Rapid Auroral Wandering During the Laschamps Event

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November 26, 2022

Abstract

41 thousand years ago, the Laschamps geomagnetic excursion caused Earth's geomagnetic field to drastically diminish to ~4% of modern values and modified the geomagnetic dipole axis. While the impact of this geomagnetic event on environmental factors and human lifestyle has been contemplated to be linked with modifications in the geospace environment, no concerted investigation has been conducted to study this until recently. We present an initial investigation of the global space environment and related plasma environments during the several phases of the Lachamps event using an advanced multi-model approach. We use recent paleomagnetic field models of this event to study the paleomagnetosphere with help of the global magnetohydrodynamic model BATS-R-US. Here we go beyond a simple dipole approximation but consider a realistic geomagnetic field configuration. The field is used within BATS-R-US to generate the magnetosphere during discrete epochs spanning the peak of the event. Since solar conditions have remained fairly constant over the last ~100k years, modern estimates of the solar wind were used to drive the model. Finally, plasma pressure and currents generated by BATS-R-US at their inner boundary are used to compute auroral fluxes using a stand-alone version of the MAGNIT model, an adiabatic kinetic model of the aurora. Our results show that changes in the geomagnetic field, both in strength and the dipole tilt angle, have profound effects on the space environment and the ensuing auroral pattern. Magnetopause distances during the deepest phase of the excursion match previous predictions by studies like Cooper et al. (2021), while high-resolution mapping of magnetic fields allow close examination of magnetospheric structure for non-dipolar configurations. Temporal progression of the event also exhibits rapid locomotion of the auroral region over ~250 years along with the movement of the geomagnetic poles. Our estimates suggest that the aurora extended further down, with the center of the oval located at near-equatorial latitudes during the peak of the event. While the study does not find evidence of any link between geomagnetic variability and habitability conditions, geographic locations of the auroral oval coincide with early human activity in the Iberian peninsula and South China Sea.

RAPID AURORAL WANDERING DURING THE LASCHAMPS EVENT

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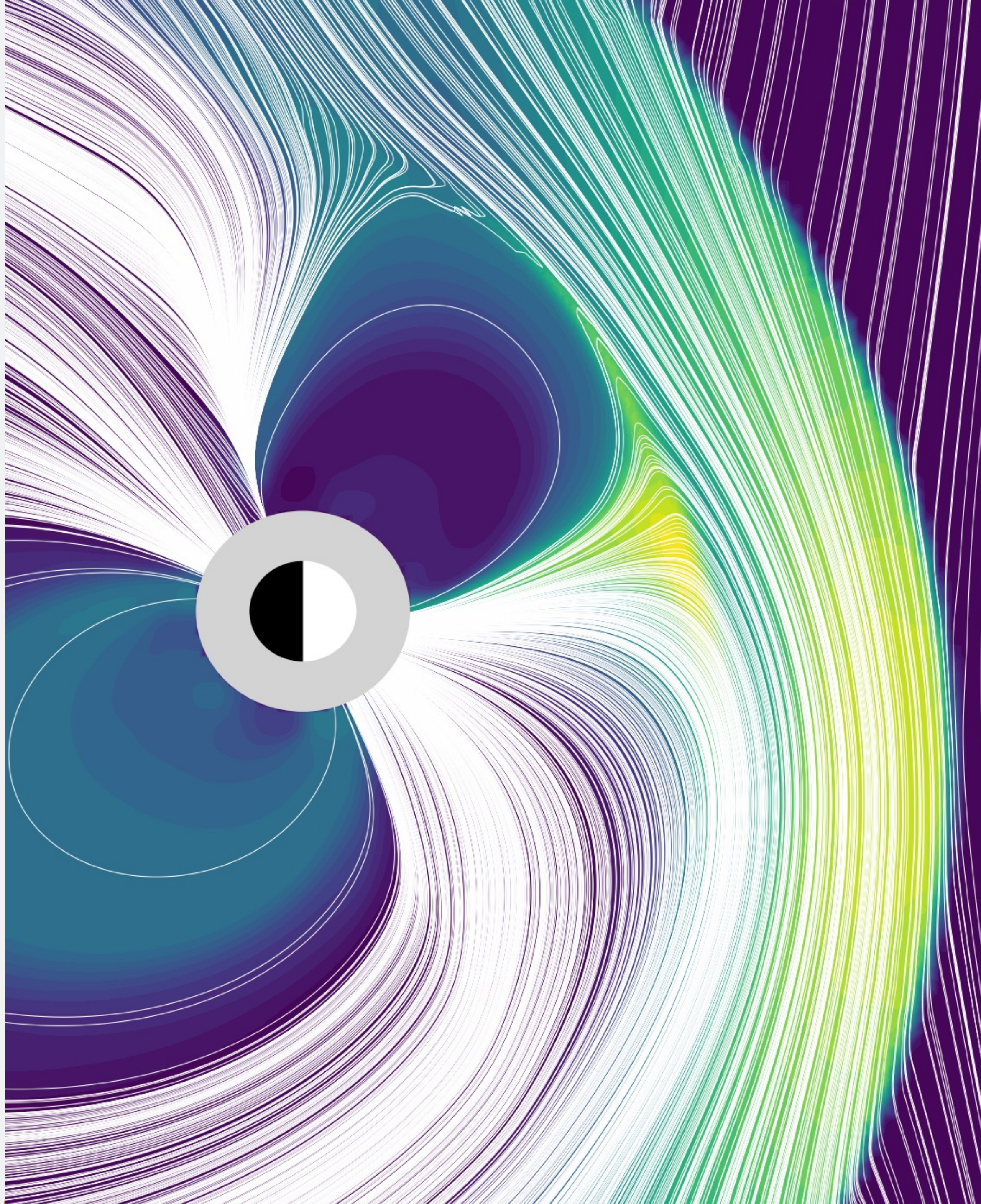
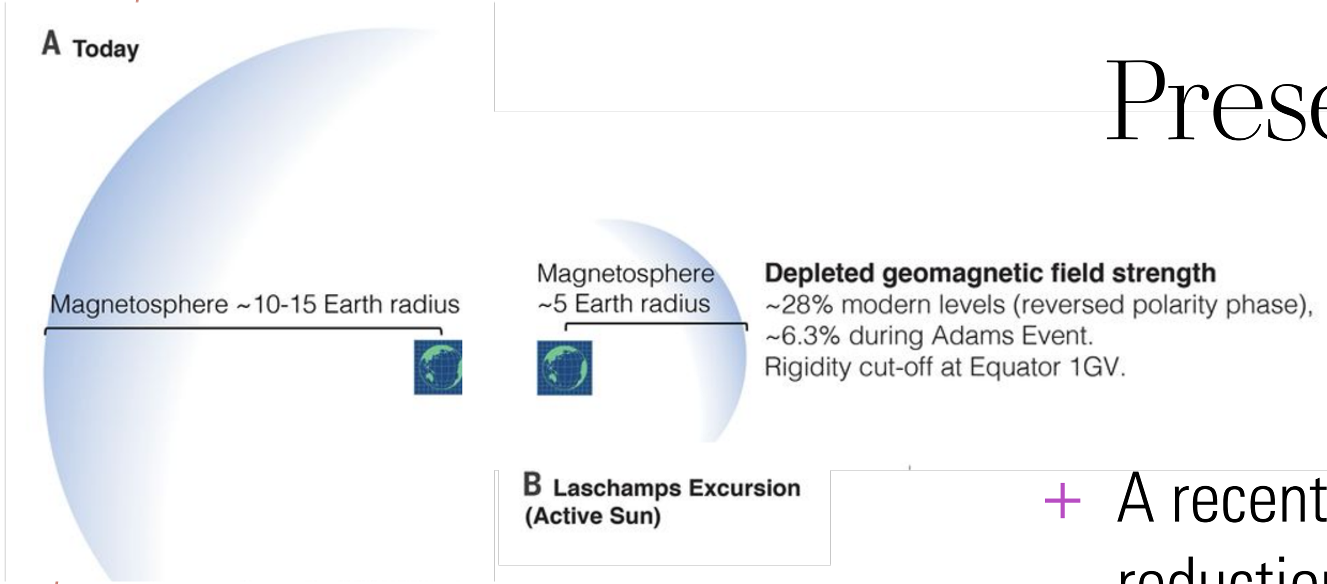
AGU FALL MEETING
New Orleans, LA & Online Everywhere
13–17 December 2021



BACKGROUND

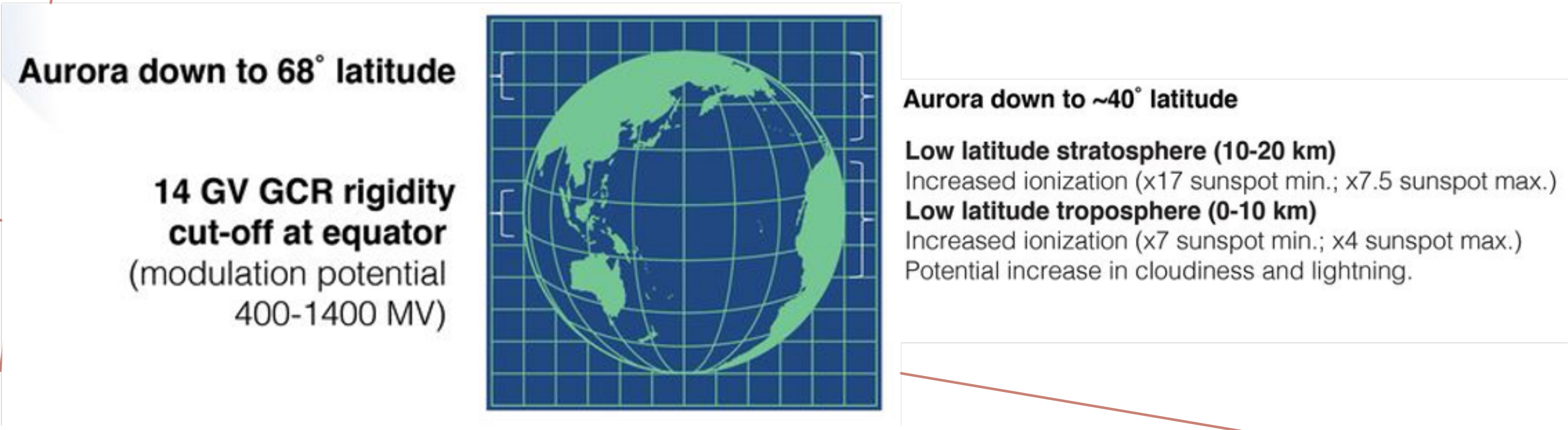
- The Laschamp Geomagnetic Excursion occurred between 42k and 40k years, over an approximate span of ~1300 years.
    - Named for Laschamp lava flows in France, where it was first discovered.
    - Studied extensively in academia, most recently using ancient *kauri* trees from New Zealand
- The geomagnetic 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.

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.

Cooper et al. (2021), Science



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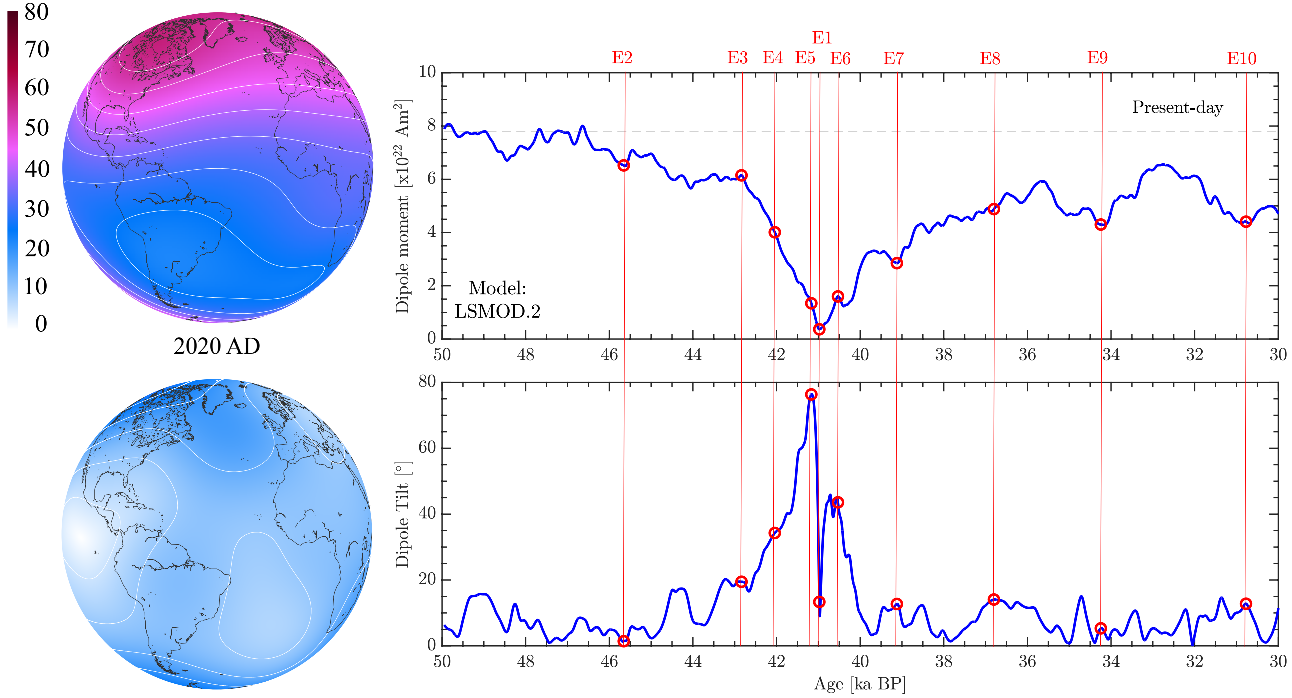
Terrestrial B-Field:
LSMOD.2 Paleomagnetic Field Model

+ 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.



41 ka BP, Laschamps excursion

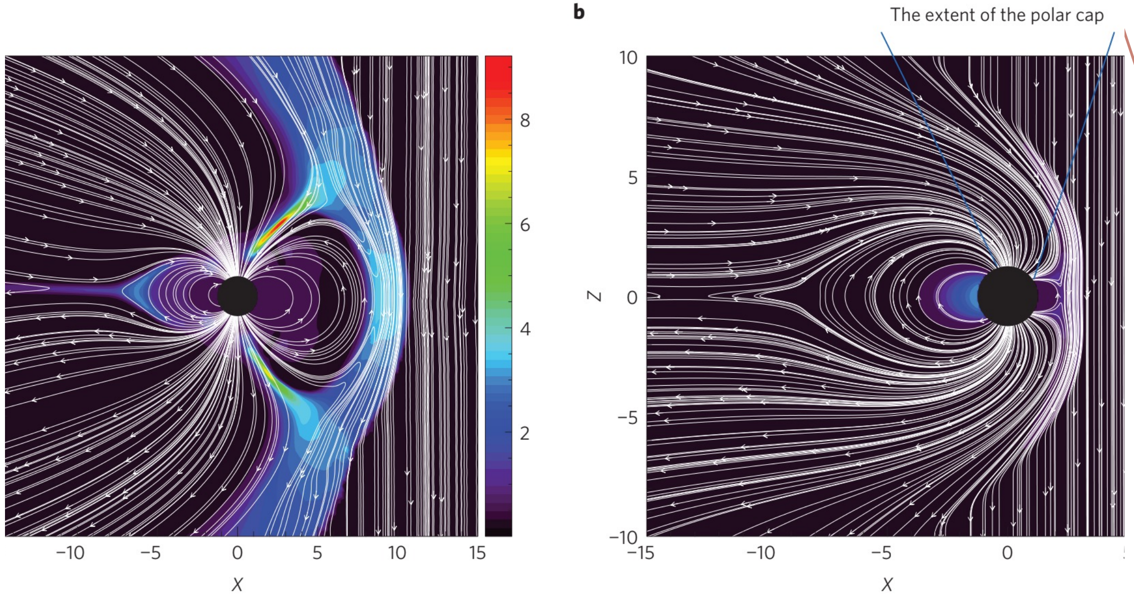
Korte et al. (2019), Frontiers in Earth Sciences
Panovska et al. (2019), Reviews of Geophysics

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.



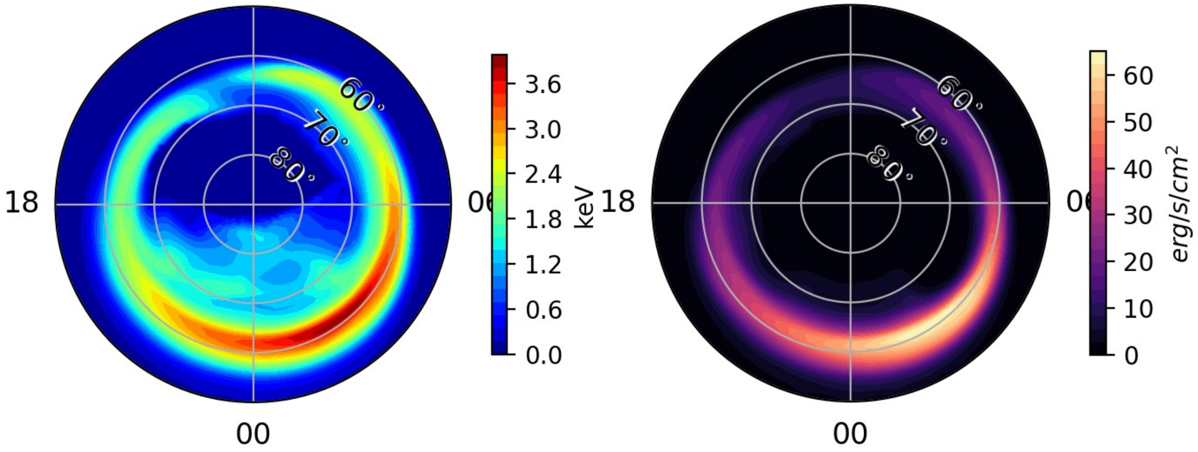
Powell et al. (1999)
Toth et al. (2005)

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.



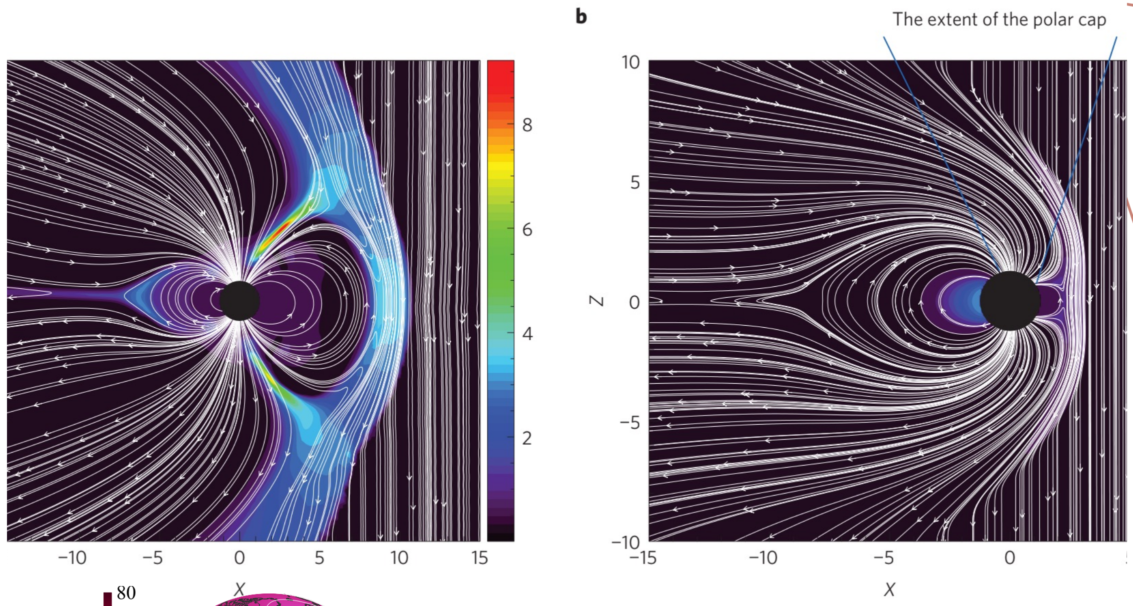
Mukhopadhyay et al. (2021), AMS Meeting
Mukhopadhyay et al. (2021), JGR Space Physics (in prep)

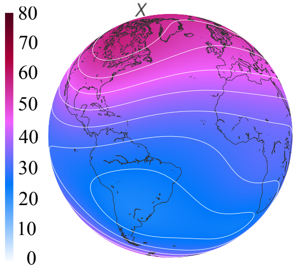
Methods

+ 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.

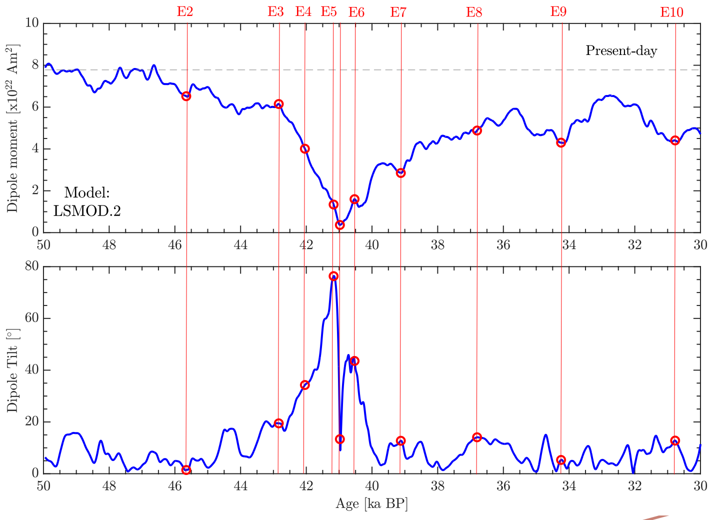
+ BATS-R-US outputs are then used by paleoMAGNIT to predict the aurora's strength, location and shape.





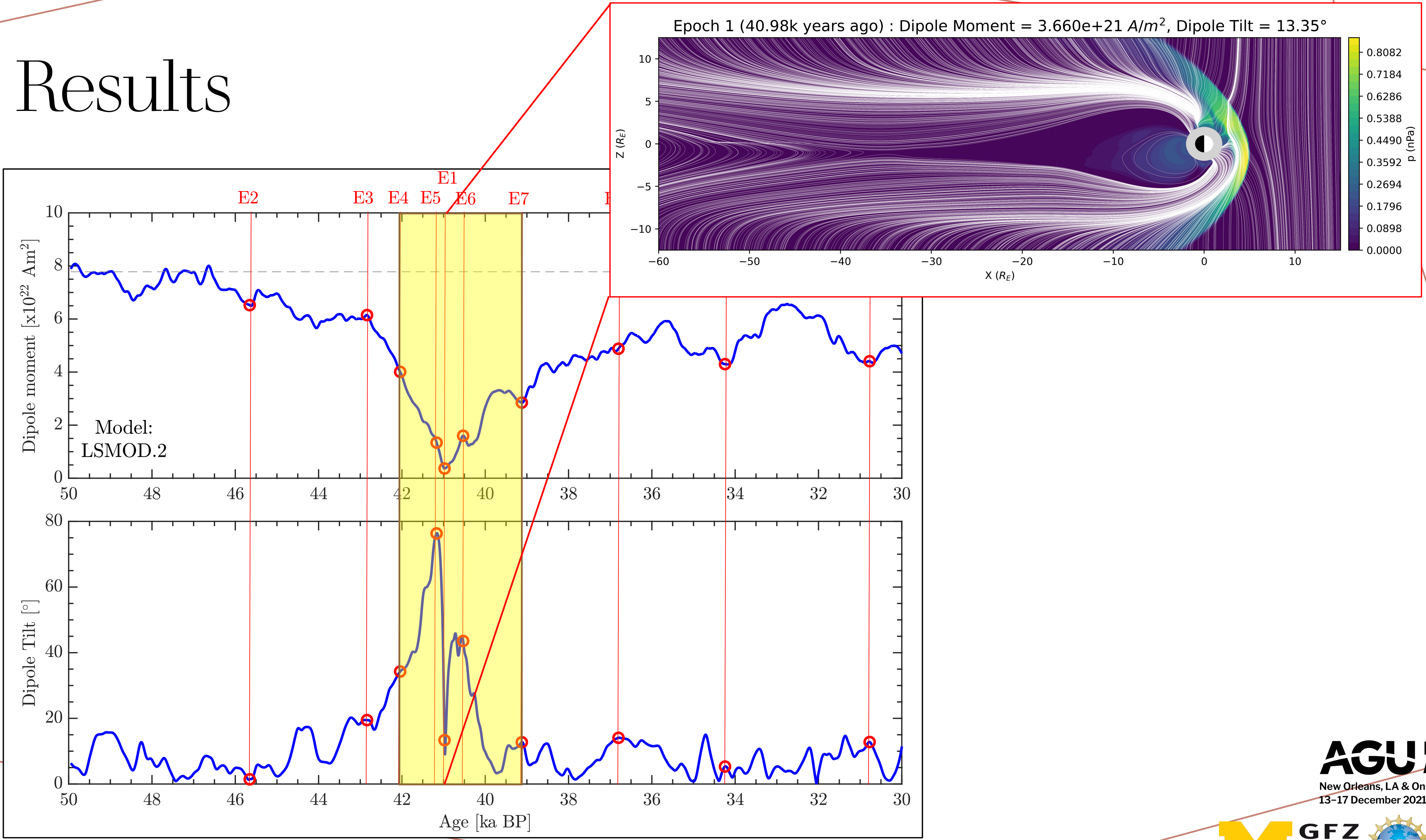
2020 AD

41 ka BP, Laschamps excursion



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



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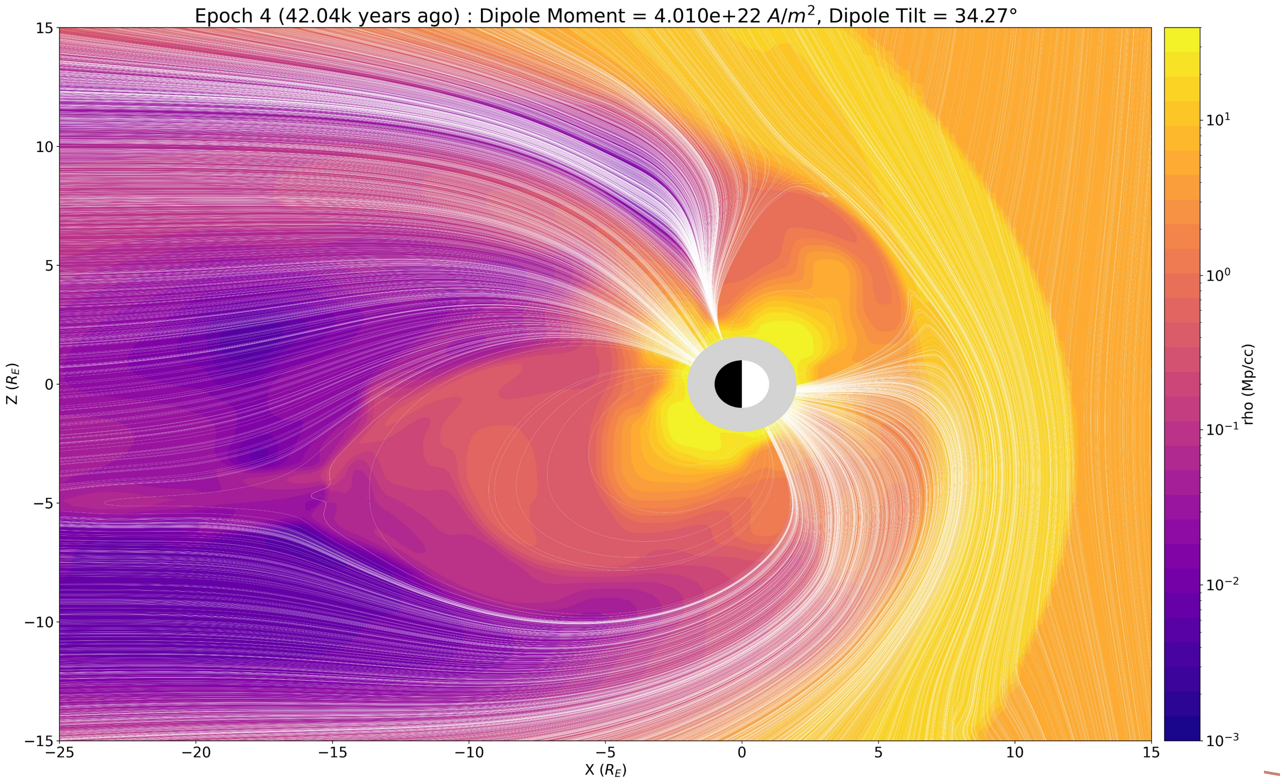
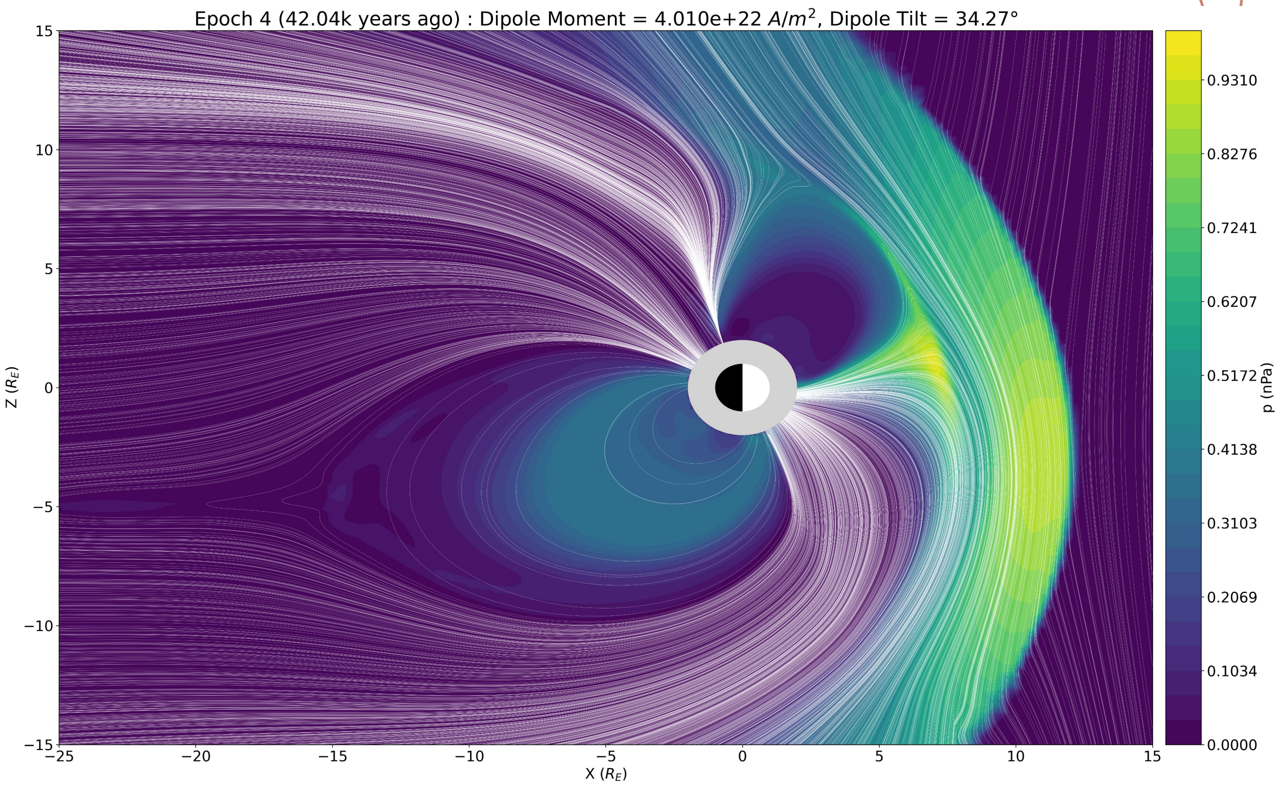
EPOCH 4 (42.04K Years ago)
Dipole moment = 4.010e+22 a/m², Dipole tilt = 34.27°

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

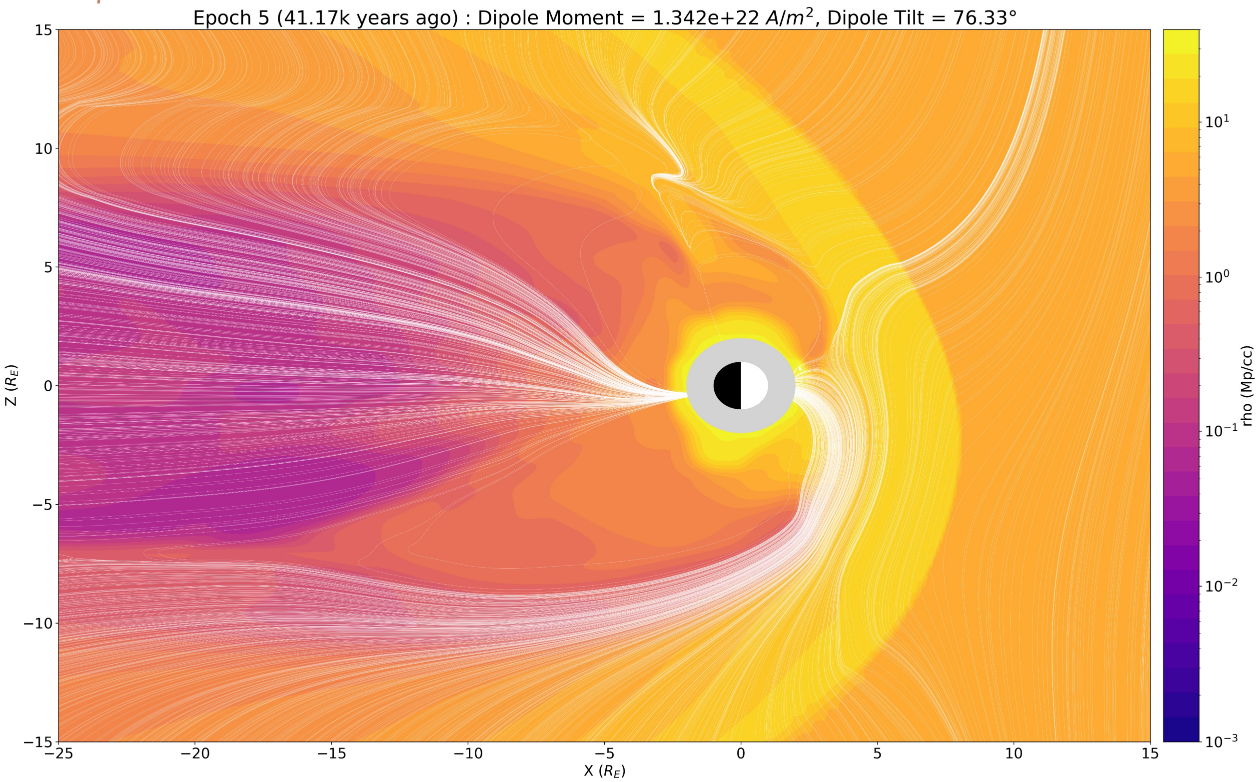


Pressure on the y=0 plane with Bx and Bz field lines

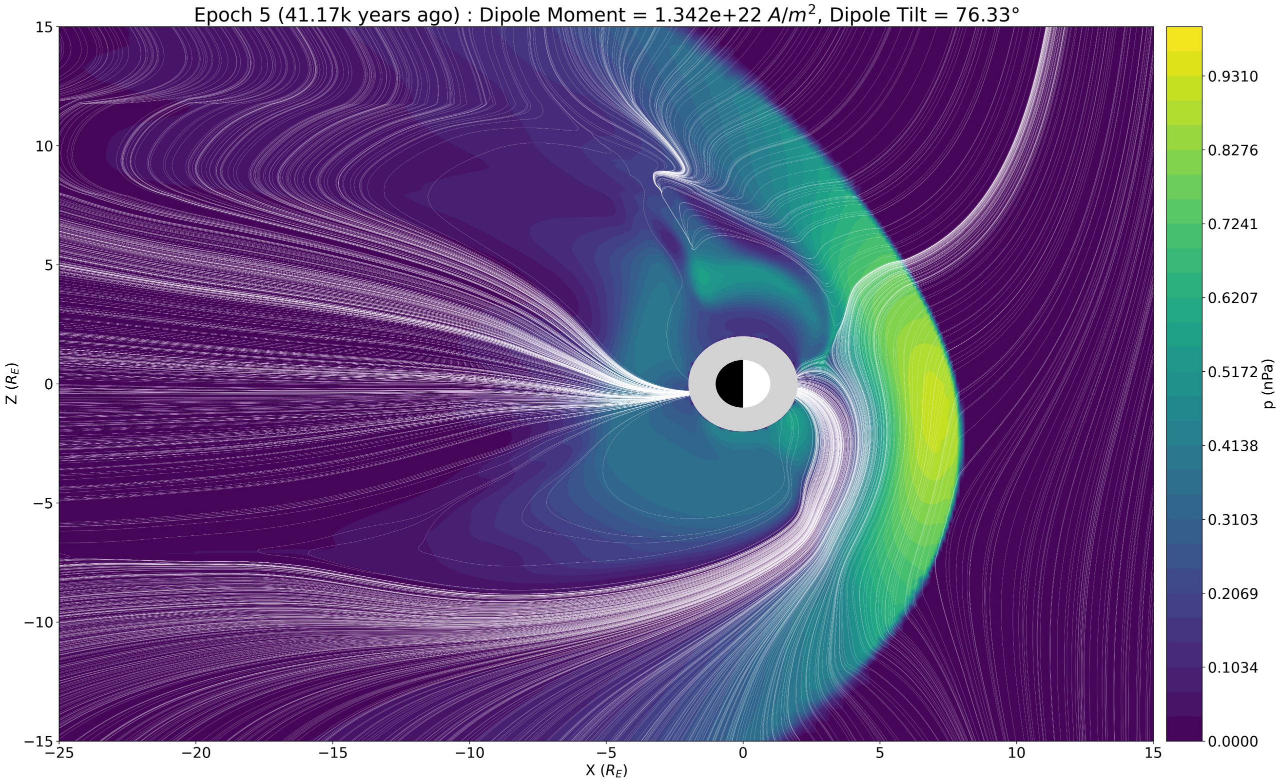


EPOCH 5 (41.17K Years ago)
Dipole moment = 1.342e+22 a/m^2, Dipole tilt = 76.33°

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

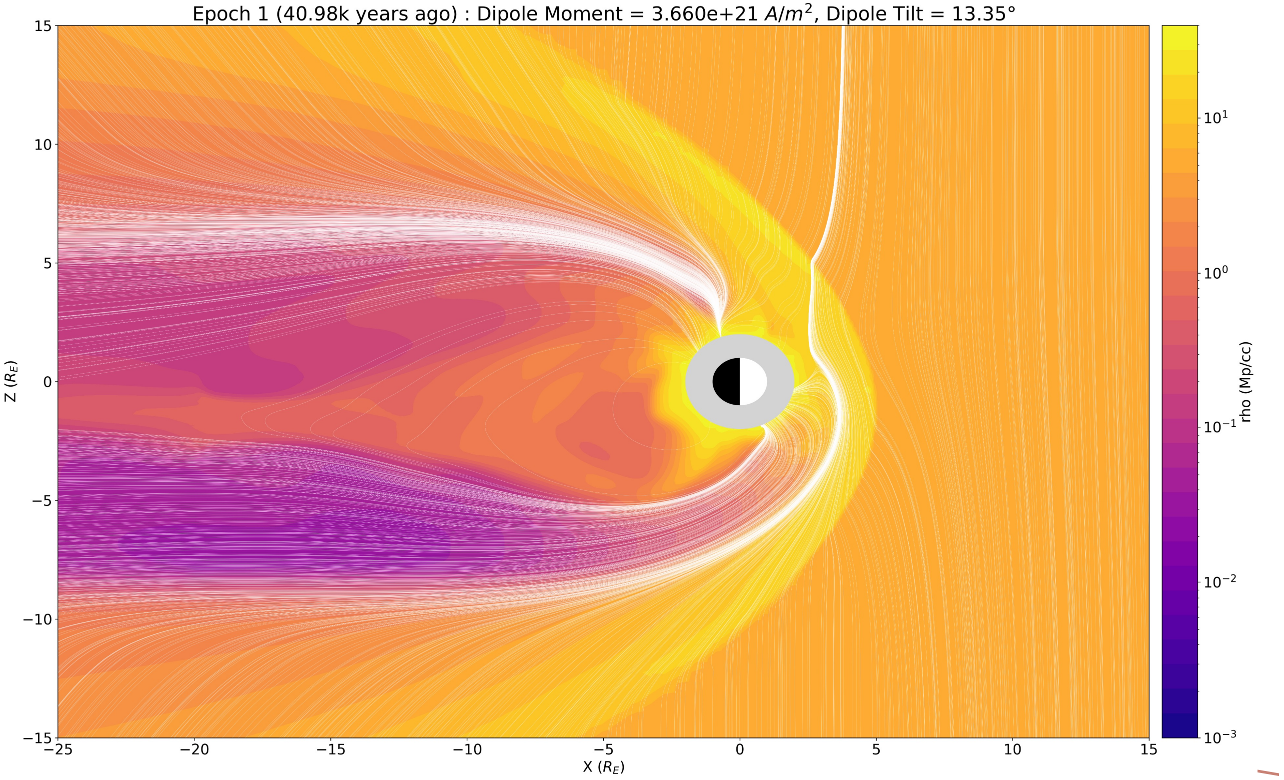


Pressure on the y=0 plane with Bx and Bz field lines

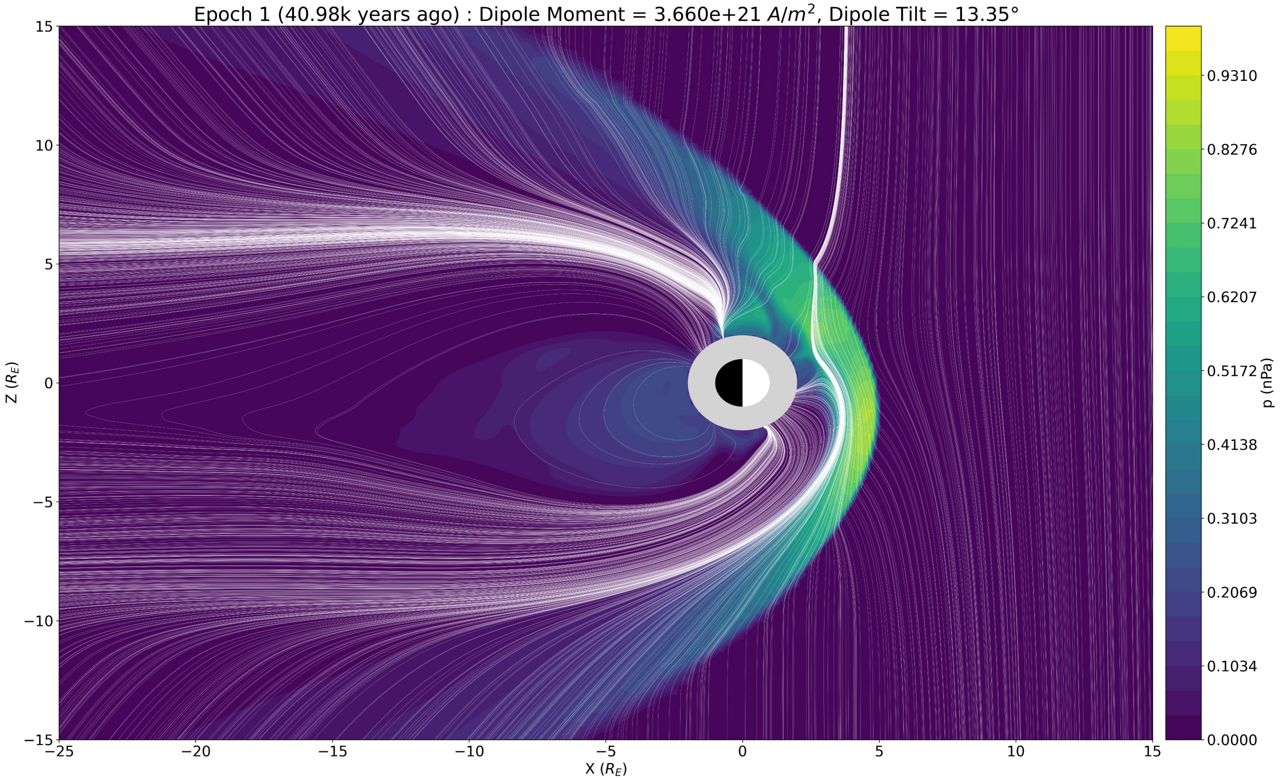


EPOCH 1 (40.98K Years ago)
Dipole moment = 3.660e+21 a/m^2, Dipole tilt = 13.35°

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

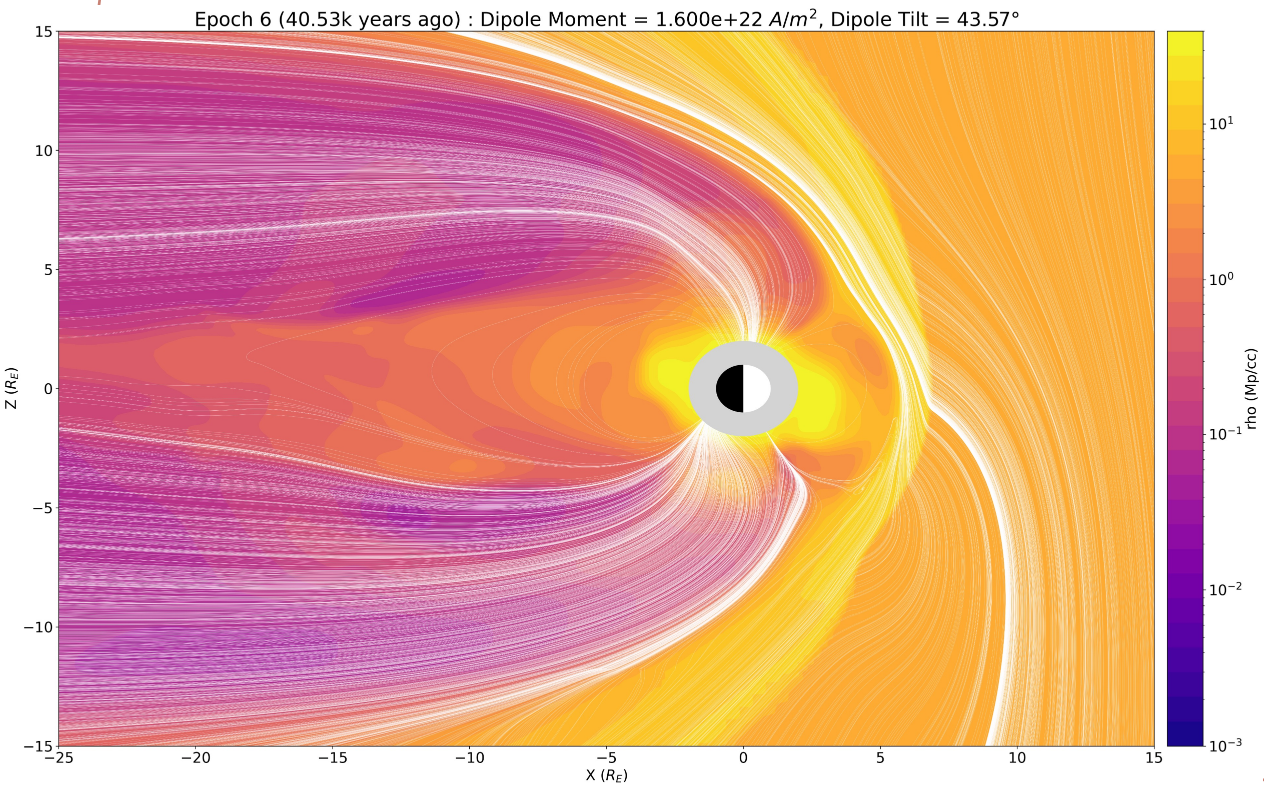


Pressure on the y=0 plane with Bx and Bz field lines

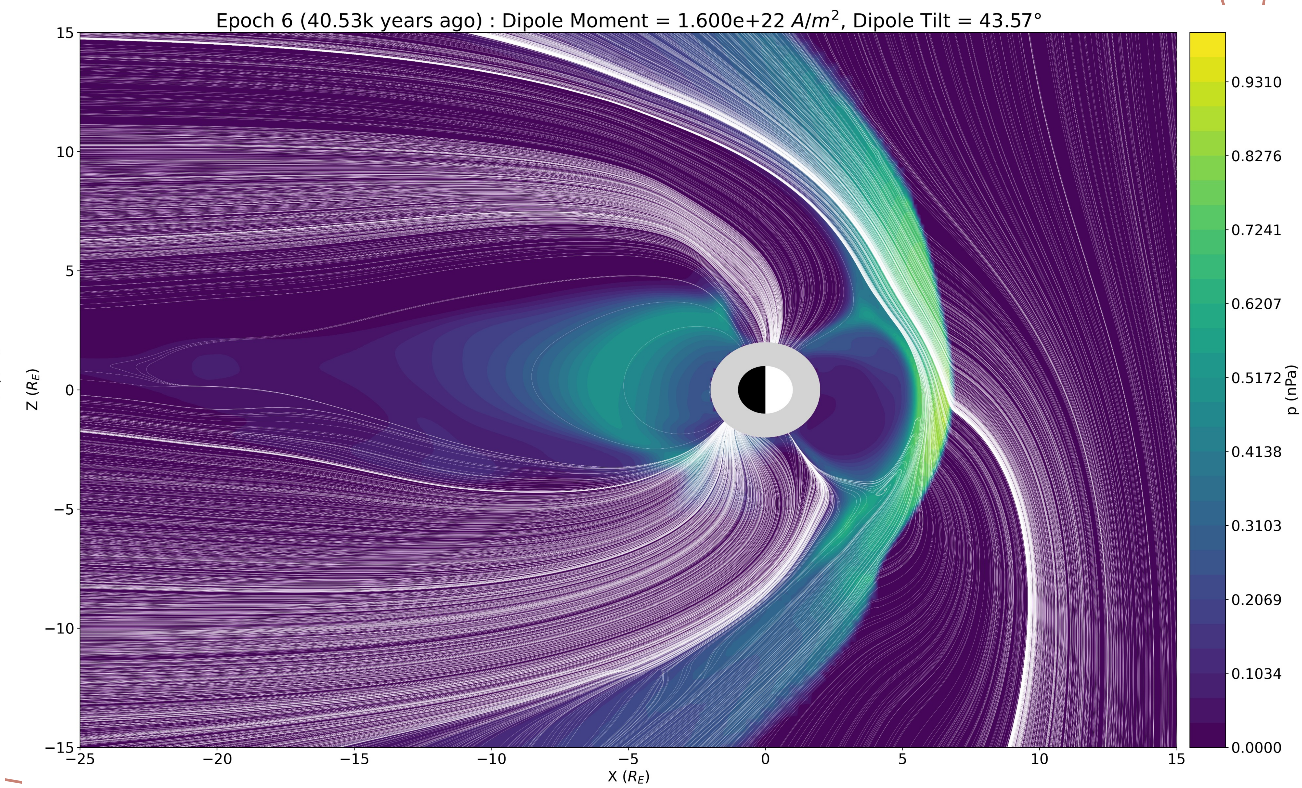


EPOCH 6 (40.53K Years ago)
Dipole moment = 1.600e+22 a/m^2, Dipole tilt = 43.57°

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

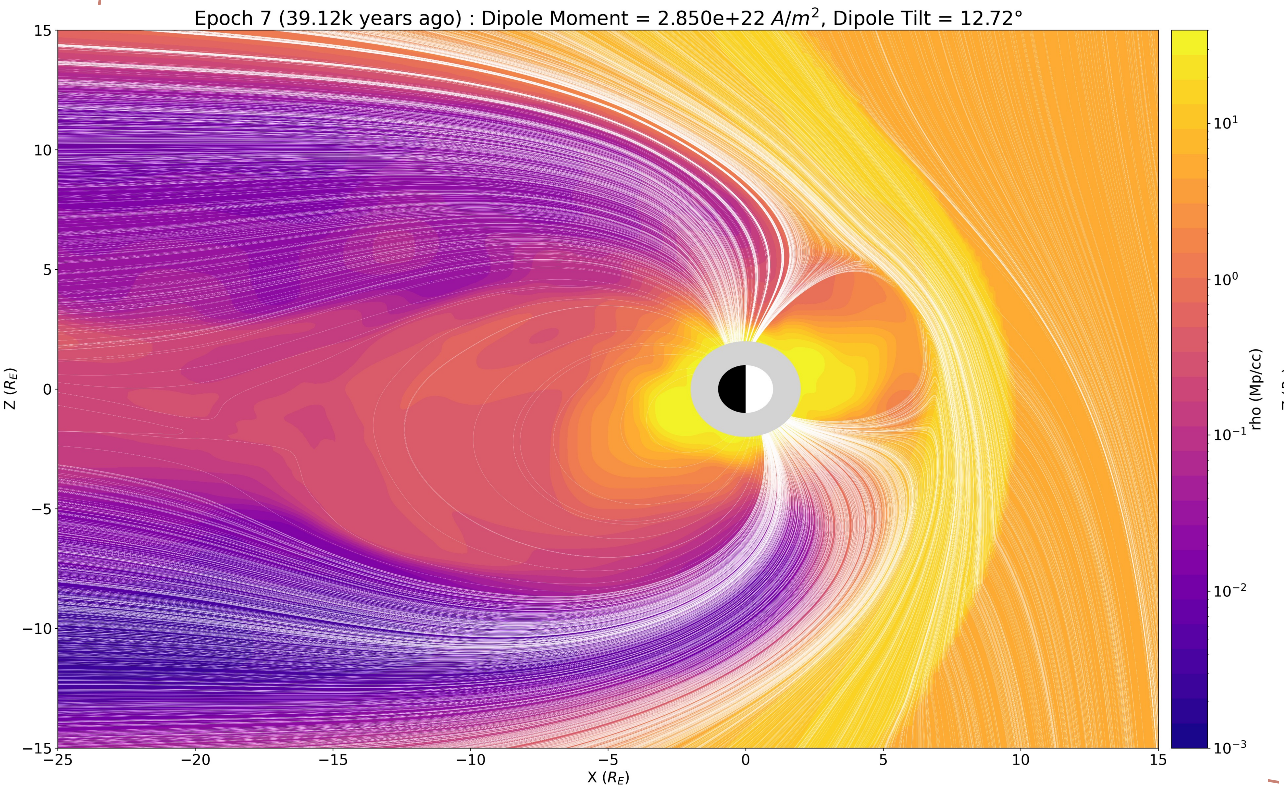


Pressure on the y=0 plane with Bx and Bz field lines

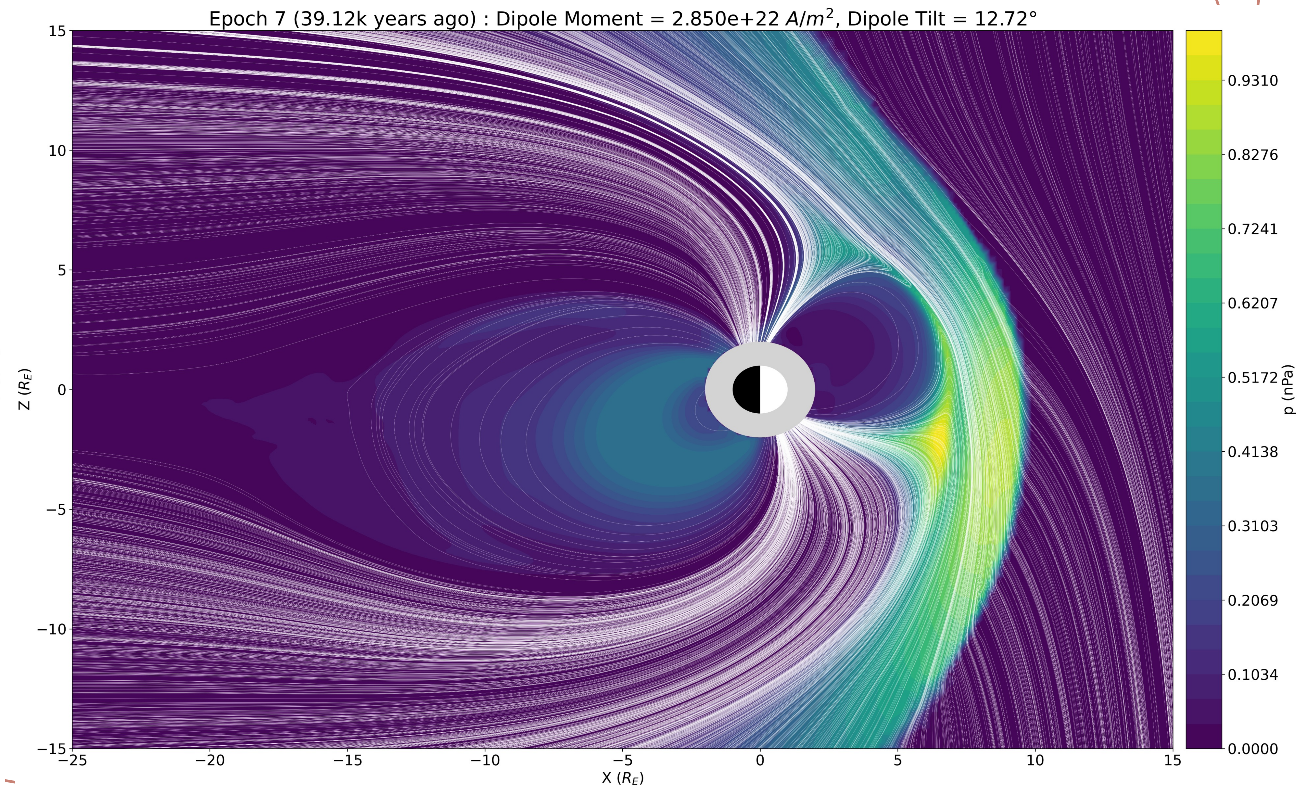


EPOCH 7 (39.12K Years ago)
Dipole moment = 2.850e+22 a/m^2, Dipole tilt = 12.72°

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

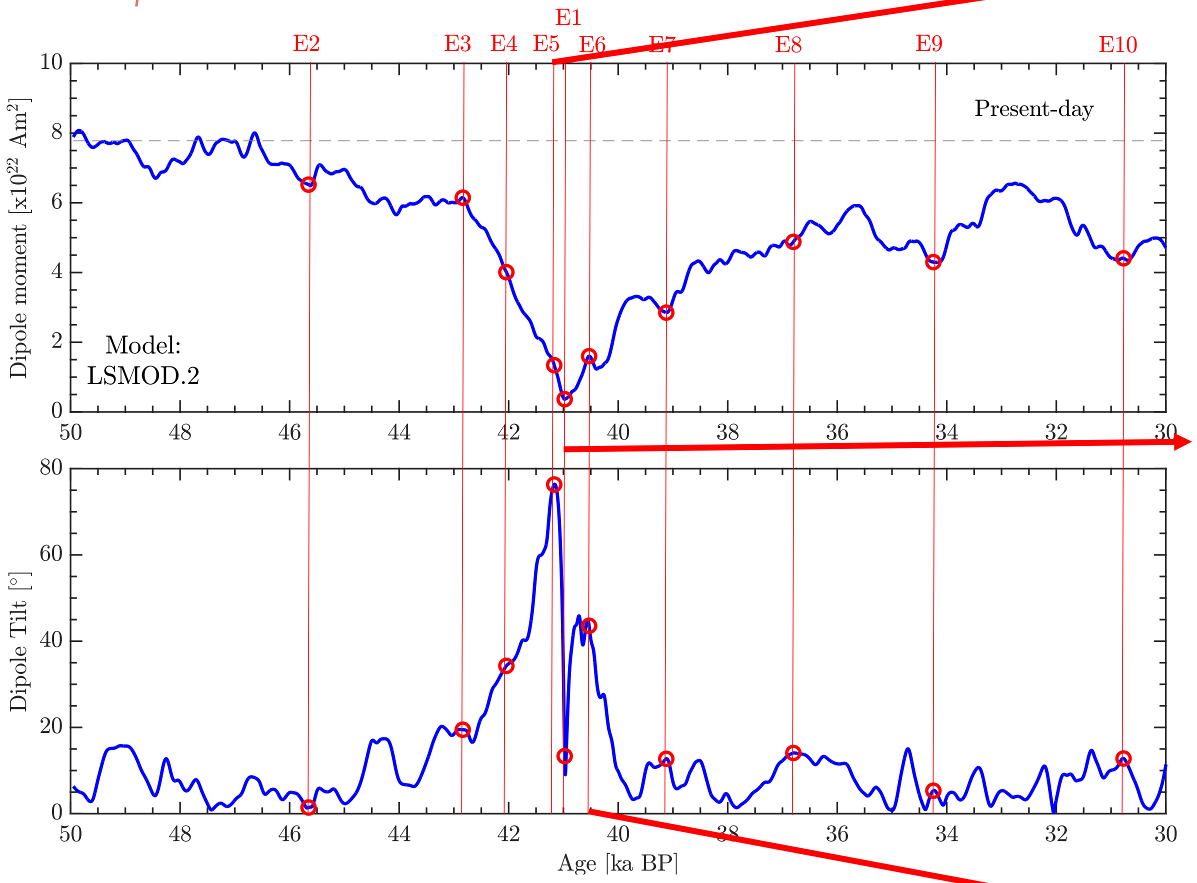


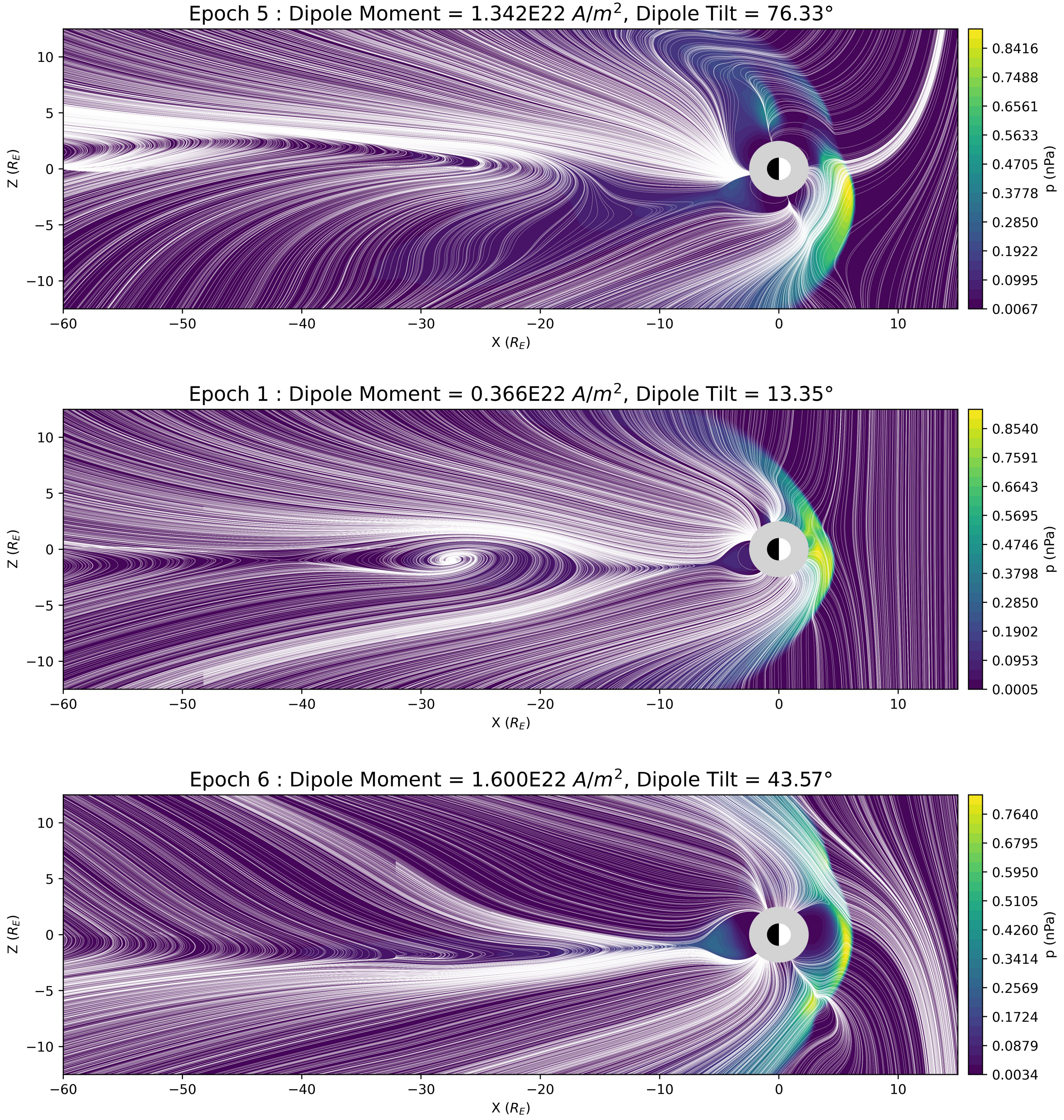
Pressure on the y=0 plane with Bx and Bz field lines



Q1. How realistic are these results?

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



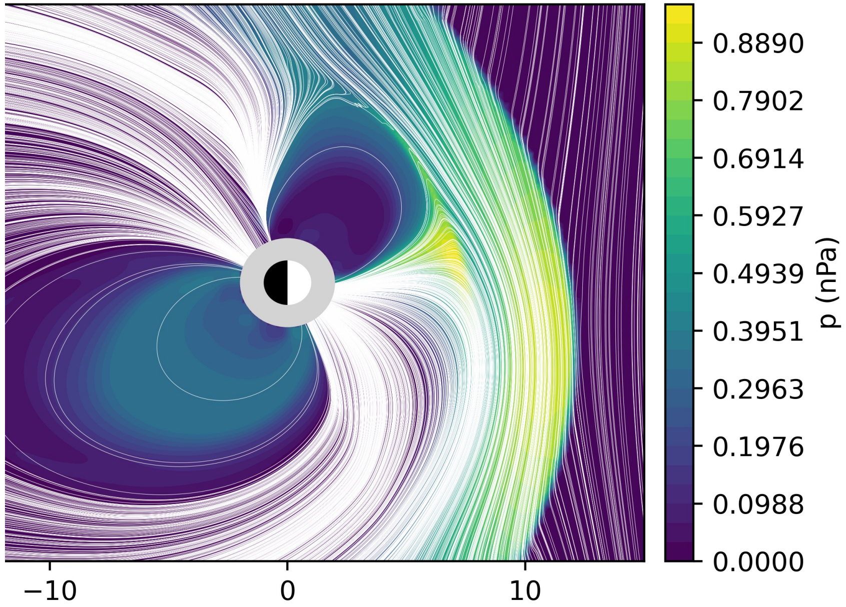


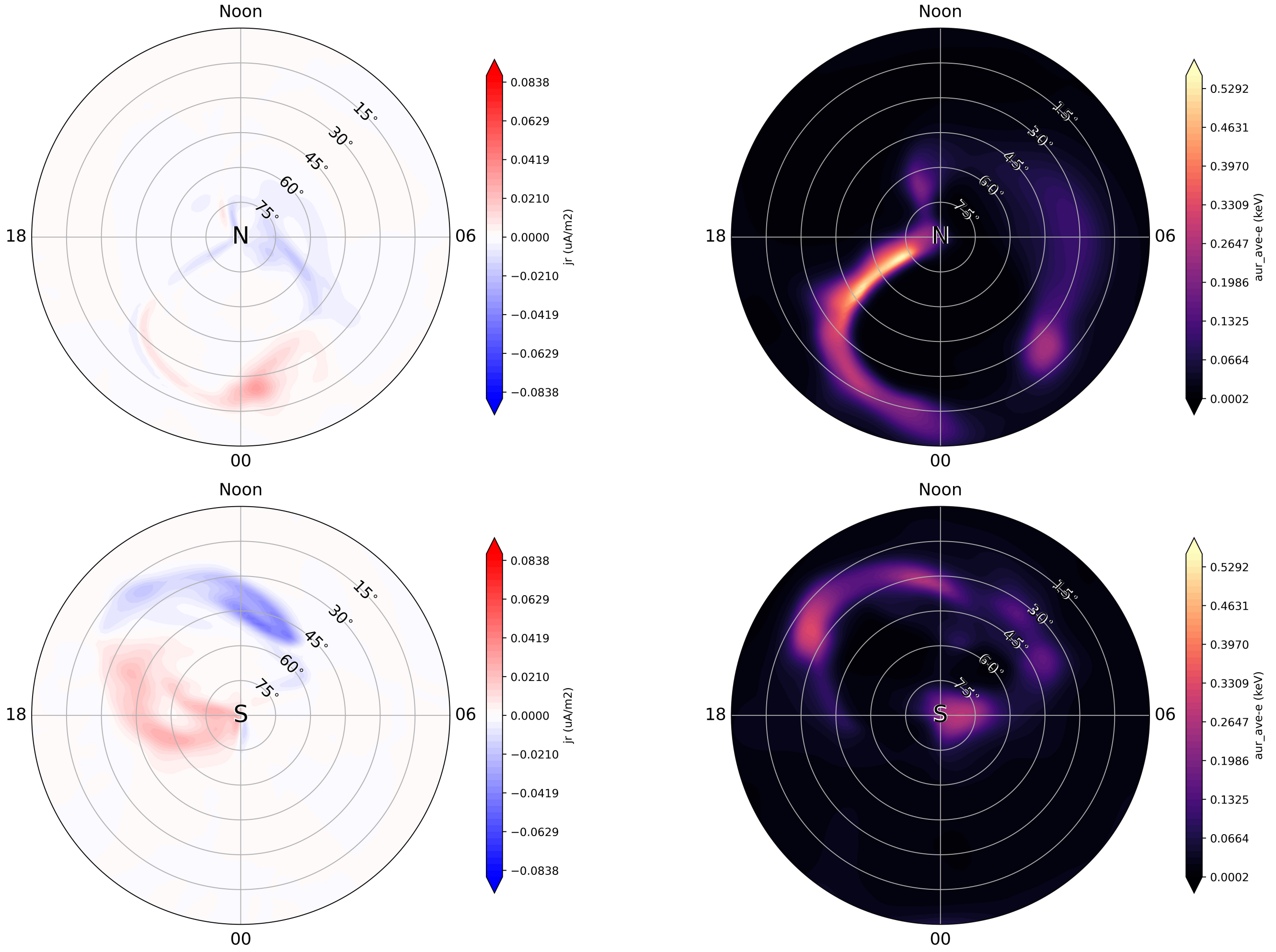
Q2. How significant are these results?

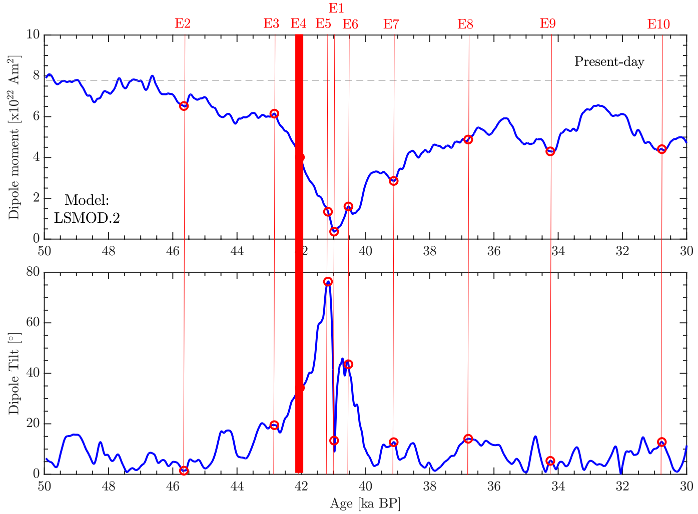
A. We are looking at a detailed study of the change in the magnetosphere over the peak of the event (from 42k to 39k years).

Epoch 4

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

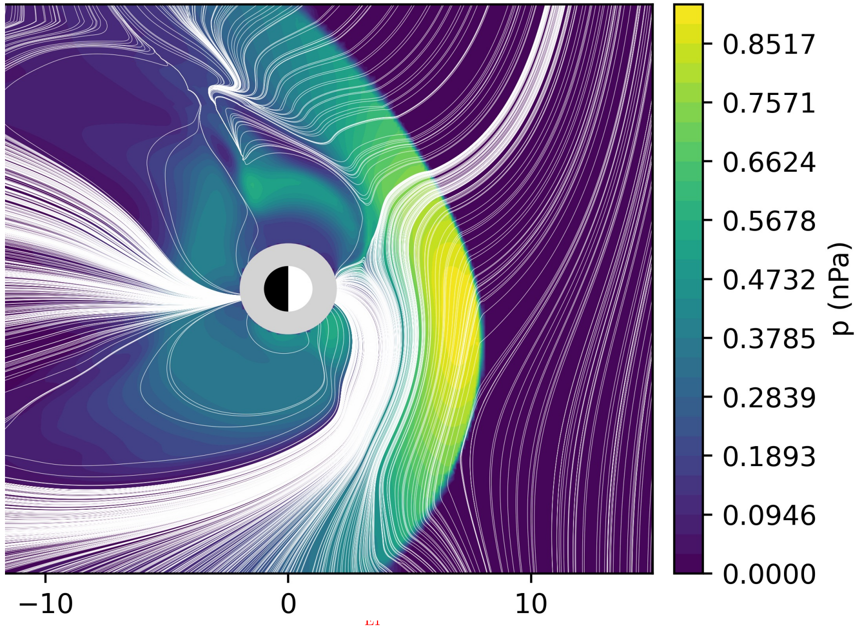


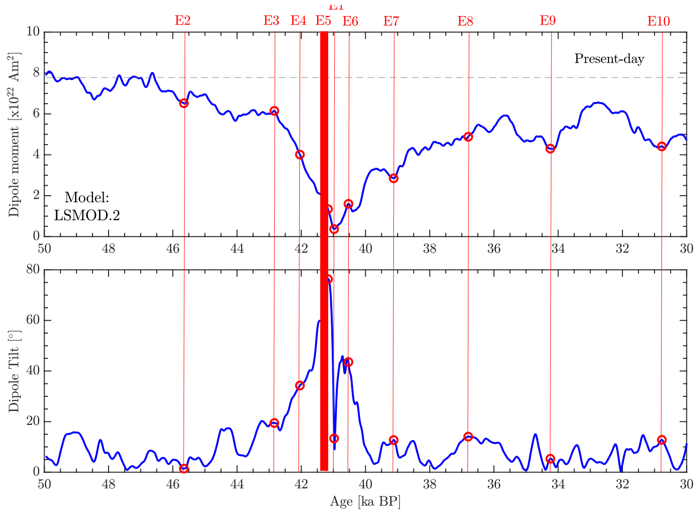


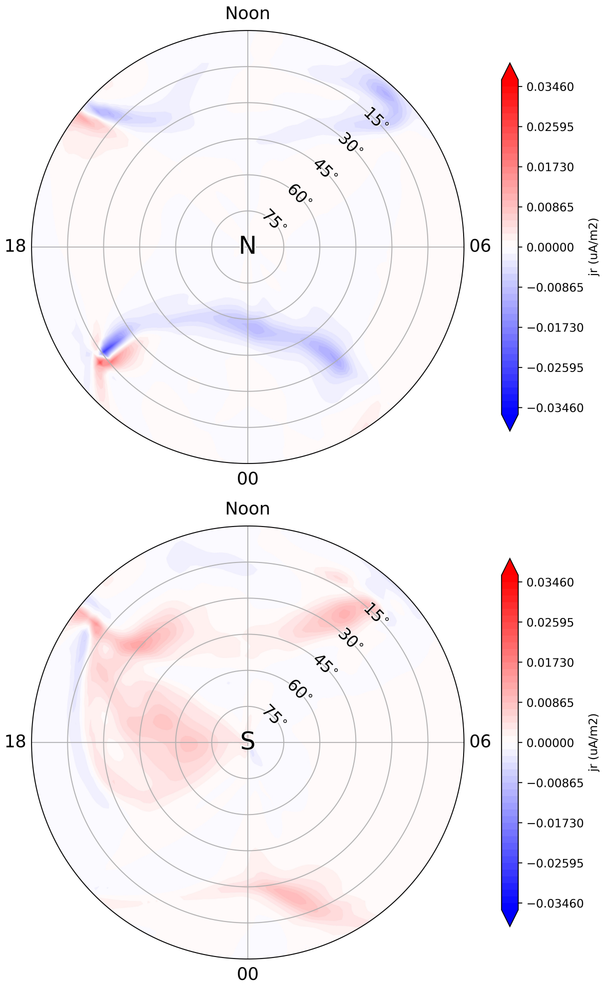


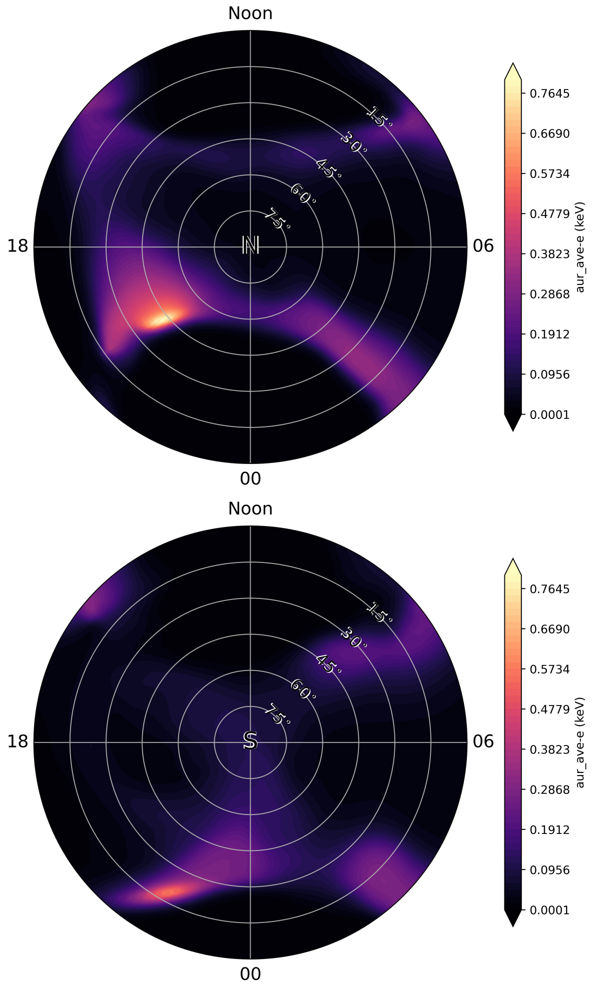
Epoch 5

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









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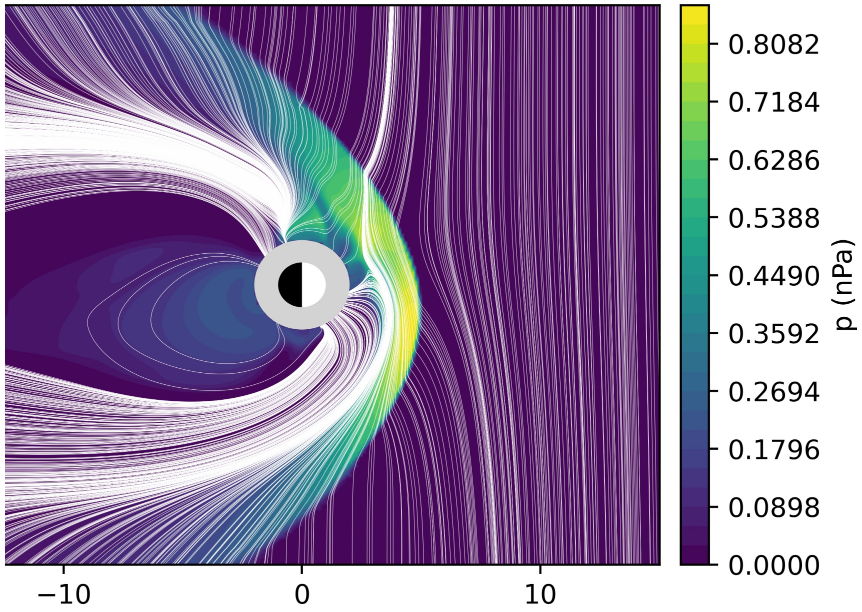
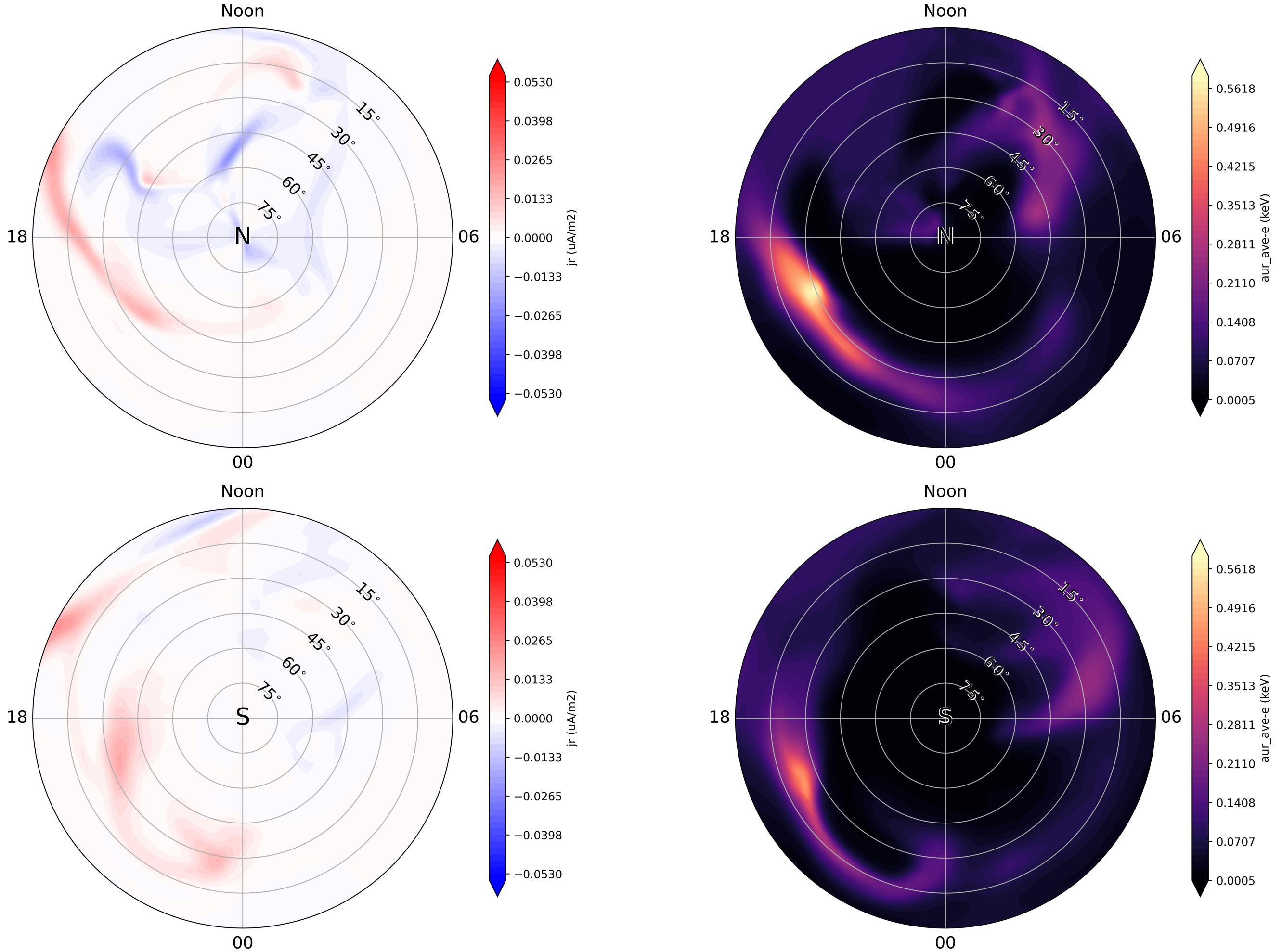
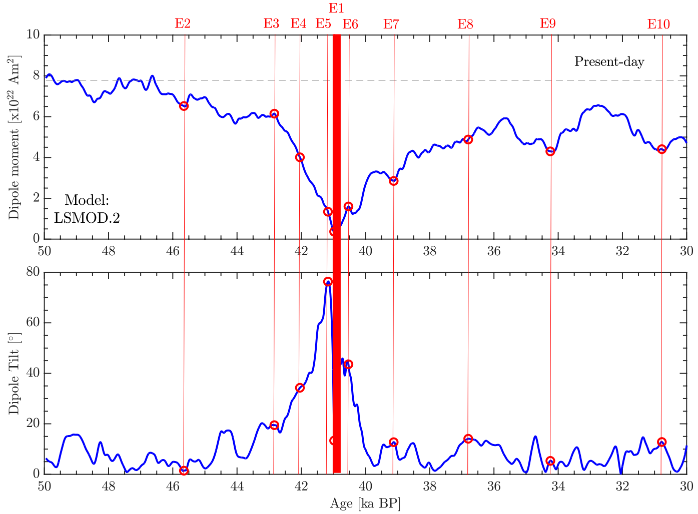
Epoch 1

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

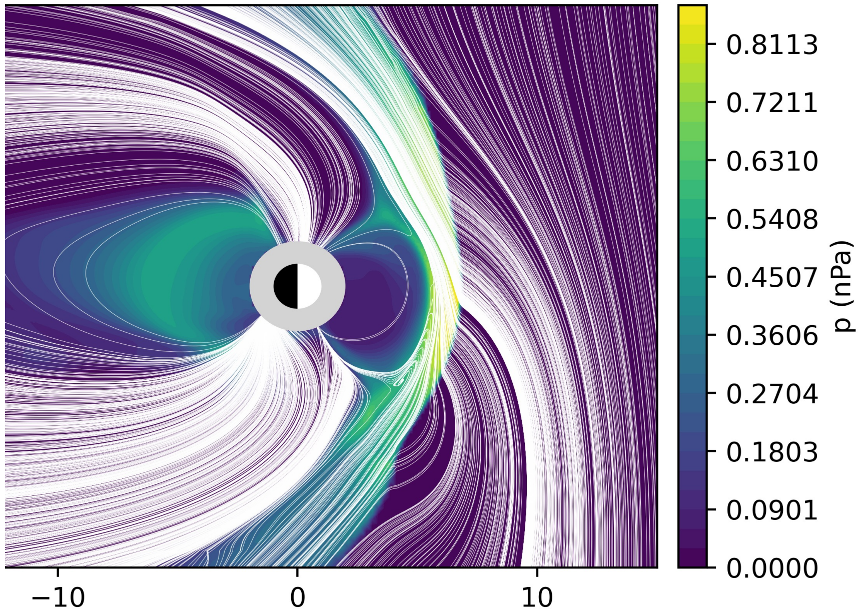


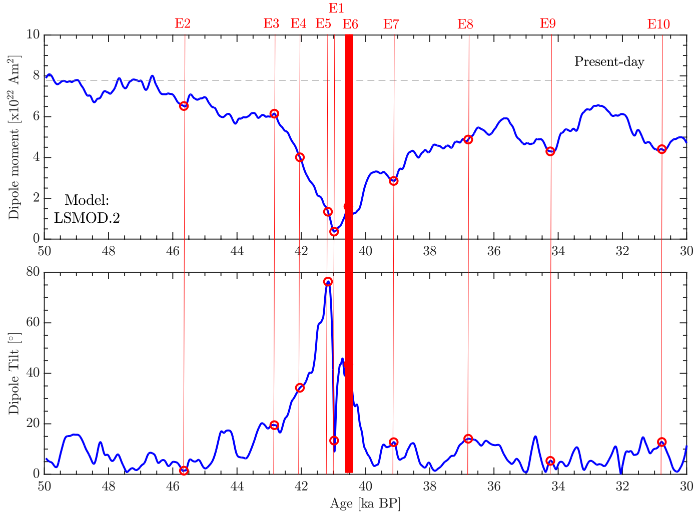


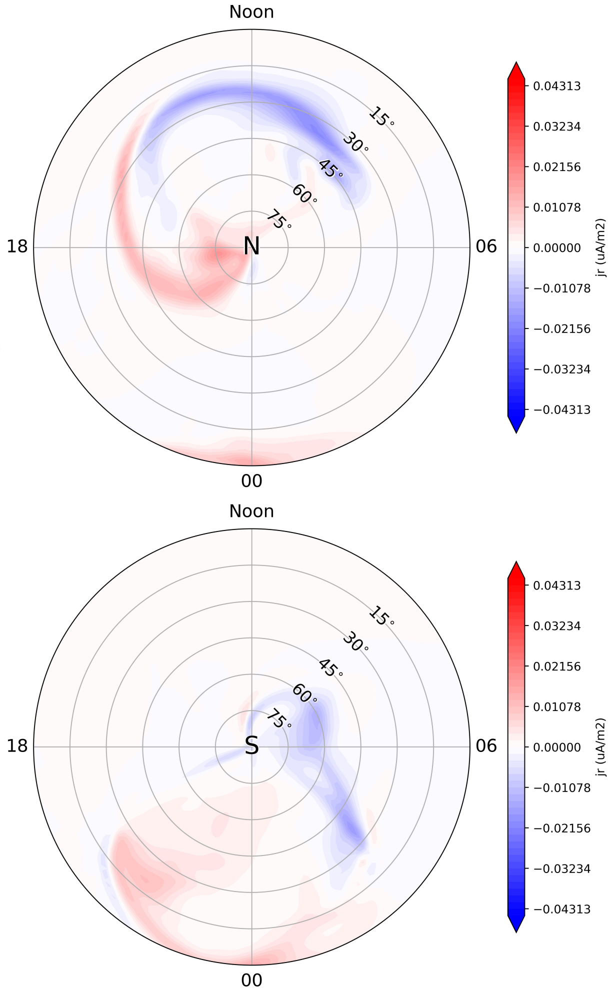


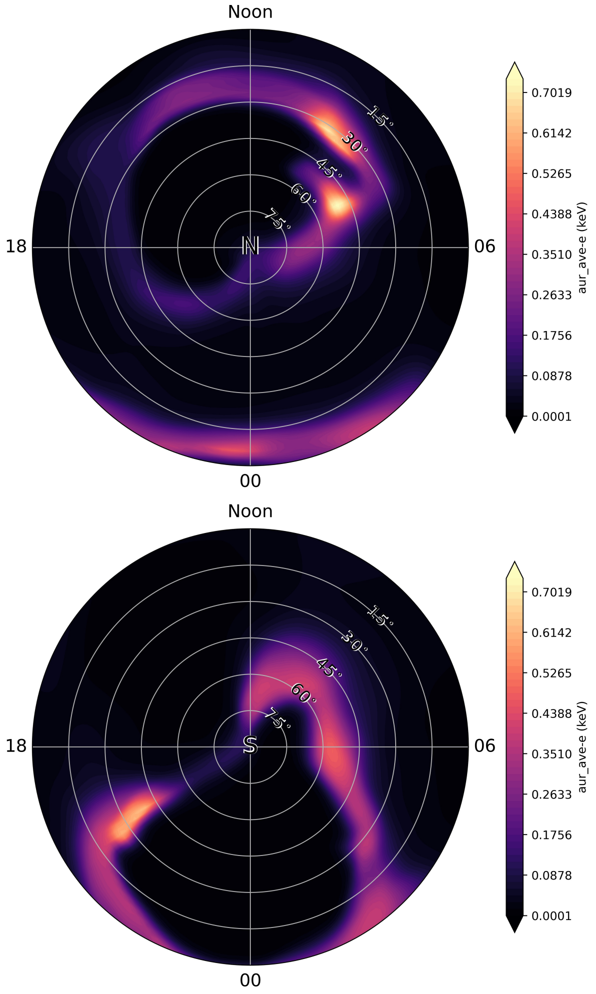
Epoch 6

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

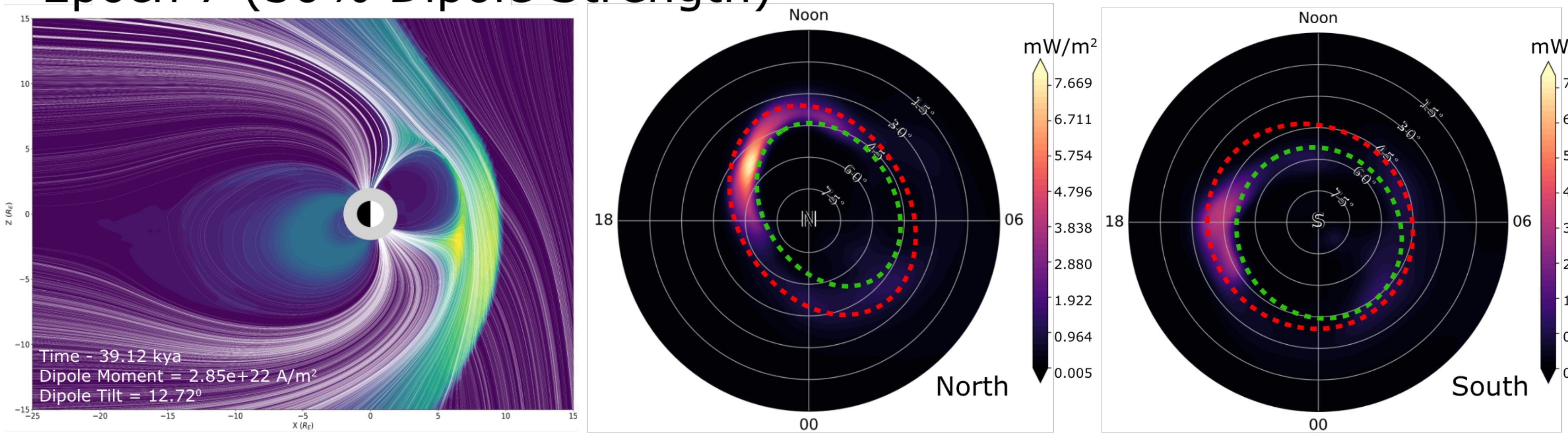




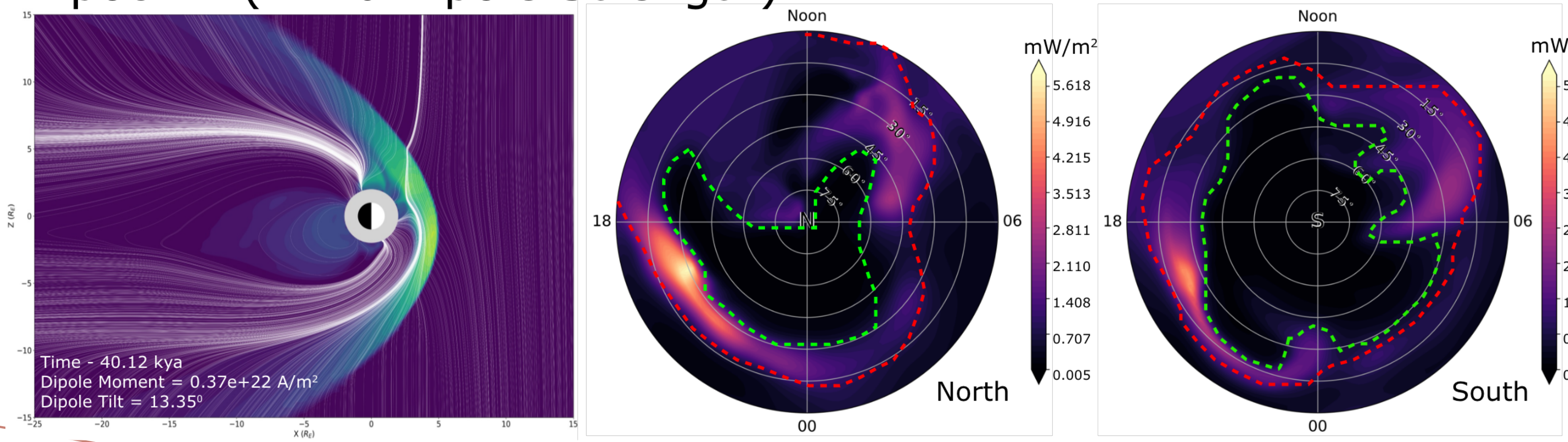


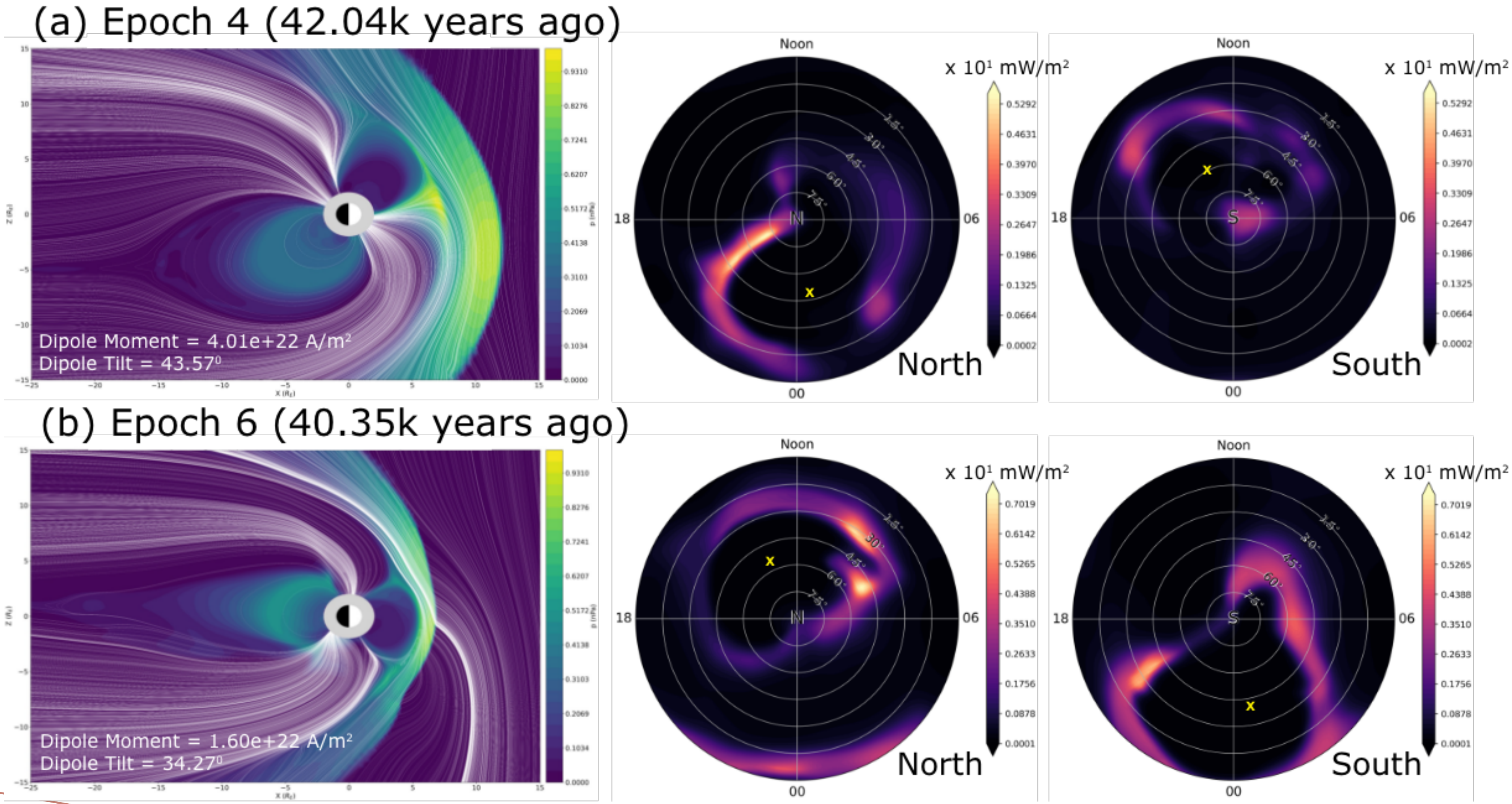


Epoch 7 (30% Dipole Strength)



Epoch 1 (~4% Dipole Strength)



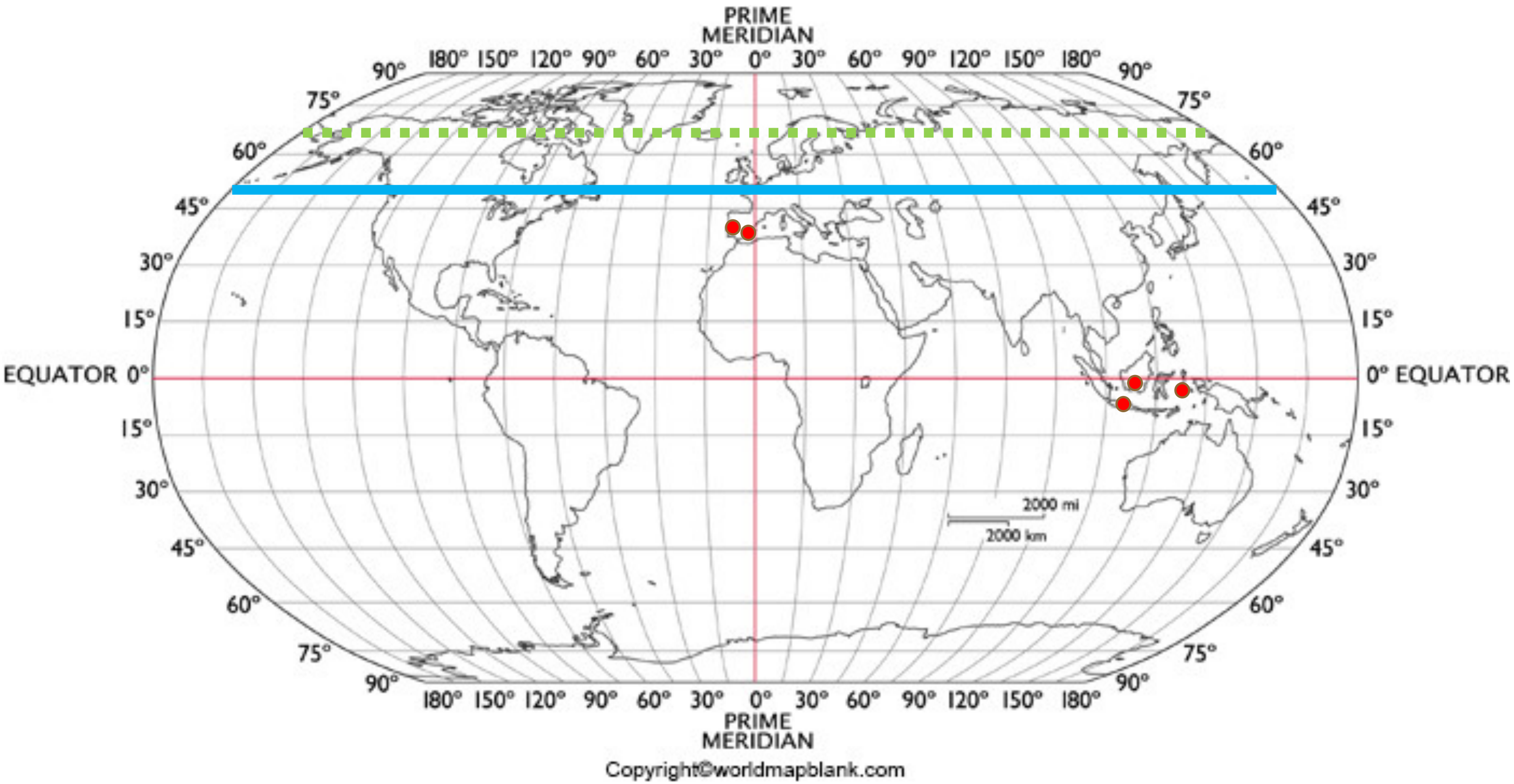

(a) Epoch 4 (42.04k years ago)
Dipole Moment = 4.01e+22 A/m²
Dipole Tilt = 43.57⁰
Noon
18
06
00
N
North
S
South
x 10¹ mW/m²
0.5292
0.4631
0.3970
0.3309
0.2647
0.1986
0.1325
0.0664
0.0002
(b) Epoch 6 (40.35k years ago)
Dipole Moment = 1.60e+22 A/m²
Dipole Tilt = 34.27⁰
x 10¹ mW/m²
0.7019
0.6142
0.5265
0.4388
0.3510
0.2633
0.1756
0.0878
0.0001
North
South

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.

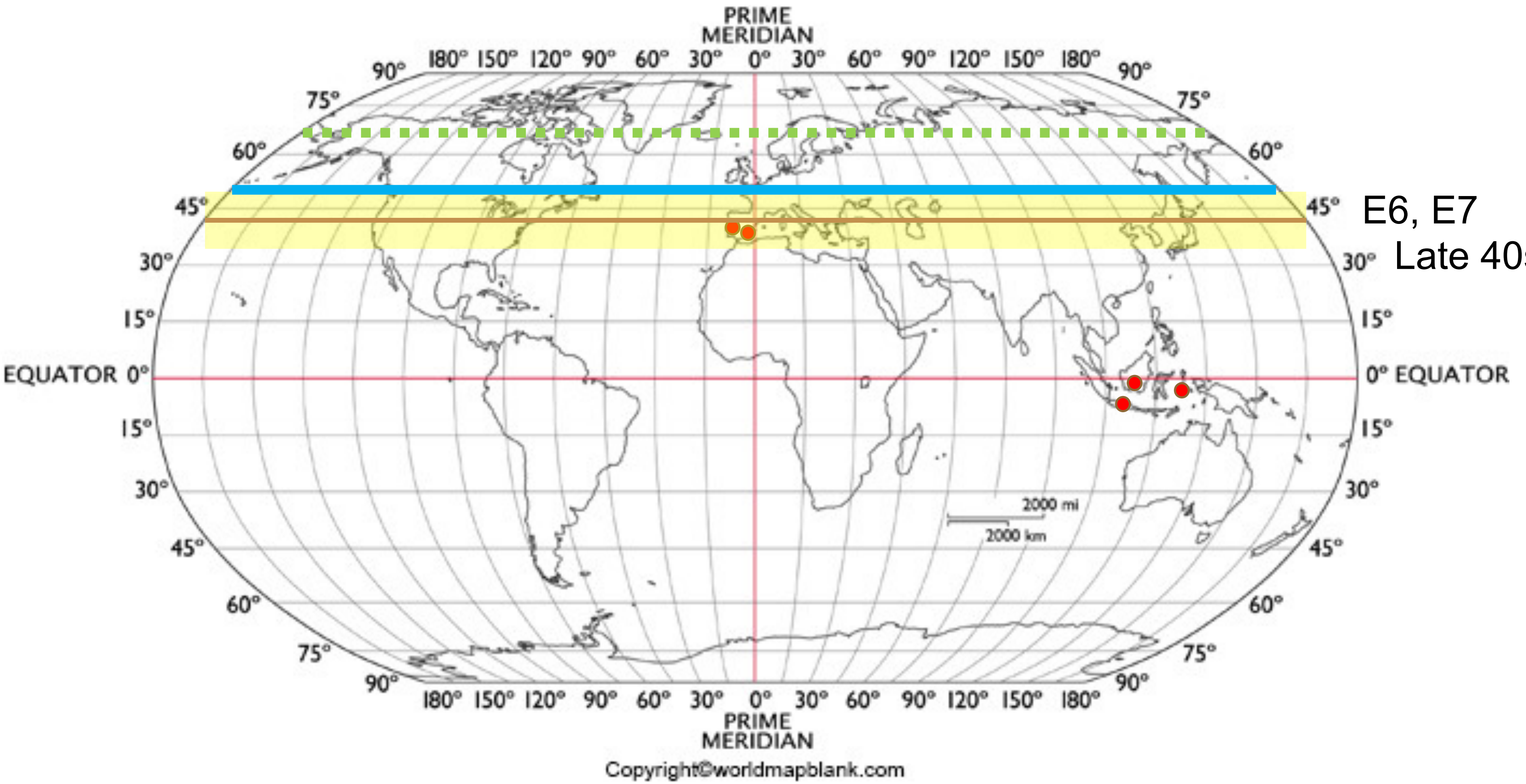
- Our study can potentially explain why in places like Indonesia (*Aubert et al. 2019*) or the Iberian Peninsula (*Pike et al. 2018*), there would have been a decent possibility of seeing the aurora which might have affected human behaviour.



Auroral Boundary (Modern Values; Moderate Solar Driving)

Auroral Boundary (as suggested in Cooper+ 2021)

Traces of Human Civilization during the Laschamp Period

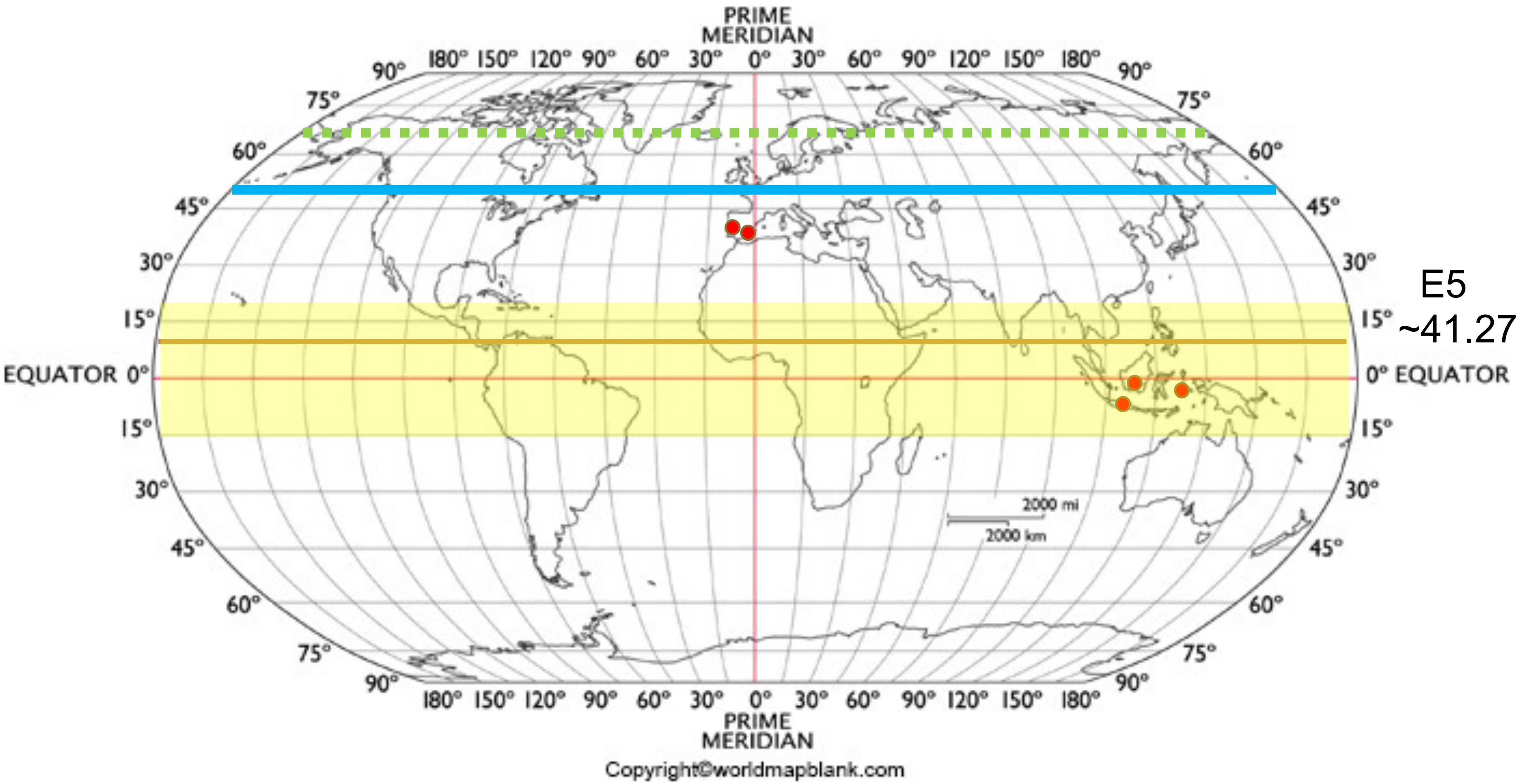


E6, E7
Late 40s ka

Auroral Boundary
(Modern Values; Moderate Solar Driving)

Auroral Boundary
(as suggested in Cooper+ 2021)

Traces of Human Civilization during the Laschamp Period



E5
~41.27 ka

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.

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