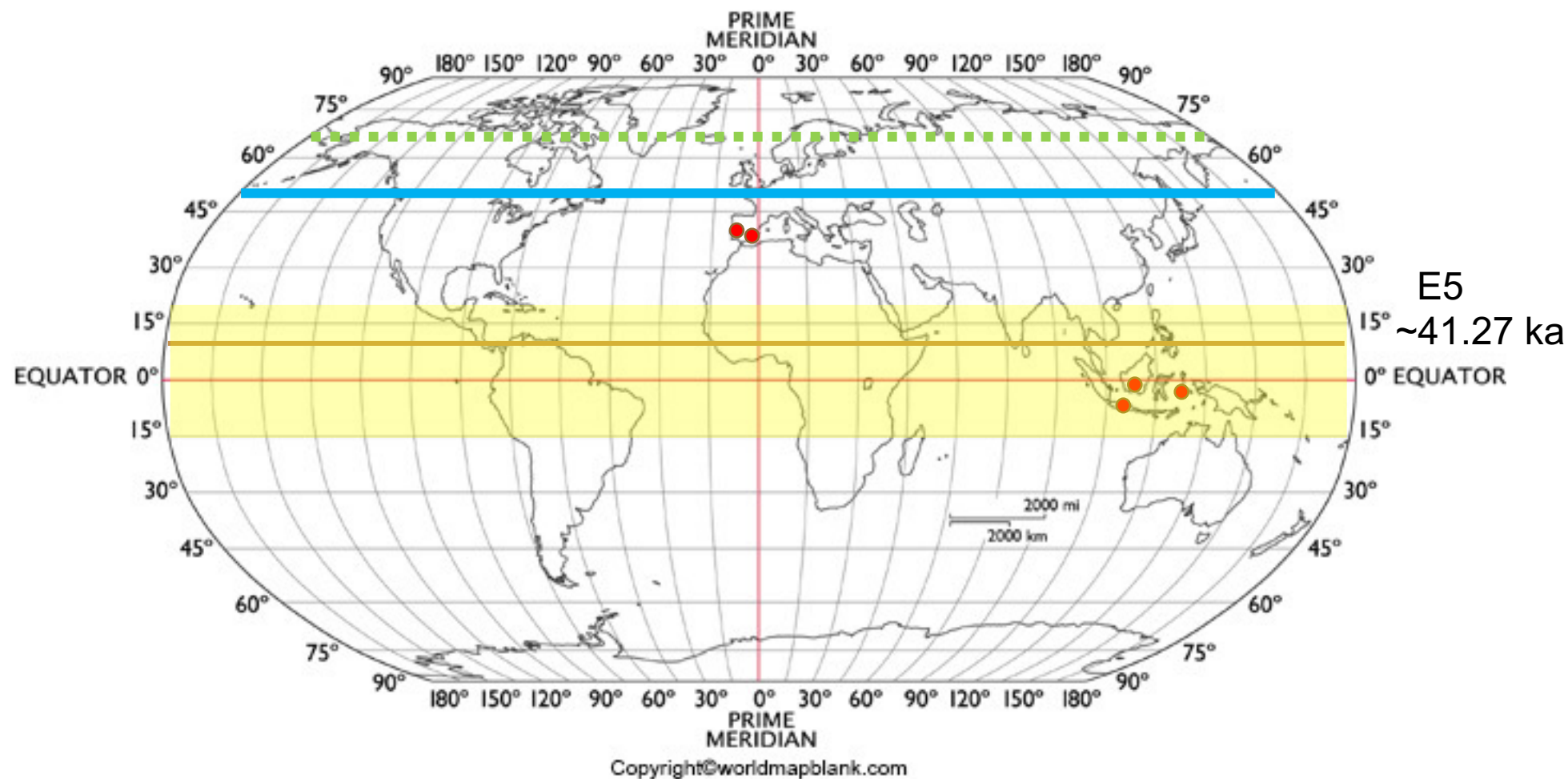
E6, E7  
Late 40s ka

----- Auroral Boundary  
(Modern Values; Moderate  
Solar Driving)

— Auroral Boundary  
(as suggested in Cooper+ 2021)

• Traces of Human Civilization during  
the Laschamp Period





----- Auroral Boundary  
 (Modern Values; Moderate  
 Solar Driving)

— Auroral Boundary  
 (as suggested in Cooper+ 2021)

• Traces of Human Civilization during  
 the Laschamp Period

# *CONCLUDING REMARKS*

- Using a combination of a paleomagnetic field model, a global MHD model and an auroral precipitation model, we conducted simulations of the geospace variations during the Laschamps Event.
  - Simulations were carried over distinct epochs and varying geomagnetic conditions.
  - Nominal solar wind conditions were used to simulate the study.
- Our estimates show that Earth's magnetosphere underwent a sea change during the excursion peak.
  - Epoch 5 exhibits the largest dipole tilt seen during this excursion. The resulting configuration of the magnetosphere is comparable to Neptune's pole-on magnetospheric configuration.
  - The dipole strength is lowest during Epoch 1, when the dayside magnetosphere is nearly non-existent. Epochs 4, 6 and 7 show reasonable dipole-like features.
- Auroral simulations show both expansion and rapid wandering of the auroral oval, as the dipole tilt changes.
  - The auroral oval expands beyond the estimates suggested in recent studies, and constantly moves between Epoch 4 & 7.
  - The location of the magnetospheric cusp and the auroral oval match with regions of prehistoric anthropogenic activity of the same era found in anthropological surveys, indicating a deeper impact of the geomagnetic changes.