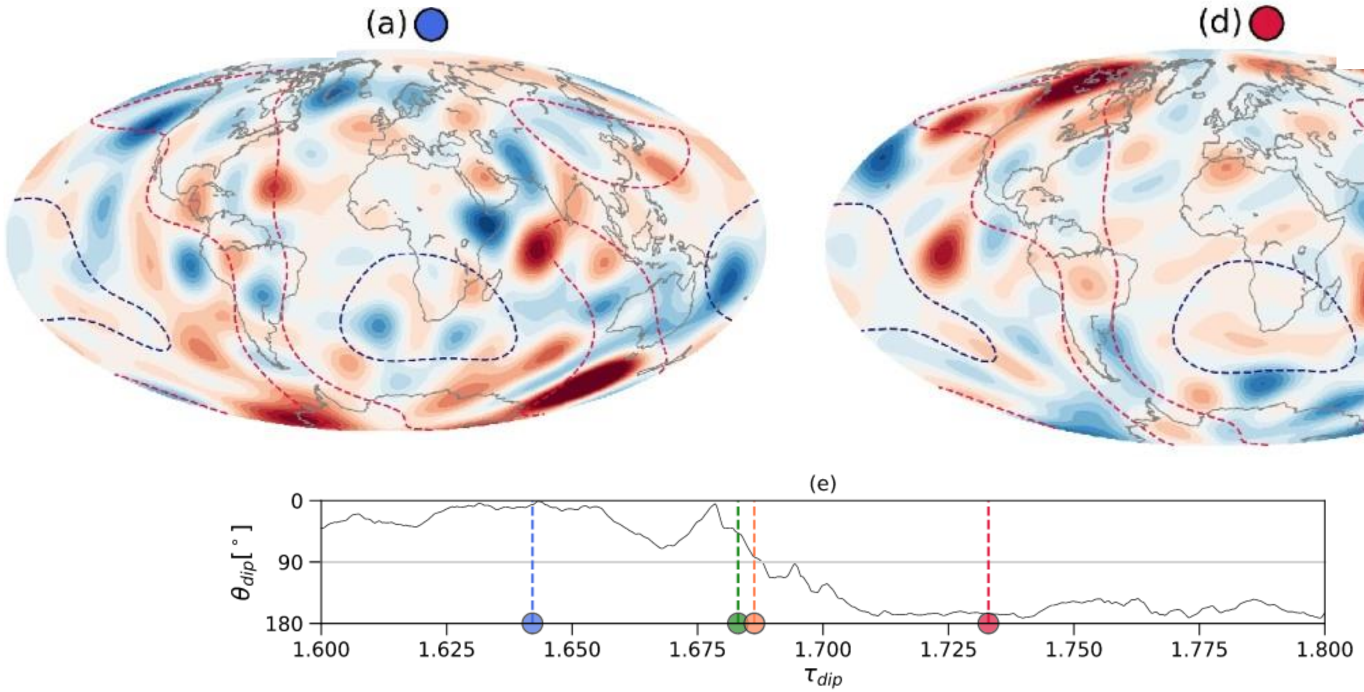
Reversal precursors in paleomagnetic field models and numerical dynamo simulations

Mathis **COLAS**

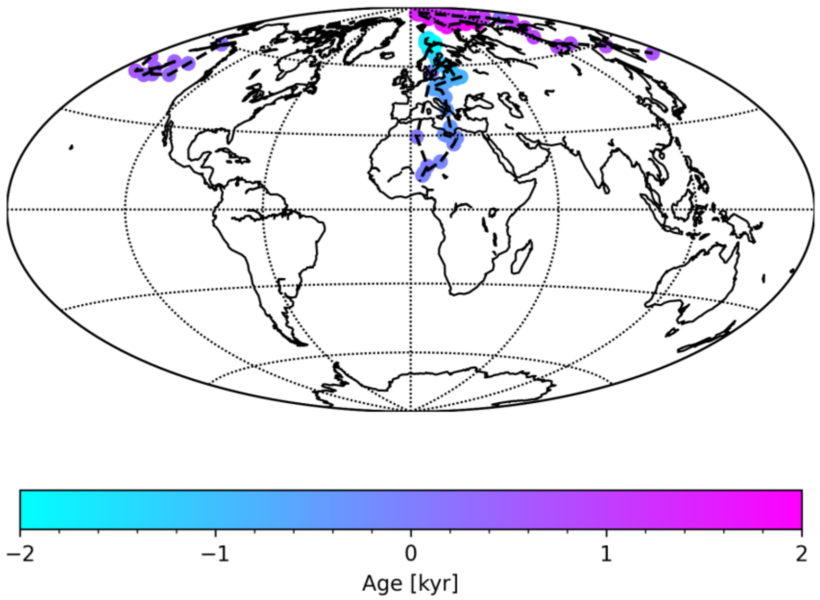
Supervised by Filipe Terra-Nova and Hagay Amit



Introduction – Drastic changes in Earth magnetic field

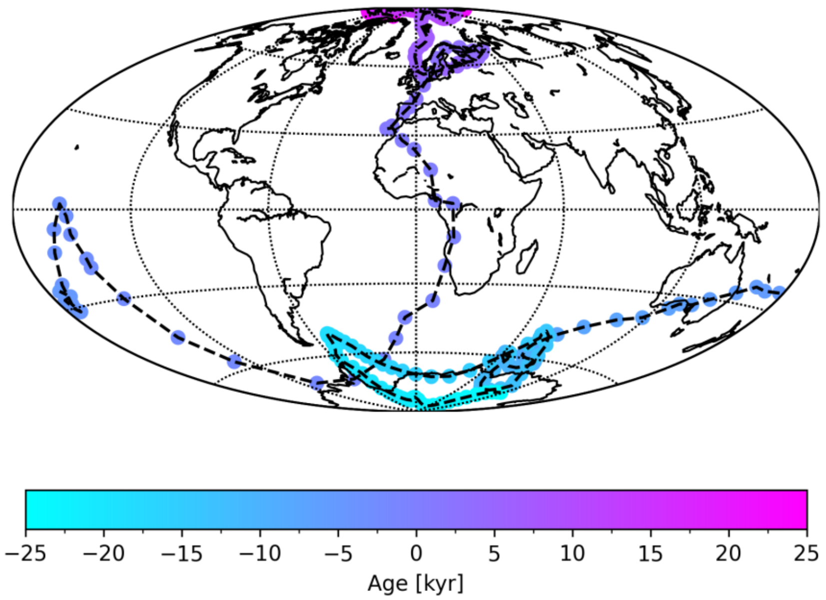
Dipole axis drift during transitions

Excursion



LSMOD.2 model of Korte et al. (2019)

Reversal

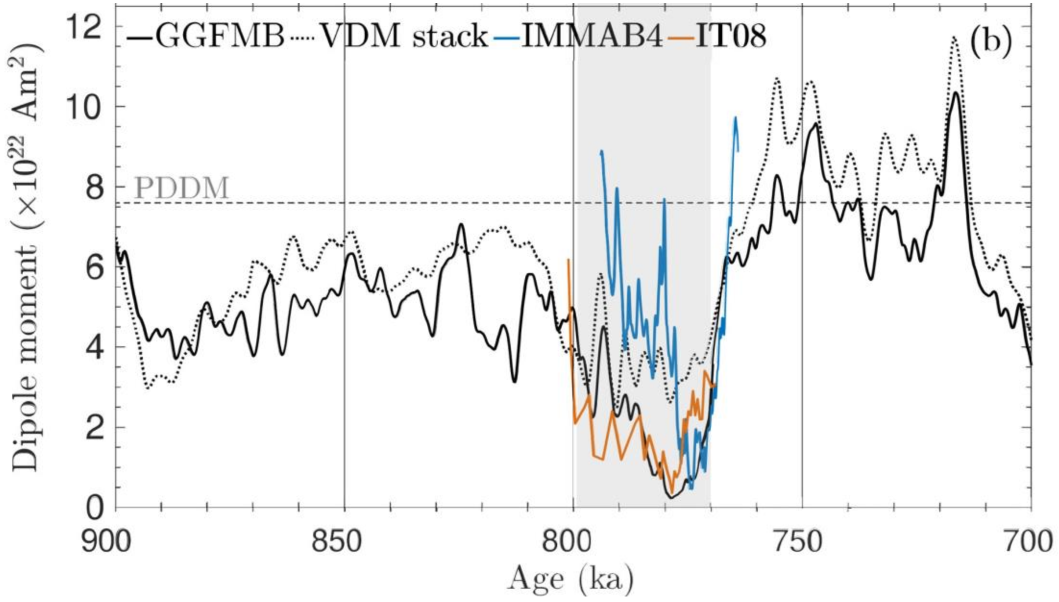


GGFMB model of Mahgoub et al. (2023)

Polarity of the field in the last 350 Myr

Data from Melott et al. (2018)

Motivation – Precursors for geomagnetic reversal



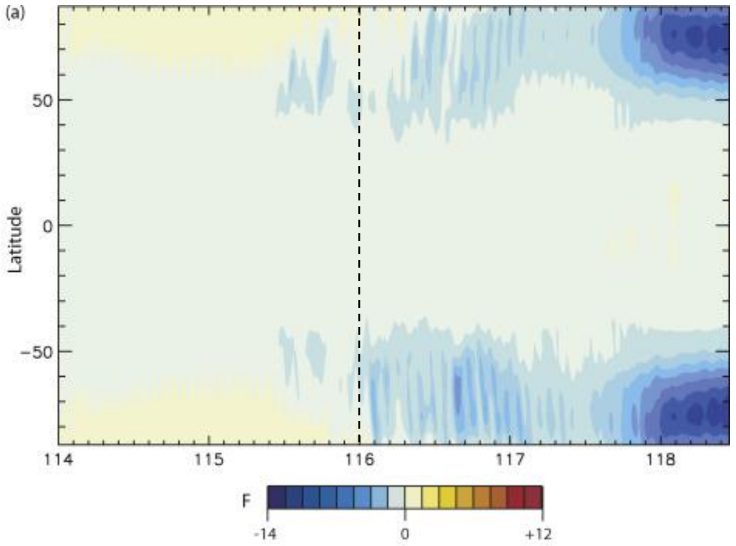
Mahgoub et al. (2023): presence of precursor around 10 kyr before the reversal.

⇒ dipole moment decrease following by a recovery

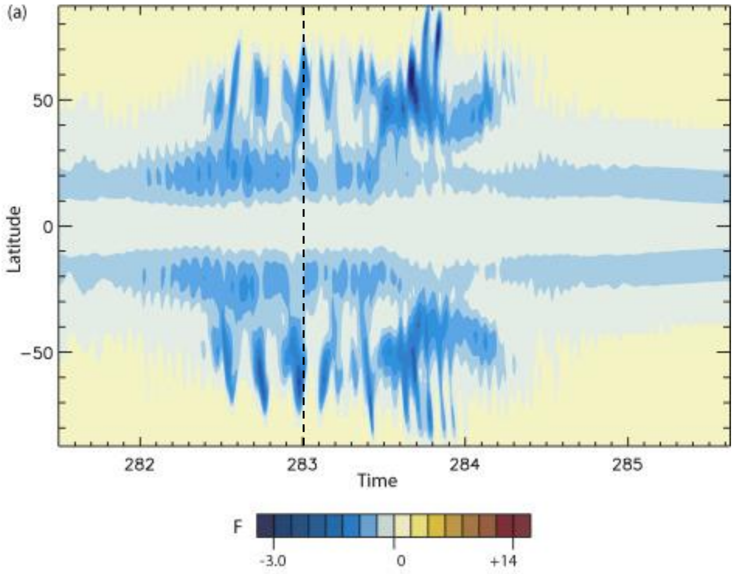
Problem: Did not set threshold value

Olson et al. (2009): contribution of reversed flux to axial dipole is around 40% for reversing dipole collapse and around 20% for non reversing dipole collapse

Problem: $Rm\sim100$ very far from the $Rm\sim1000$ of Earth



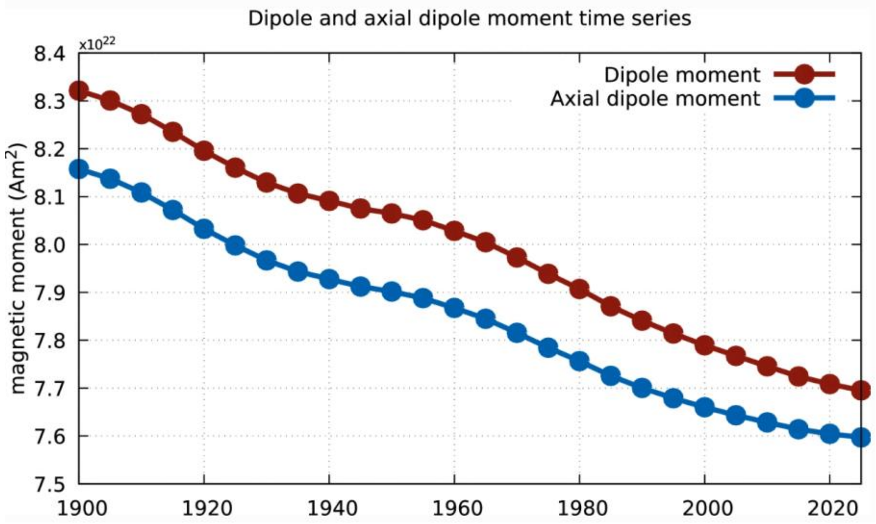
Reversing



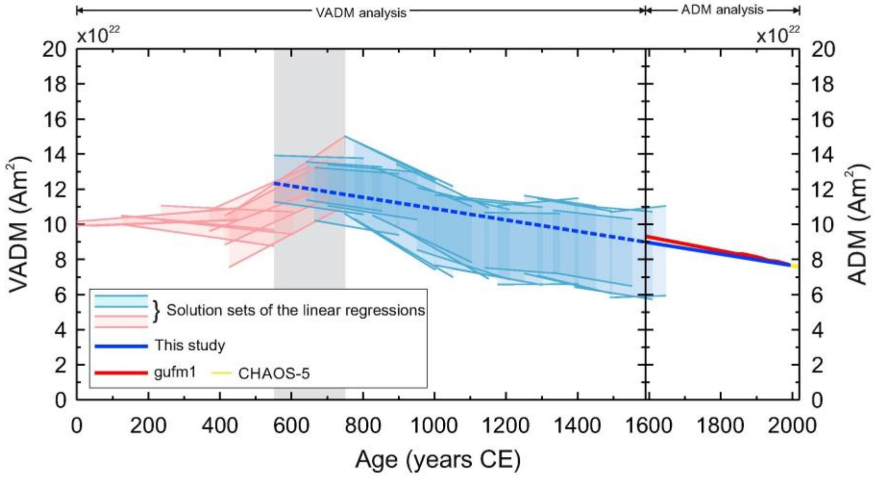
Non reversing

Motivation – Current state of geomagnetic field

Alken et al. (2021): since the advent of geomagnetic intensity measurements, the dipole decreases rapidly



Poletti et al. (2018): the rapid decrease of the dipole started about a millenium before present



Olson & Amit (2006): decreasing of normal flux and increasing of reversed flux in the southern hemisphere

Methods – Definition and precursor candidates

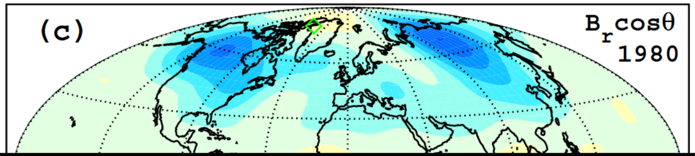
Definition of excursion and reversal: dipole tilt > 45° (Laj and Channel, 2007)

Precursor candidates:

- Candidates in physical space:

1. PSV index (Panovska & Constable, 2017): $P_i = \frac{\left(\frac{\pi}{2} - |\lambda_p(\lambda,\phi)|\right) M_0}{\pi M(\lambda,\phi)}$

2. Proportion of reversed flux contribution to the axial dipole: $\chi_R = \frac{\int B_r^R \cos\theta dS}{\int B_r \cos\theta dS}$



[redacted]

Olson & Amit (2006)

- Candidates in spectral space:

3. Power spectrum: $R_n = (n+1)\left(\frac{a}{r}\right)^{2n+4} \sum_{m=0}^{n} [(g_n^m)^2 + (h_n^m)^2]$

Methods – Threshold values and reversal timing

Threshold values: defined from paleomagnetic field model without excursion and reversal, GGF100k (Panovska et al., 2018)

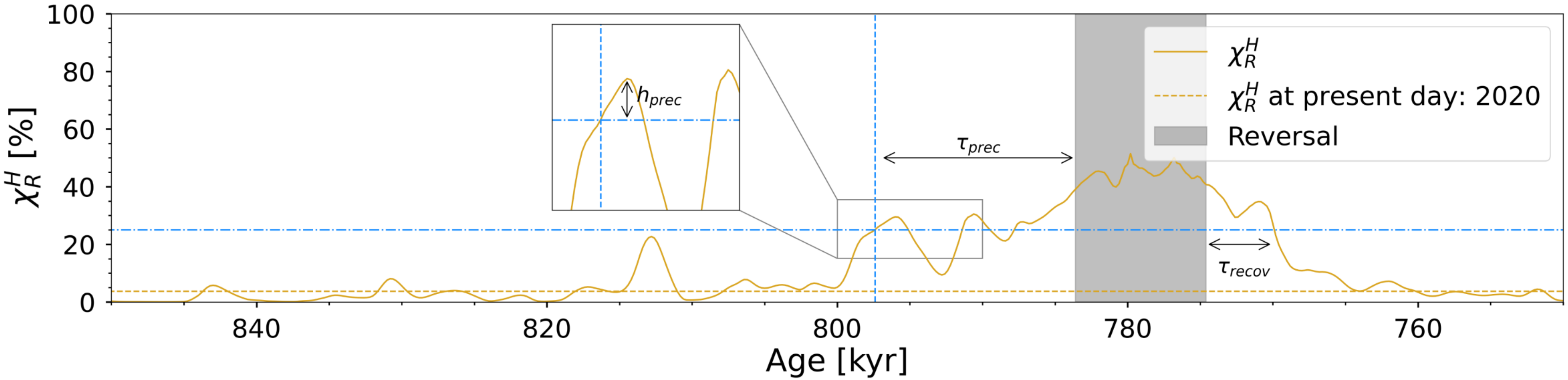
Reversal timing:

τ_{prec}: the time interval between precursor and beginning of event

τ_{recov}: the time interval between the end of event and the last crossing threshold value

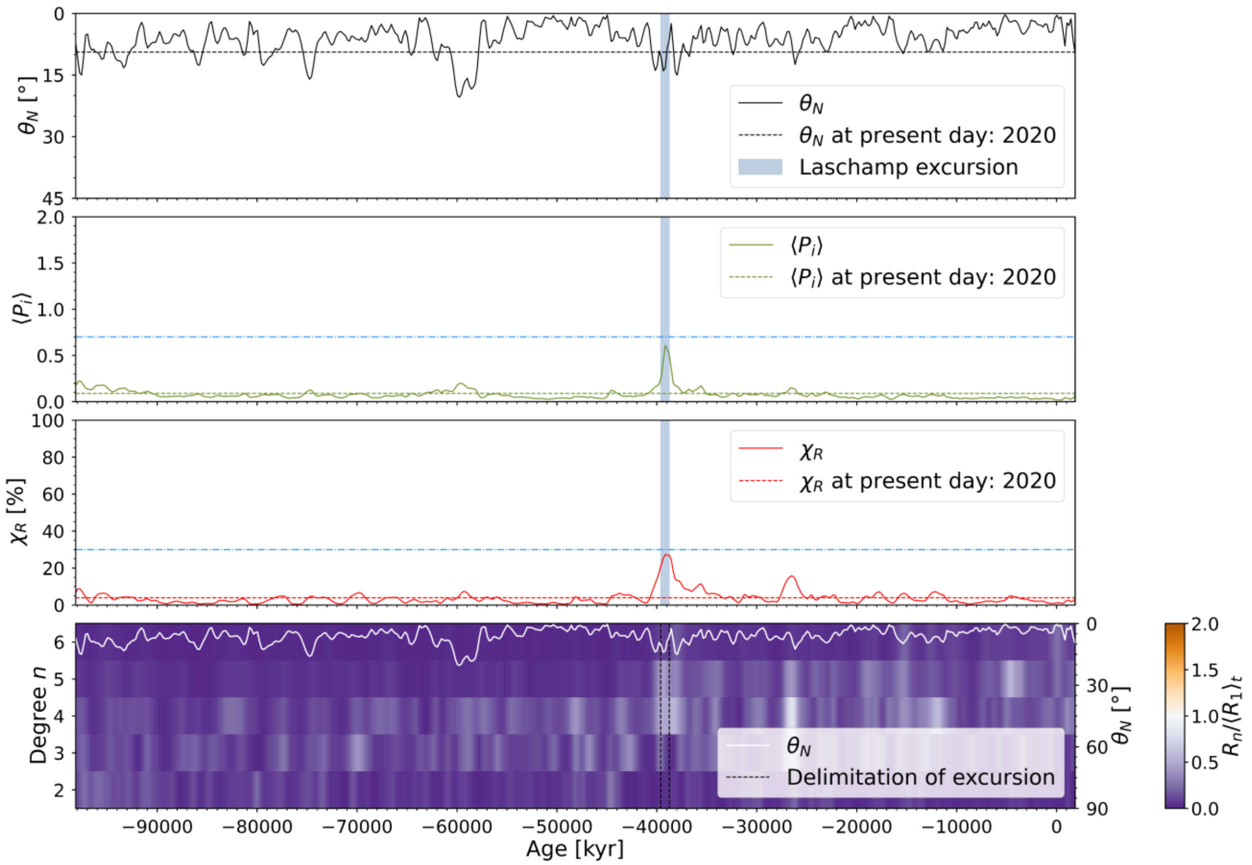
A_{prec}: the ratio between the the maximum value of the precursor and threshold value

Example:

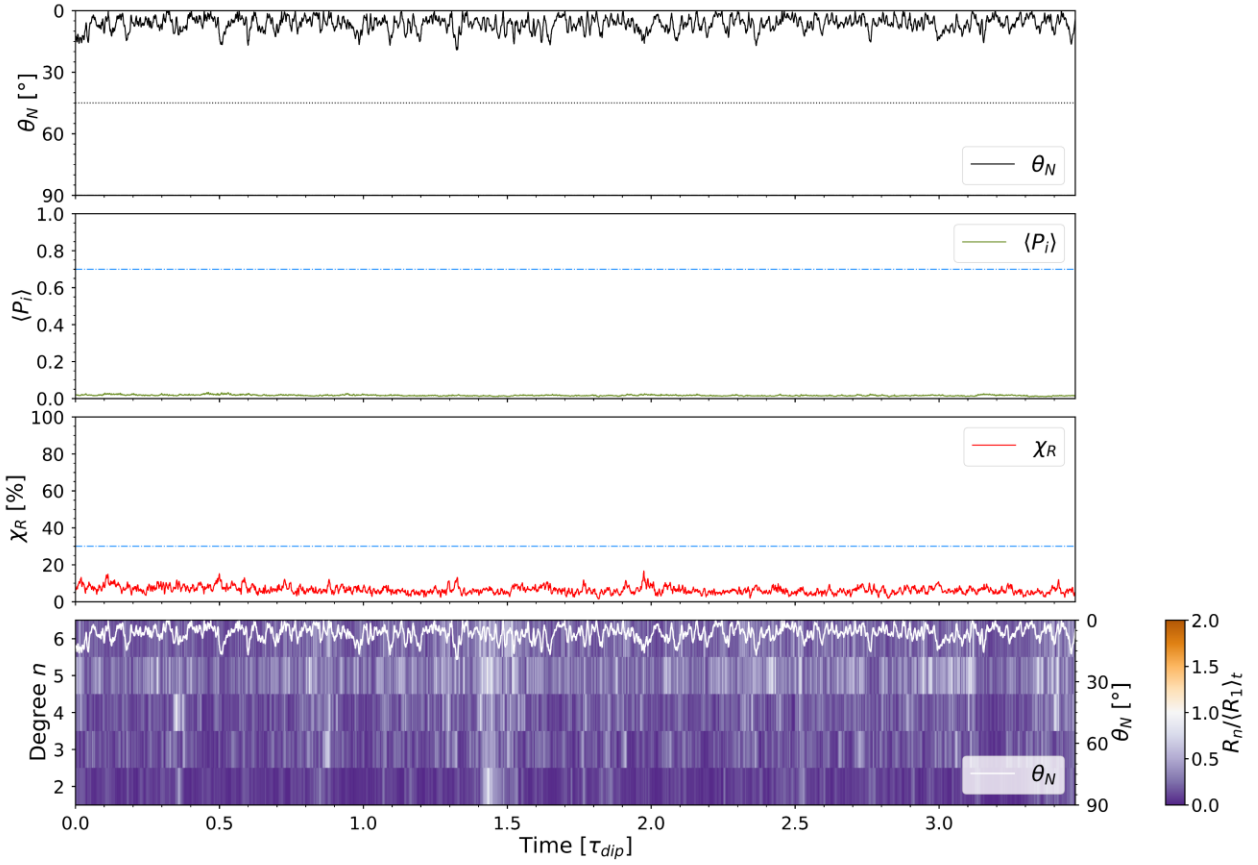


Results – Non reversing models

Paleomagnetic field model



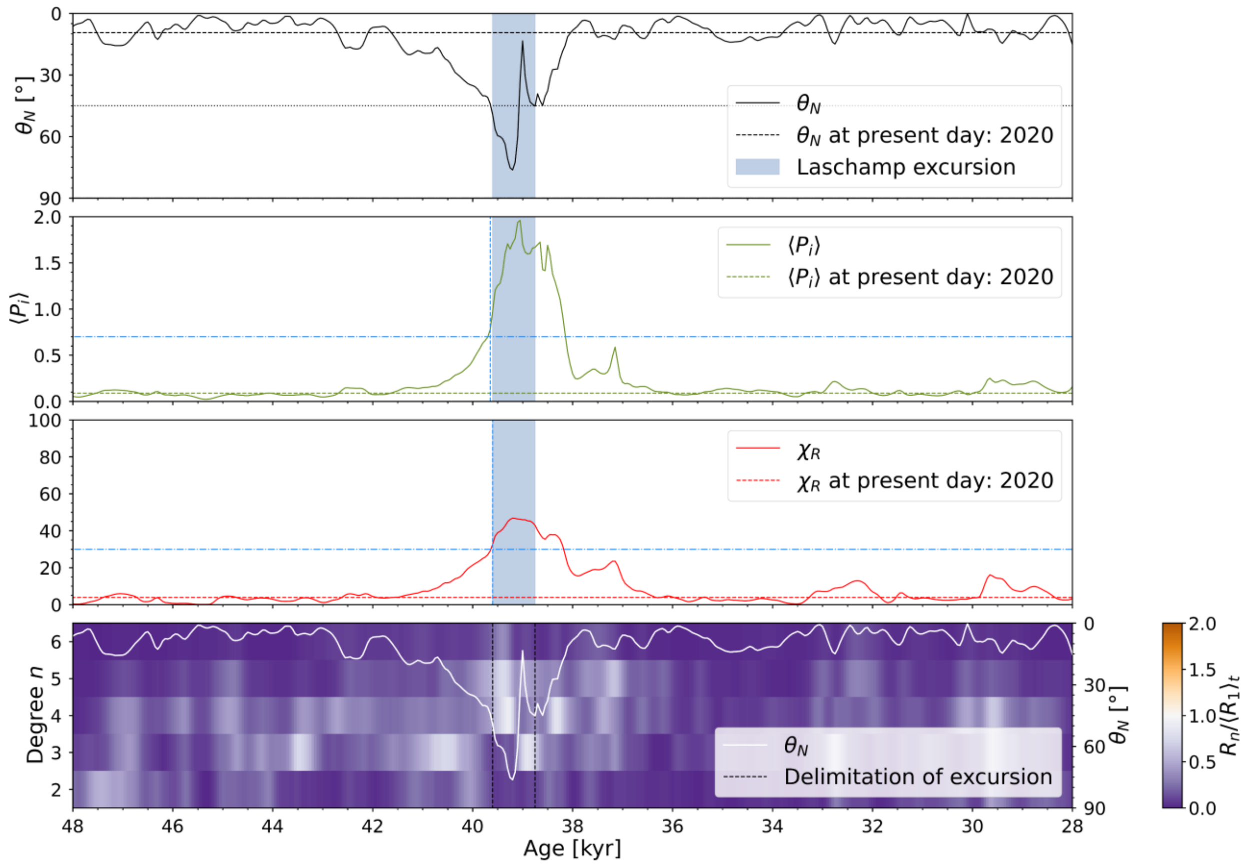
Numerical dynamo model ($Rm\sim1400$)



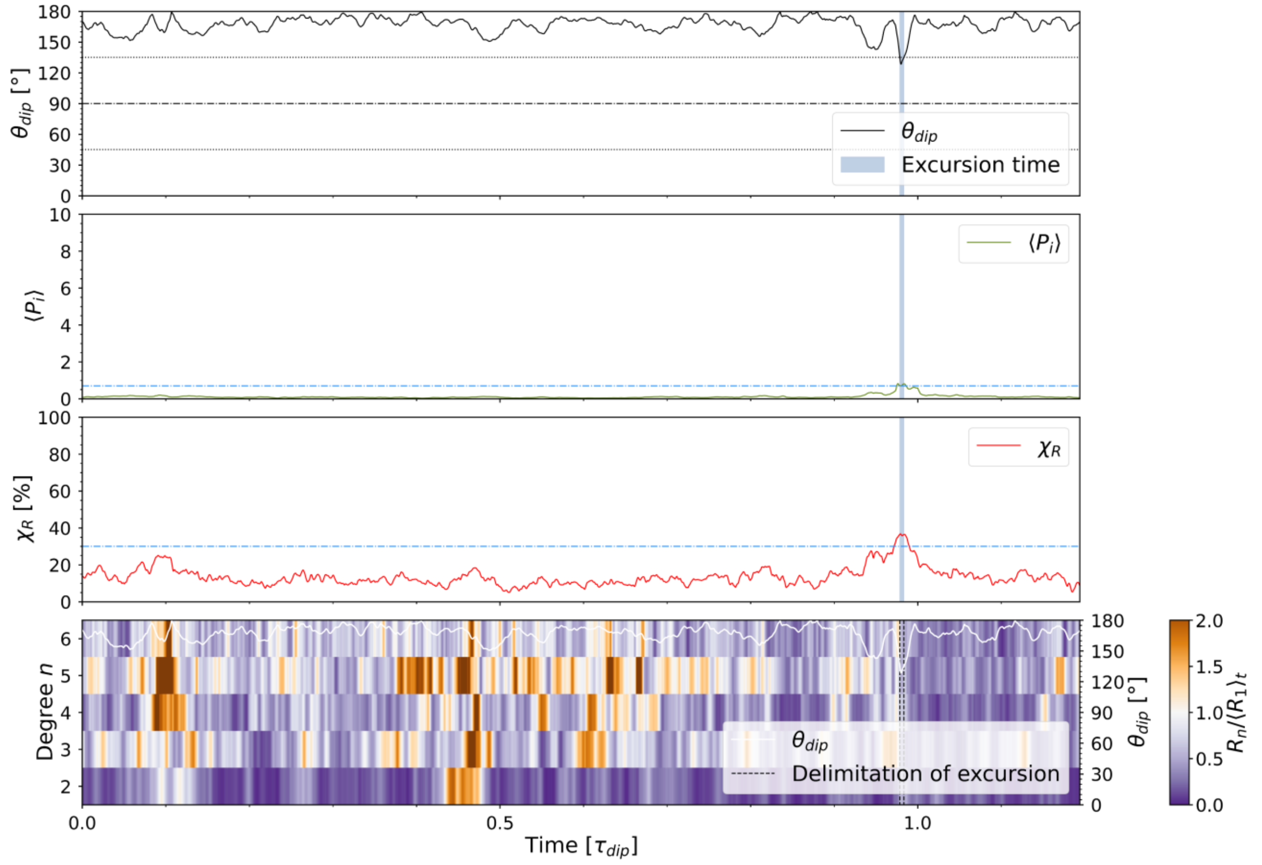
- Paleomagnetic field model covers the last excursion but dipole tilt < 45°
- Determination of threshold values based on paleomagnetic field model
- Confirmation with numerical dynamo model ($Rm\sim1400$)

Results – Excursion models

Paleomagnetic field model: Laschamp excursion



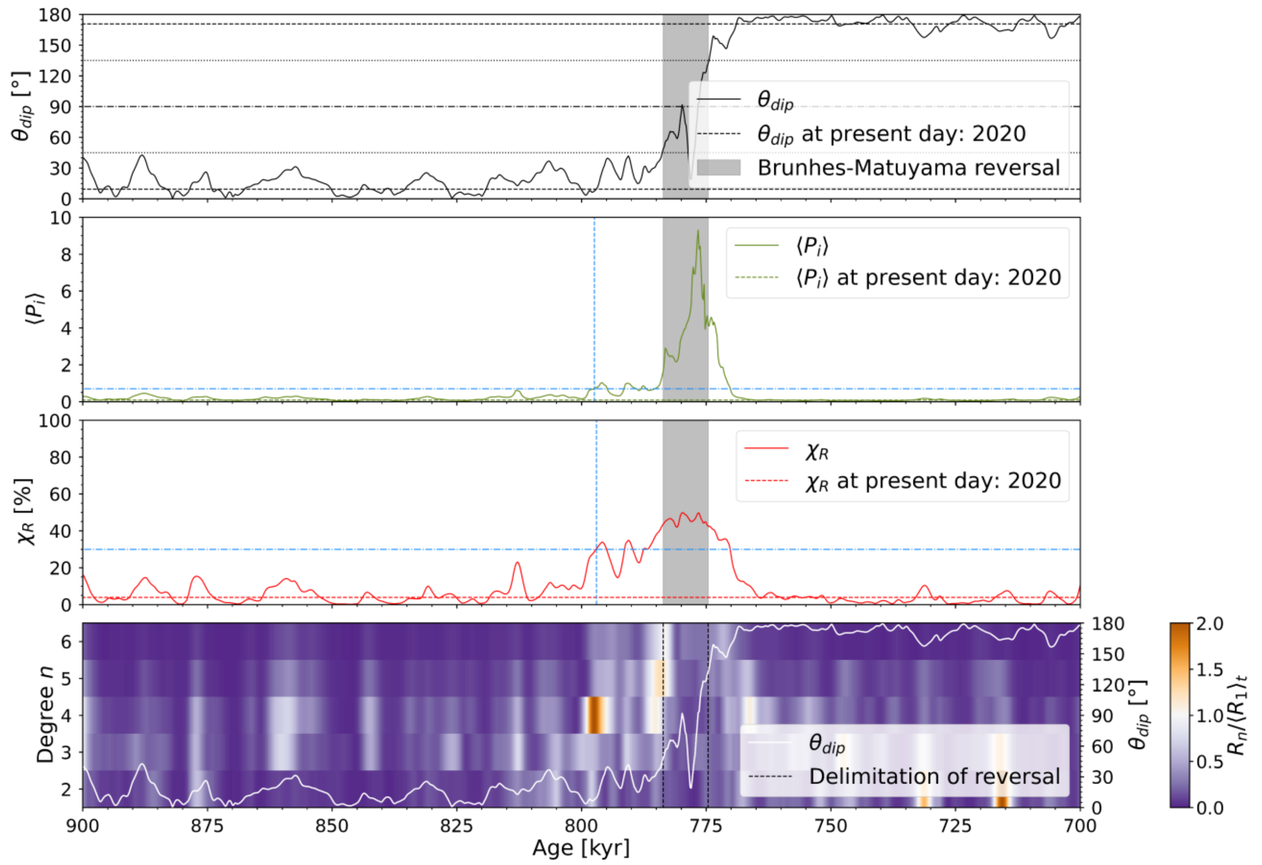
Numerical dynamo model (Rm~650)



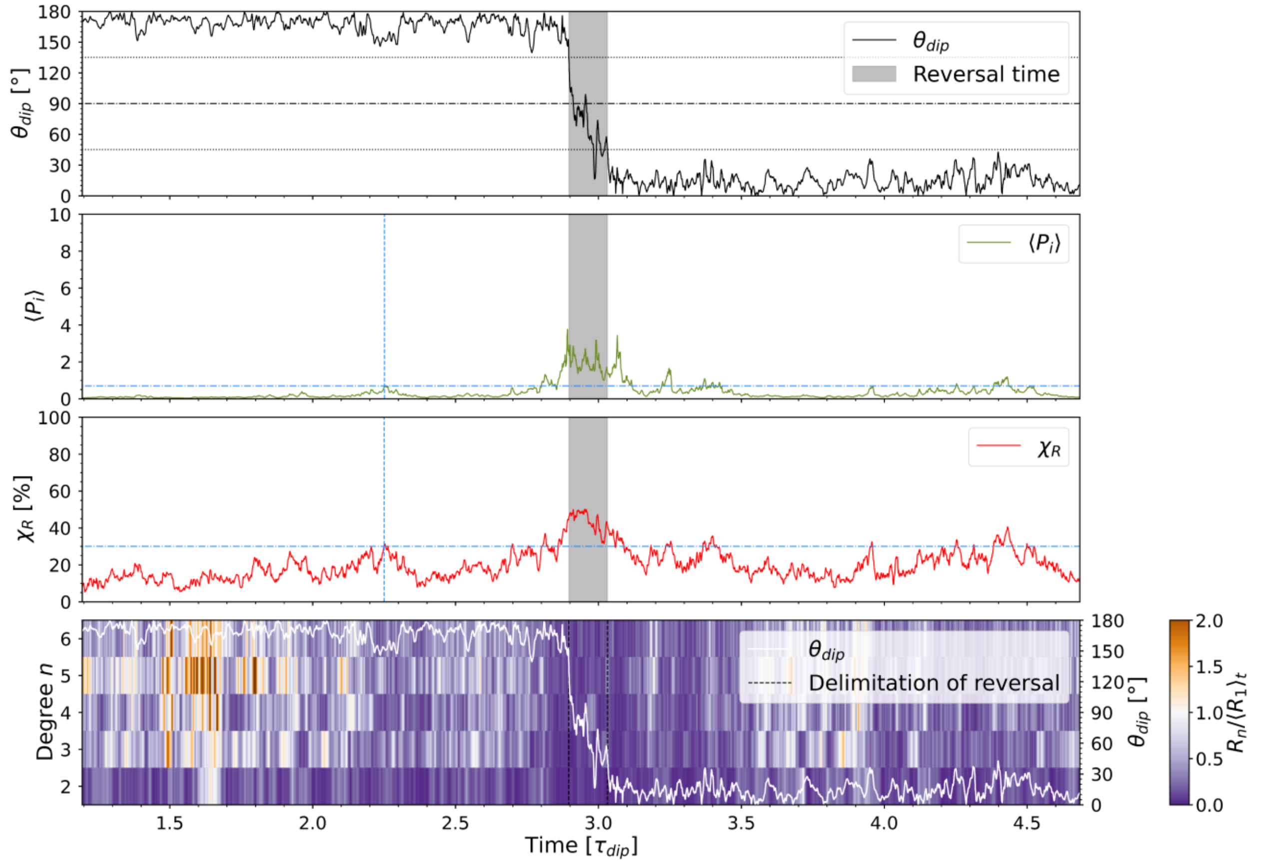
- Candidates peak during the event
- But no precursors

Results – Reversal models

Paleomagnetic field model:
Brunhes-Matuyama reversal

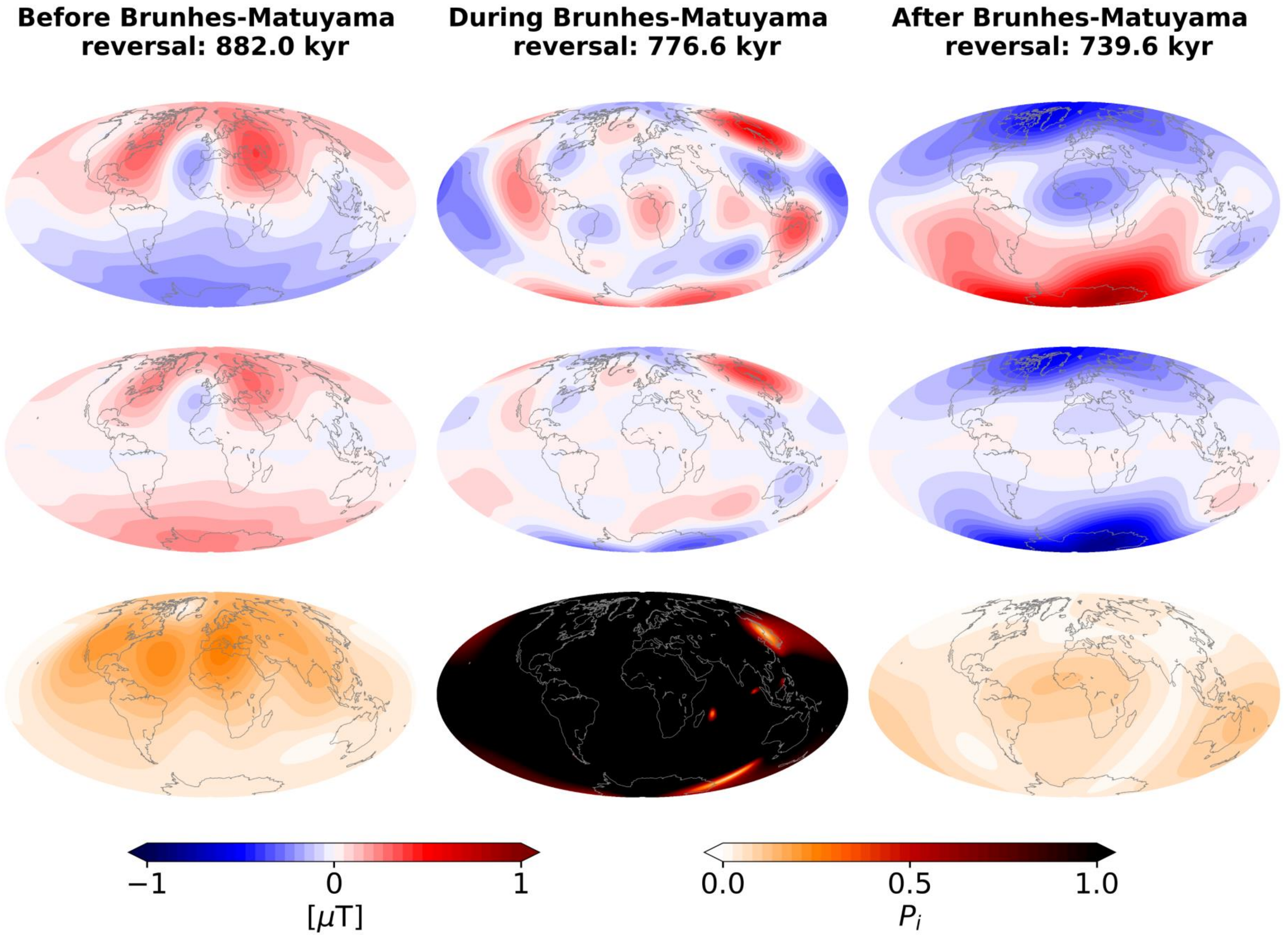


Numerical dynamo model
($Rm \sim 650$)



- Presence of precursors !
- 14 kyr before the paleomagnetic field reversal
- 25 (or 36) kyr before numerical dynamo reversal
- Dipole collapse/recovery asymmetry

Results – Field evolution during the Brunhes-Matuyama reversal



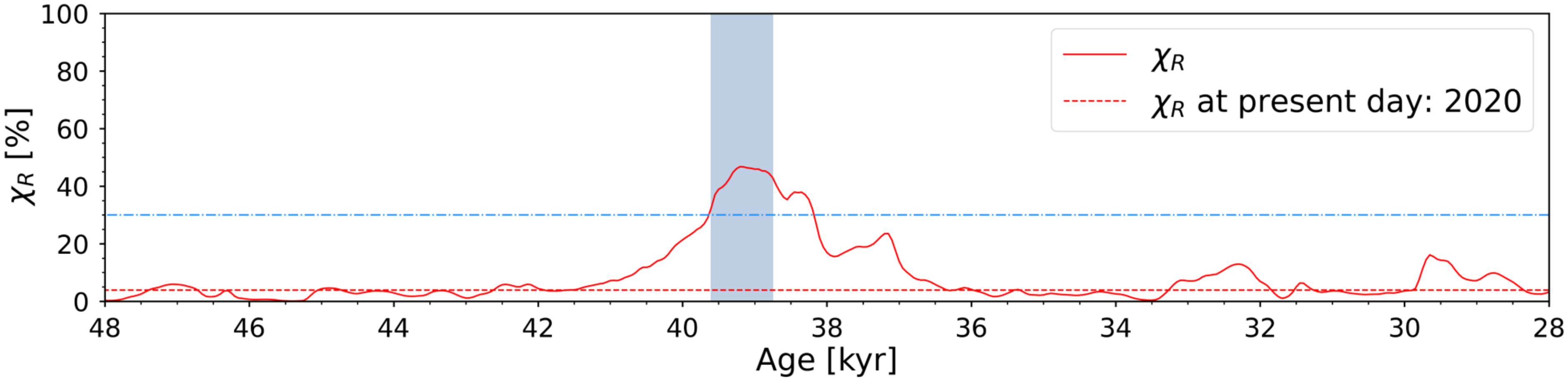
***B_r* on CMB:**
$g_1^0 > 0$ ⇒ non-dipolar ⇒ $g_1^0 < 0$

Contributions to axial dipole on CMB:
Dominant normal flux ⇒ balanced ⇒ dominant normal flux

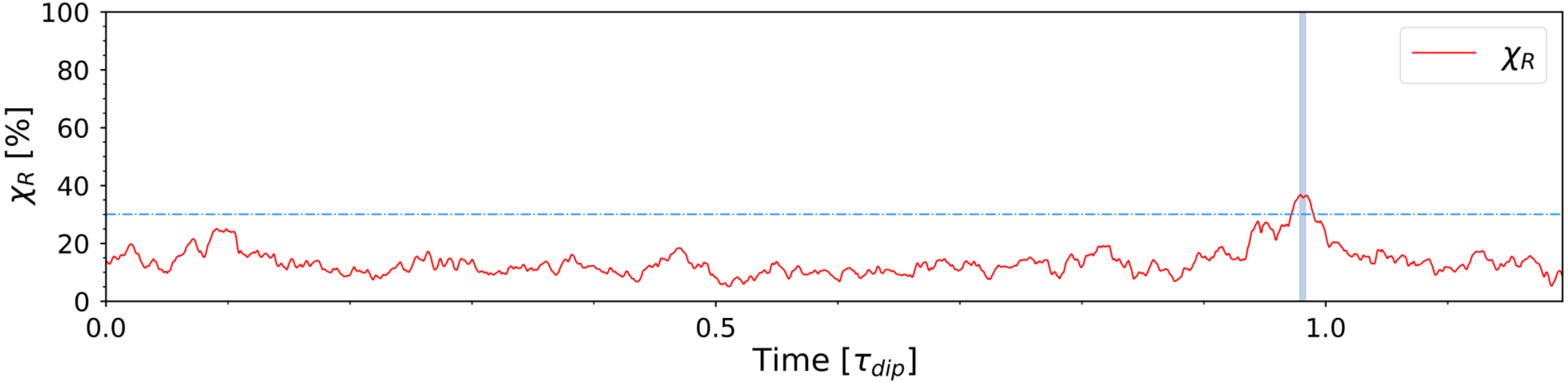
***P_i* on Earth's surface:**
Weak ⇒ strong ⇒ weak

Discussion – No precursors for excursions

Paleomagnetic field model



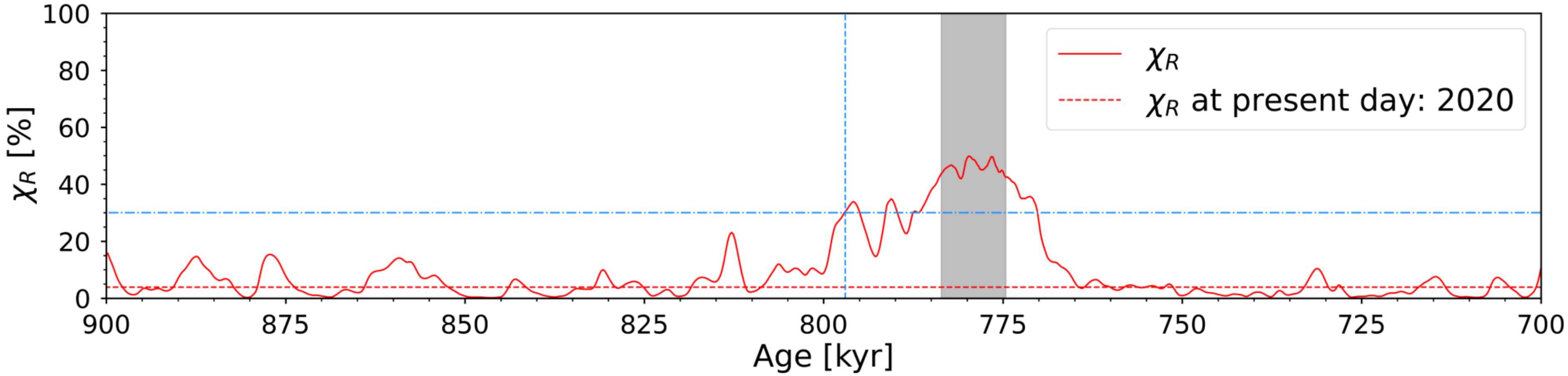
Numerical dynamo model



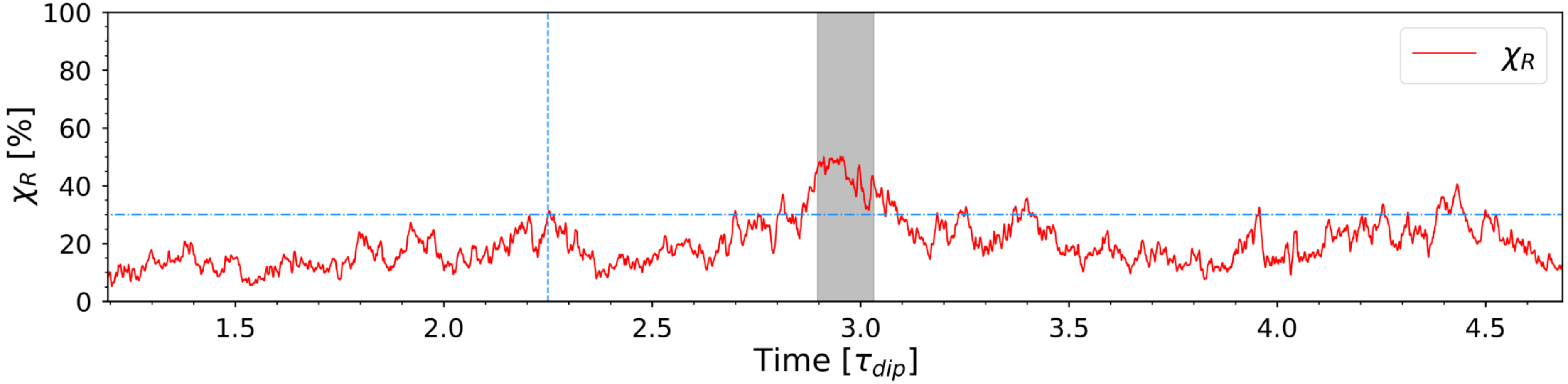
Holds for both paleomagnetic field models and numerical dynamo simulations

Discussion – Precursors for reversals

Paleomagnetic field model



Numerical dynamo model

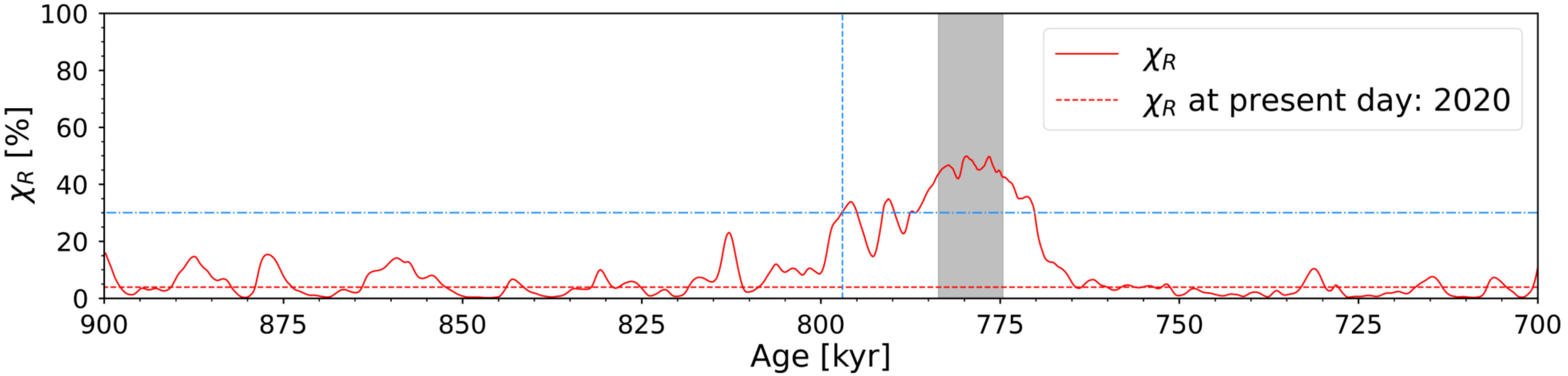


Common features:

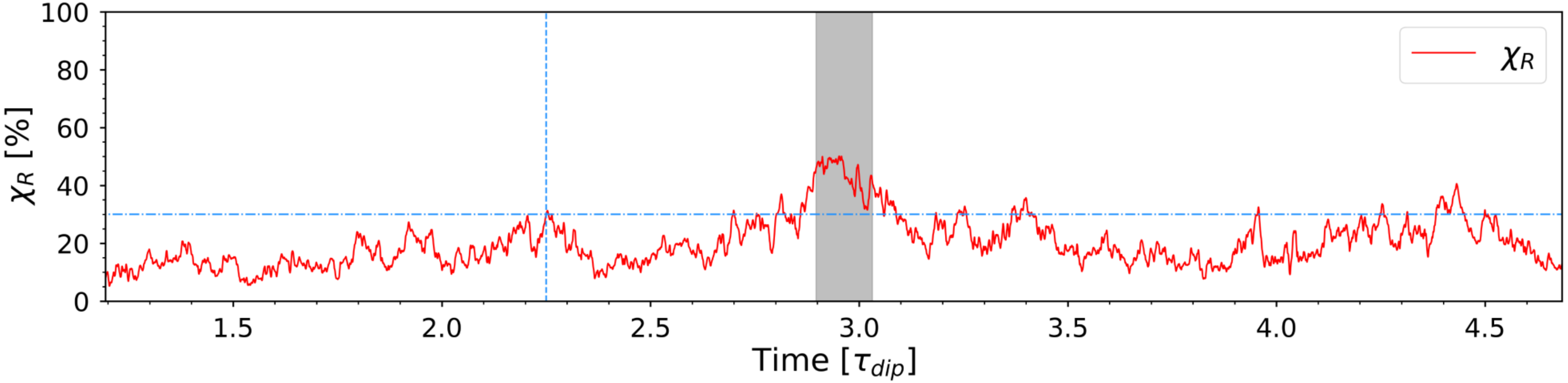
- Holds for both paleomagnetic field models and numerical dynamo simulations
- Success for all precursor candidates: spatial and spectral

Discussion – Precursors for reversals

Paleomagnetic field model



Numerical dynamo model

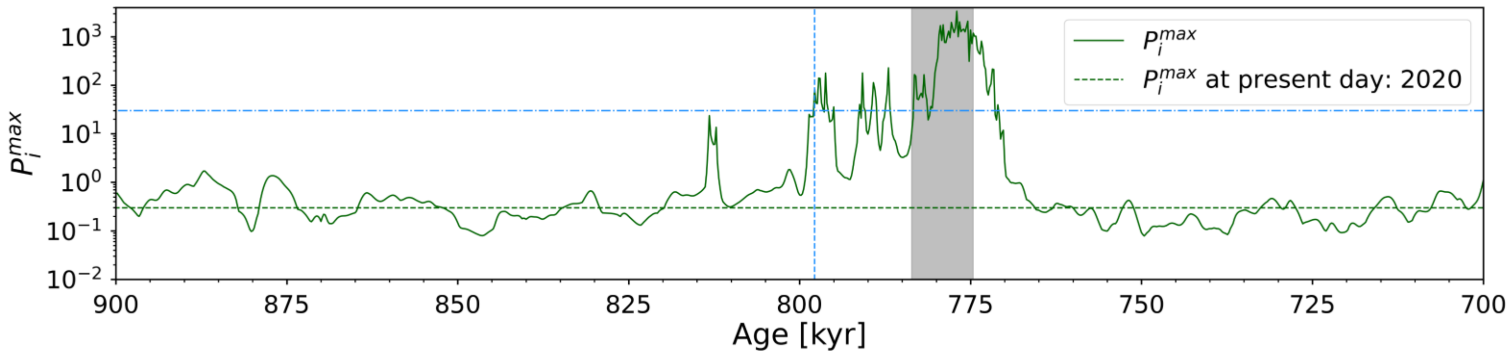


Different features:

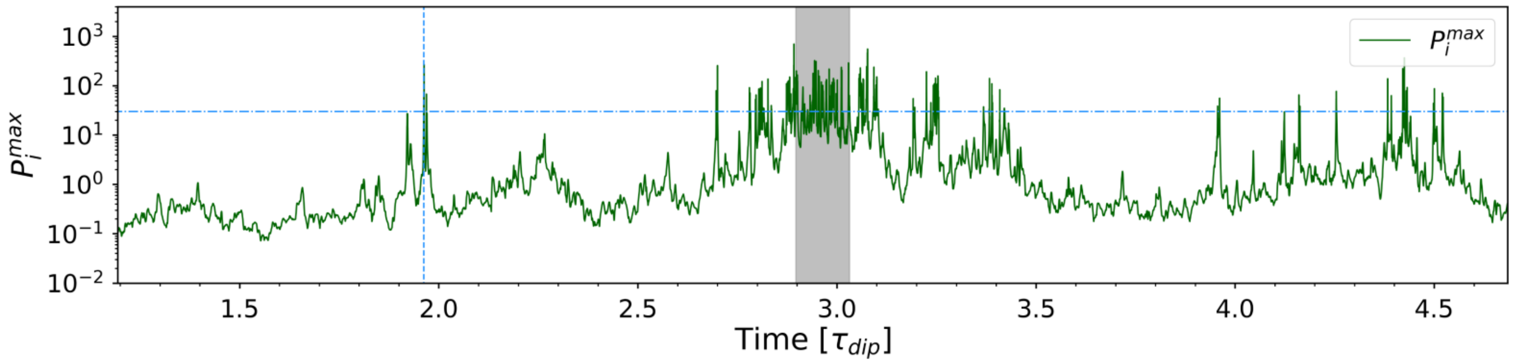
- Precursor time for **paleomagnetic field model**: 14 kyr
- Precursor time for **numerical dynamo simulation**: 25 or 36 kyr depending on candidates

Discussion – Precursors for reversals

Paleomagnetic field model



Numerical dynamo model

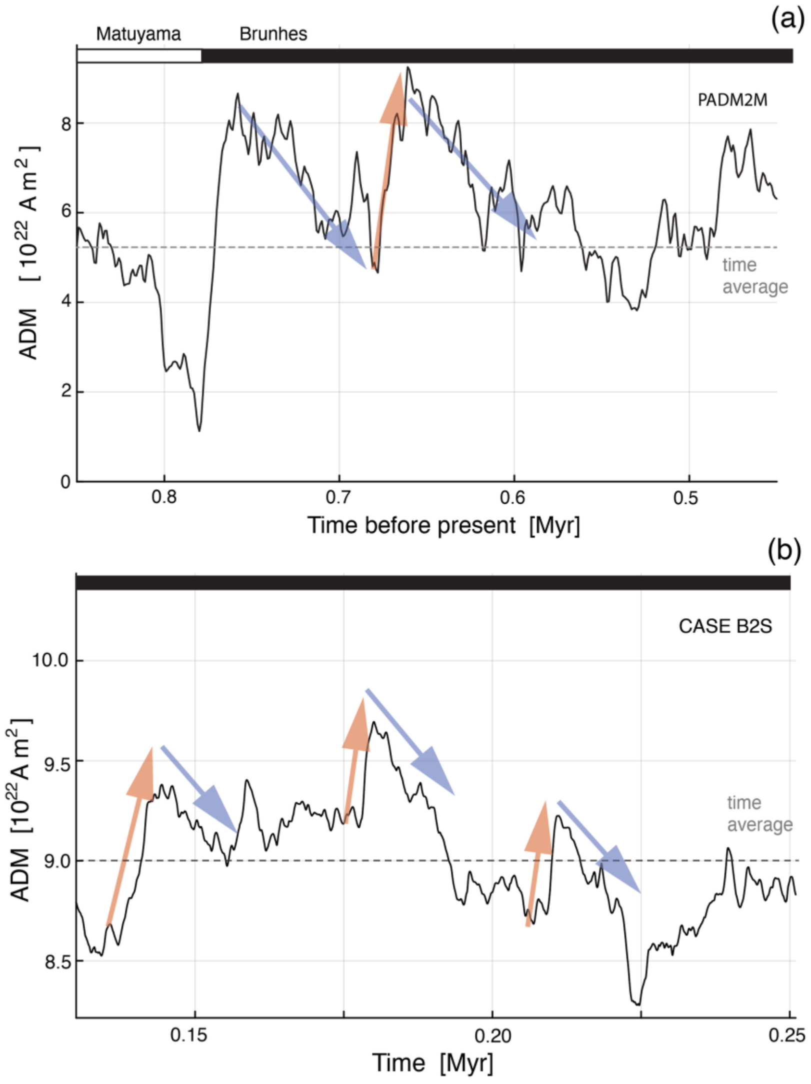


Model	GGFMB (reversal)	Numerical dynamo simulation (reversal)
$\langle P_i \rangle$	1,46	1,01
P_i^{max}	5,93	8,84
χ_R	1,13	1,04
χ_R^H	1,18	1,06
f_{dip}	1,50	1,05

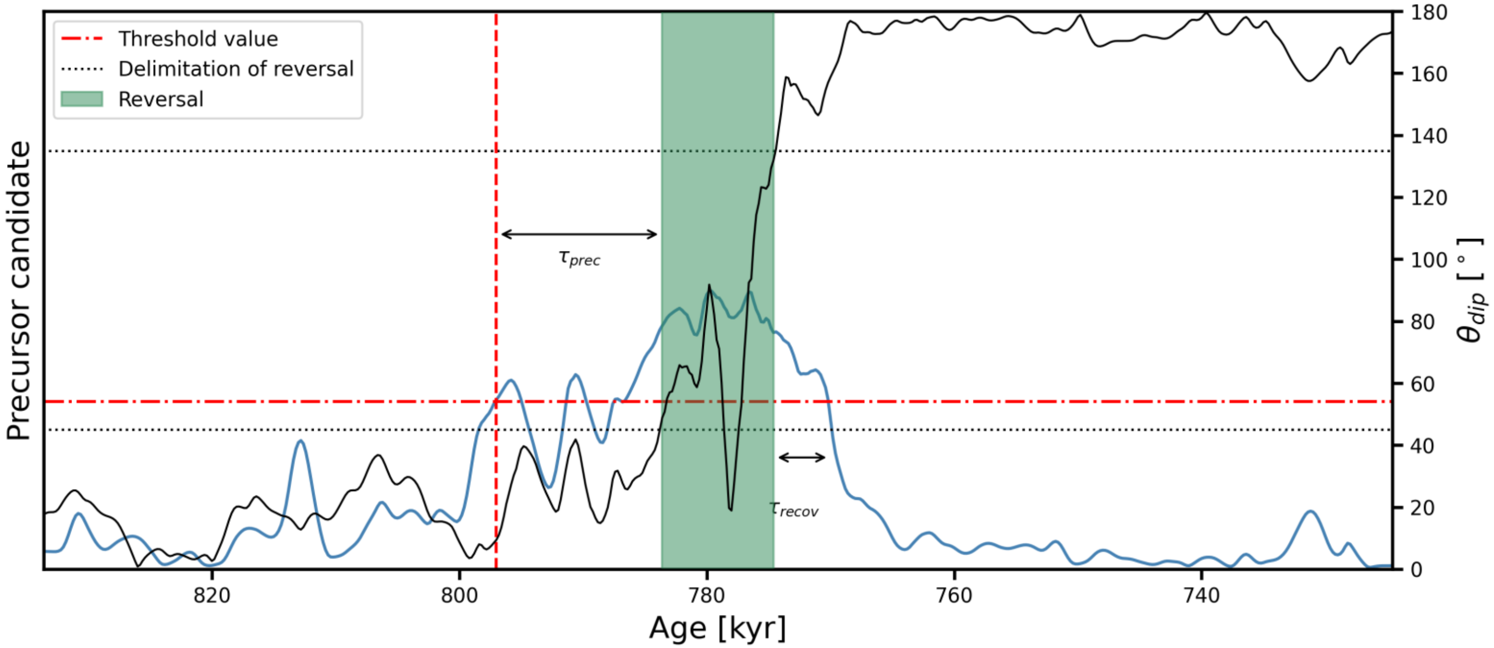
Amplitude:

- Largest for P_i^{max}
- Other precursors larger for paleomagnetic field model

Discussions – Dipole collapse/recovery asymmetry



Buffett (2023)



- $\tau_{prec} > \tau_{recov}$ for both paleomagnetic field model and numerical dynamo simulation
- Agreement with previous studies but at shorter timescales
- τ_{prec}/τ_{recov} slightly larger for paleomagnetic field model
- Reversal: kinematic disturbance from stable chron state

Conclusions

- **First study** which explores in details possible presence of precursors for reversals
- **Definition of the threshold value** should be improved (analysis of simulated dipole moment collapse events without reversals or excursions)
- **To increase the robustness of the results**, need more reversals from numerical dynamo simulations
- **If the presence of a precursor is confirmed**, give the physical mechanism