PERSISTENCE OF WEAK MAGNETIC CYCLES DURING SOLAR GRAND MINIMA PHASES

Sanghita Chandra, Chitradeep Saha,

Dibyendu Nandy

ASTRONOMICAL INSTITUTE OF THE ROMANIAN ACADEMY

Department of Physical Sciences

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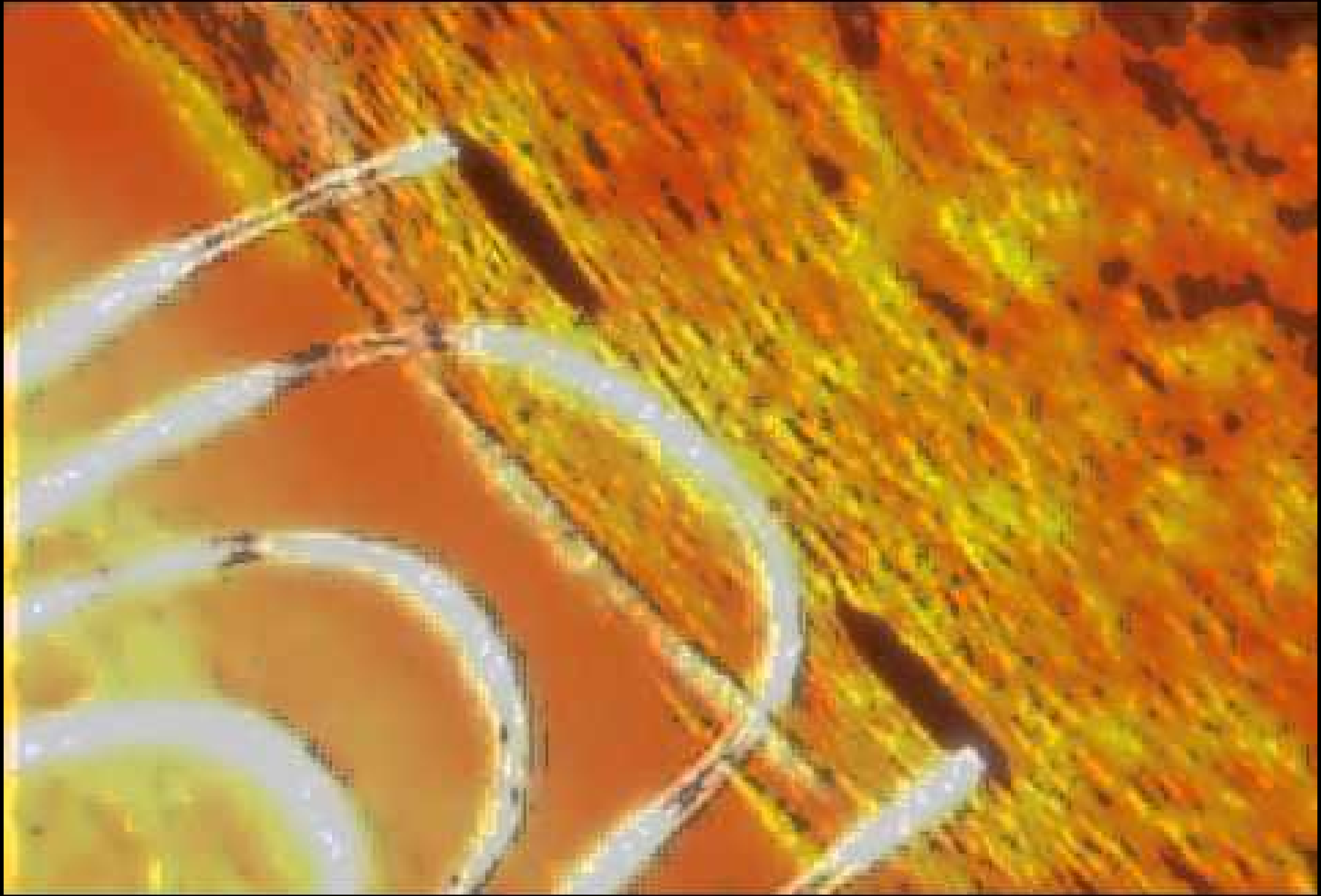
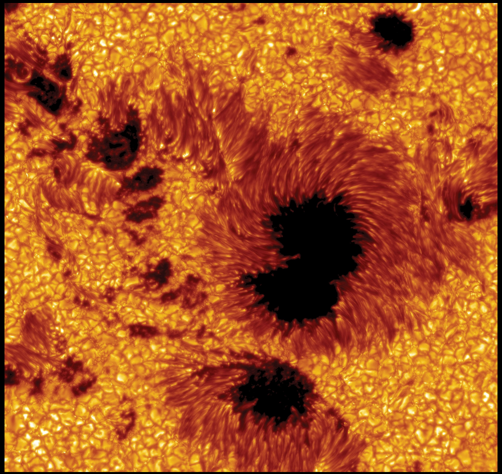
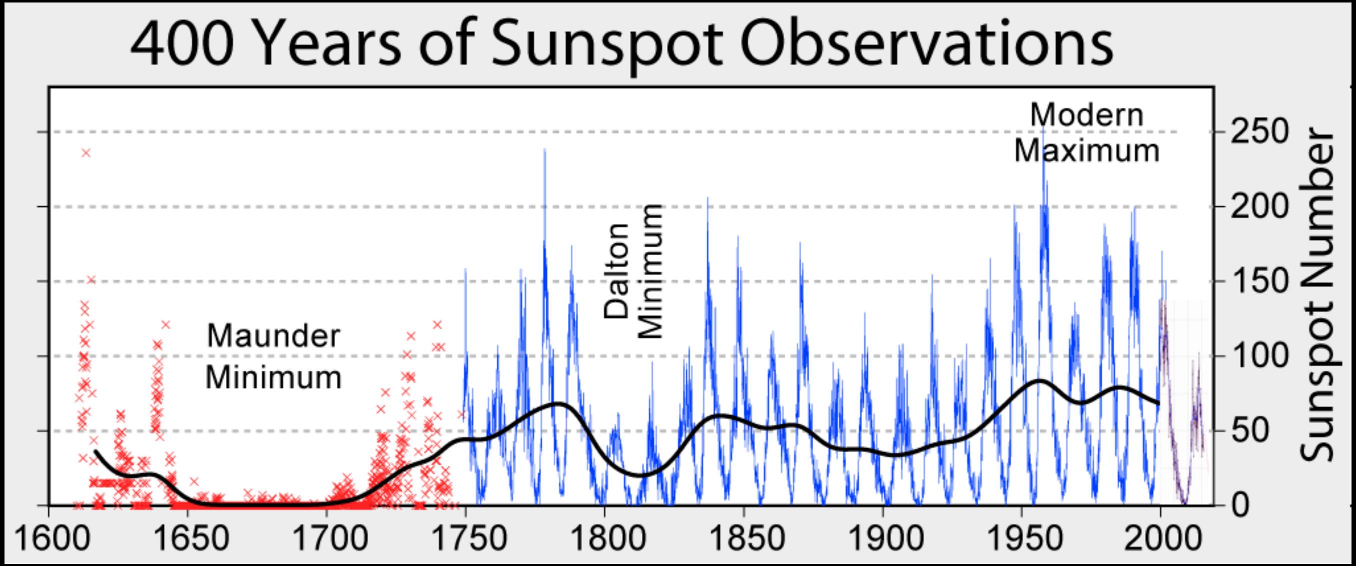




Credit: Encyclopedia Britannica

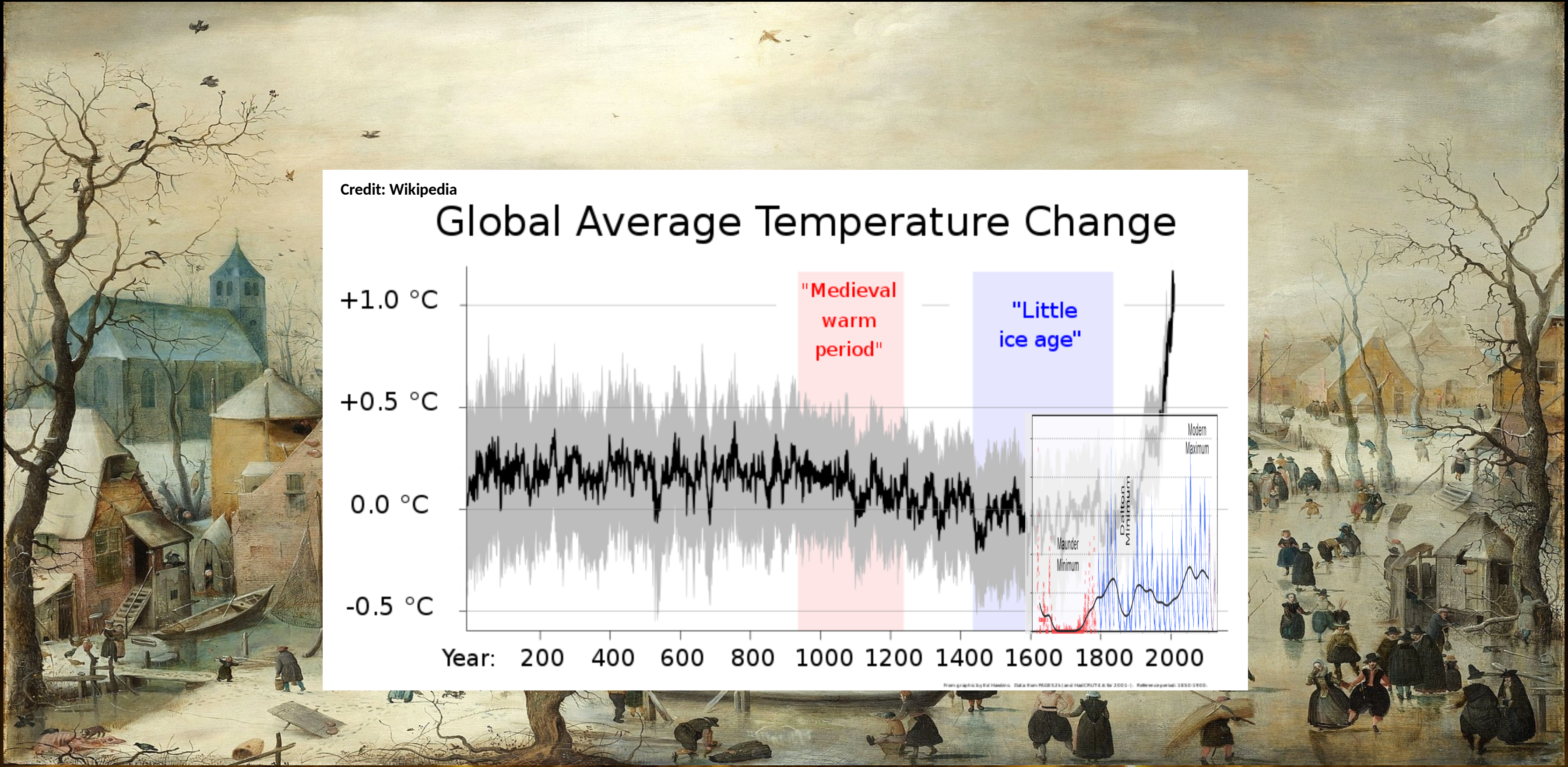
The Sun is a busy place, Magnetically speaking!



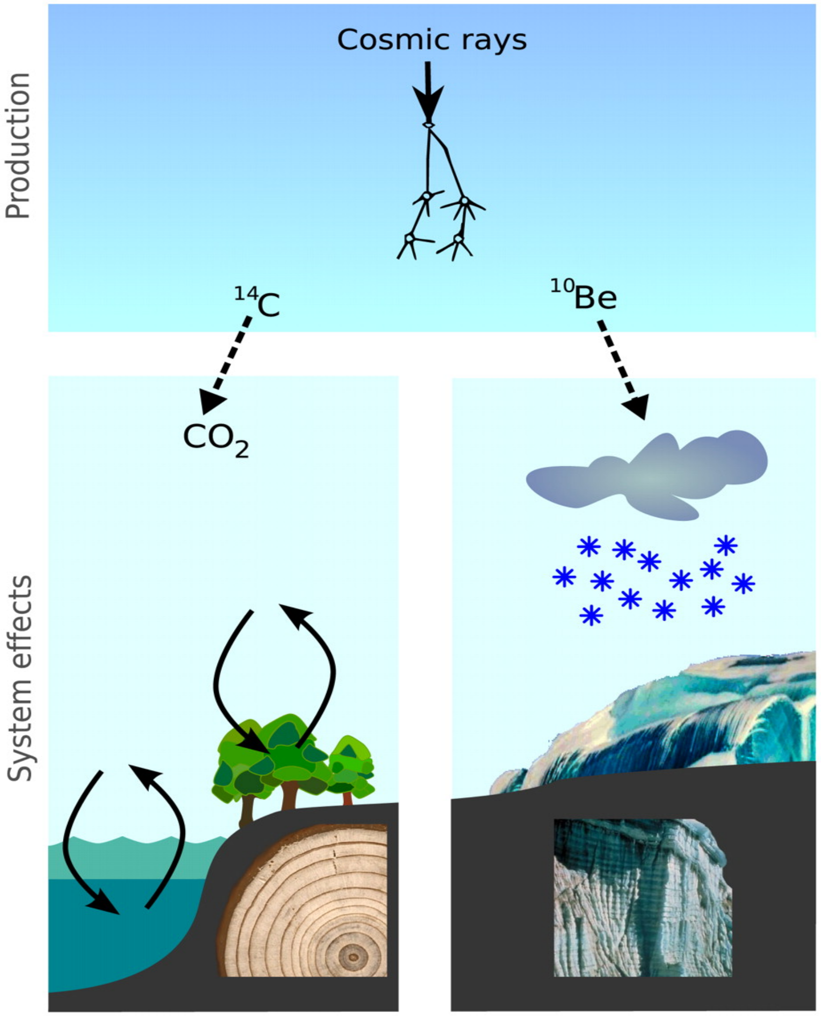
Credit: Wikipedia

Why study the quiescent phases of the **Sun**?

- The Sun is our primary source of energy and its activity modulates our space environment, space-based technologies and planetary atmospheres over short-to-long timescales *(Schrijver et al. 2015; Nandy et al. 2021)*. Grand minima are extreme activity phases accompanied by significant reduction in solar radiative, particulate and magnetic output.
- Studying long term solar activity is important as it is believed to drive planetary atmospheric dynamics related to climate. Extreme solar episodes such as the grand minima or maxima may impact terrestrial climate systems *(D. J. Easterbrook Solar Influences On Climate 2016)*.
- In the quiet Sun, magnetic features such as ephemeral regions (ERs) persist and play a role in modulating irradiance variations *(Solanki et al. A&A 2000, 2002; Krivova et al. A&A 2014)*. Whether these features persist during grand minima episodes and play a role in influencing the solar dynamo is an open question.



'Winter Landscapes with Skaters'
Art by Hendrick Avercamp, 1608 AD



Steinhilber et al. PNAS 2012

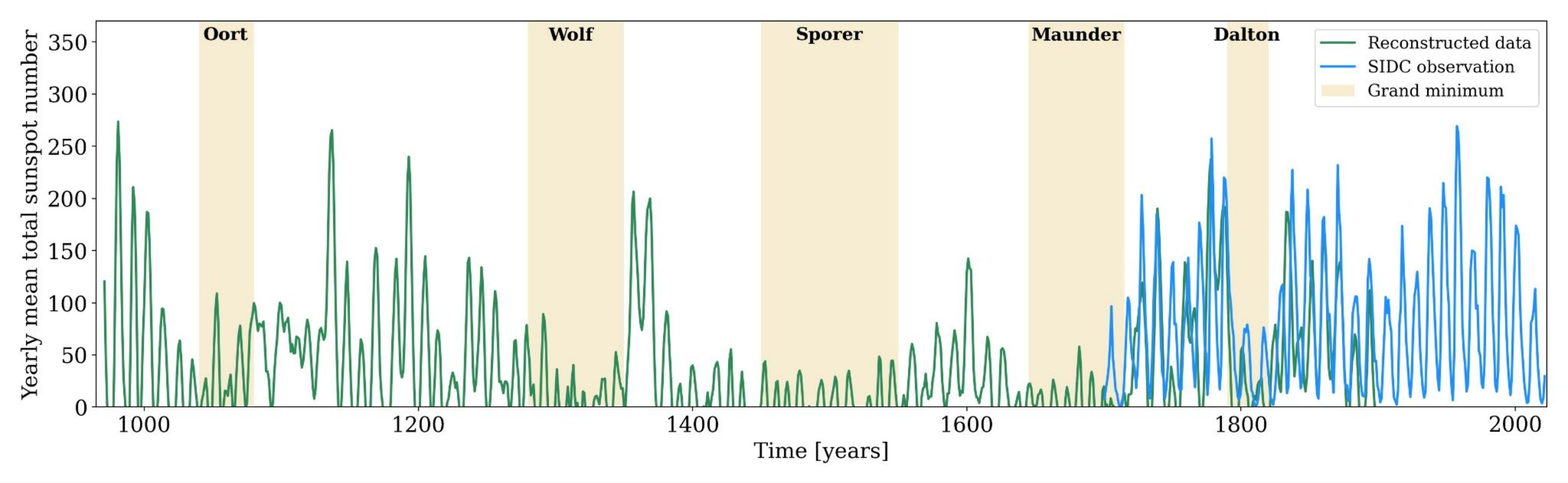
Cosmic ray particles, mostly produced by supernova explosions travel through space to reach the Earth.

The shielding action of the **geomagnetic field** and the **solar magnetic field** governs the amount of cosmic ray flux reaching the Earth.

^{10}Be and ^{14}C are produced in the Earth's atmosphere by nuclear reactions of cosmic ray particles with atmospheric nitrogen and oxygen

Sometimes the Sun slips into a ***quiescent*** phase — prolonged reduction in sunspot eruptions ⟶ **Grand Minima**

Millennium scale reconstruction of the solar activity using cosmogenic isotope abundance data



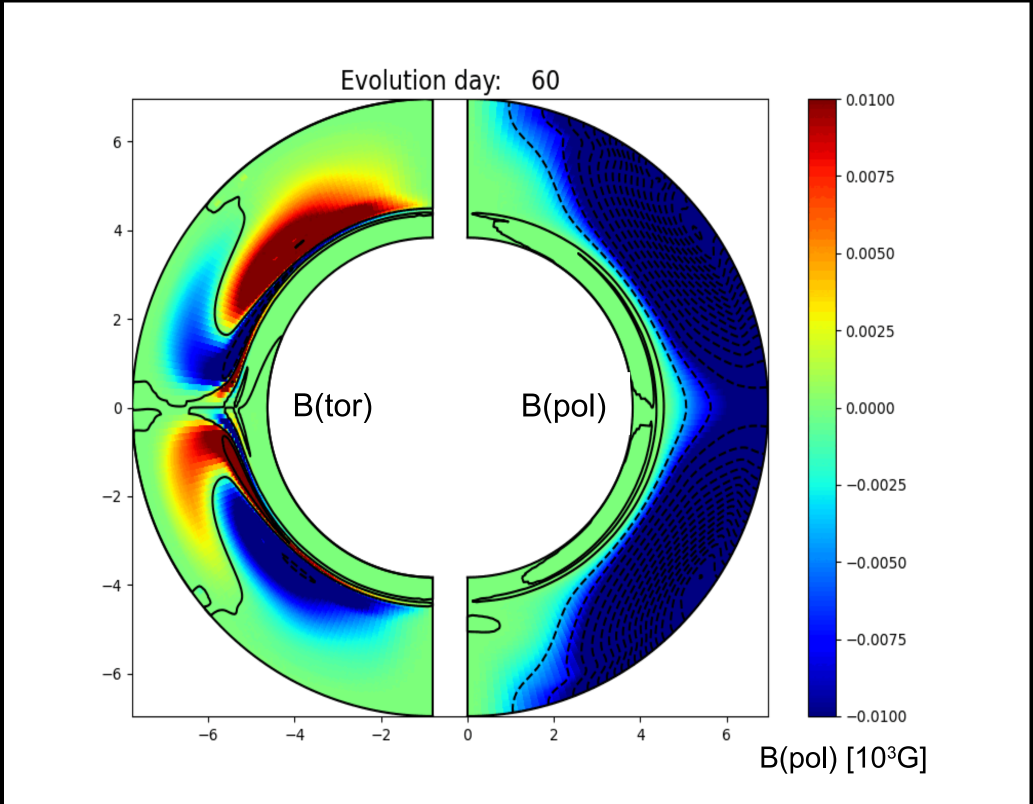
VizieR Online Data Catalog: 1000-year sunspot series (Usoskin et al., 2021)

Magnetic field generation in the Sun (Solar dynamo): SURYA model

The global magnetic field of the Sun has two mutually coupled components -- the poloidal and toroidal fields.

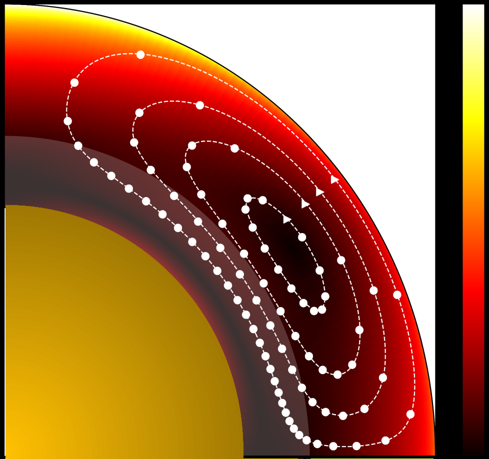
$$\mathbf{B} = B(r,\theta)e_\phi + \nabla \times [A(r,\theta)e_\phi]$$

The dynamo is driven by non-linear, stochastically forced mean field and Babcock-Leighton poloidal sources.



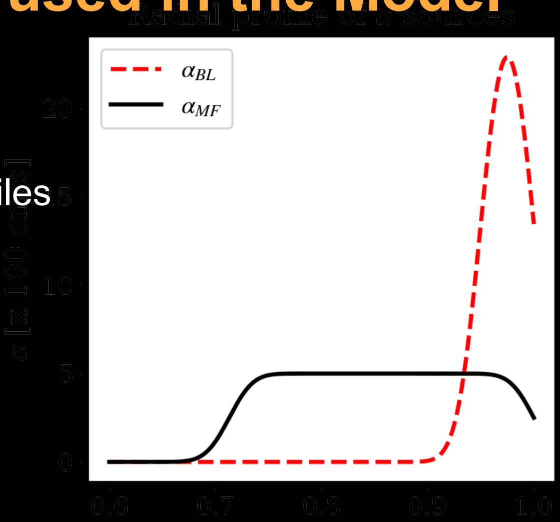
Nandy and Choudhuri *Science (2002)*, Chatterjee et al. *A&A (2004)*

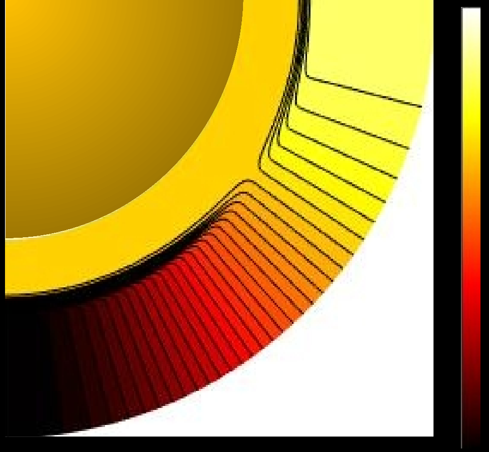
Spatial Distribution of Various Profiles used in the Model



Advection Profile

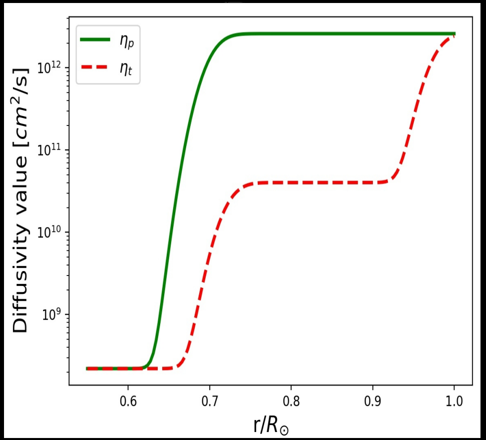
Source profiles



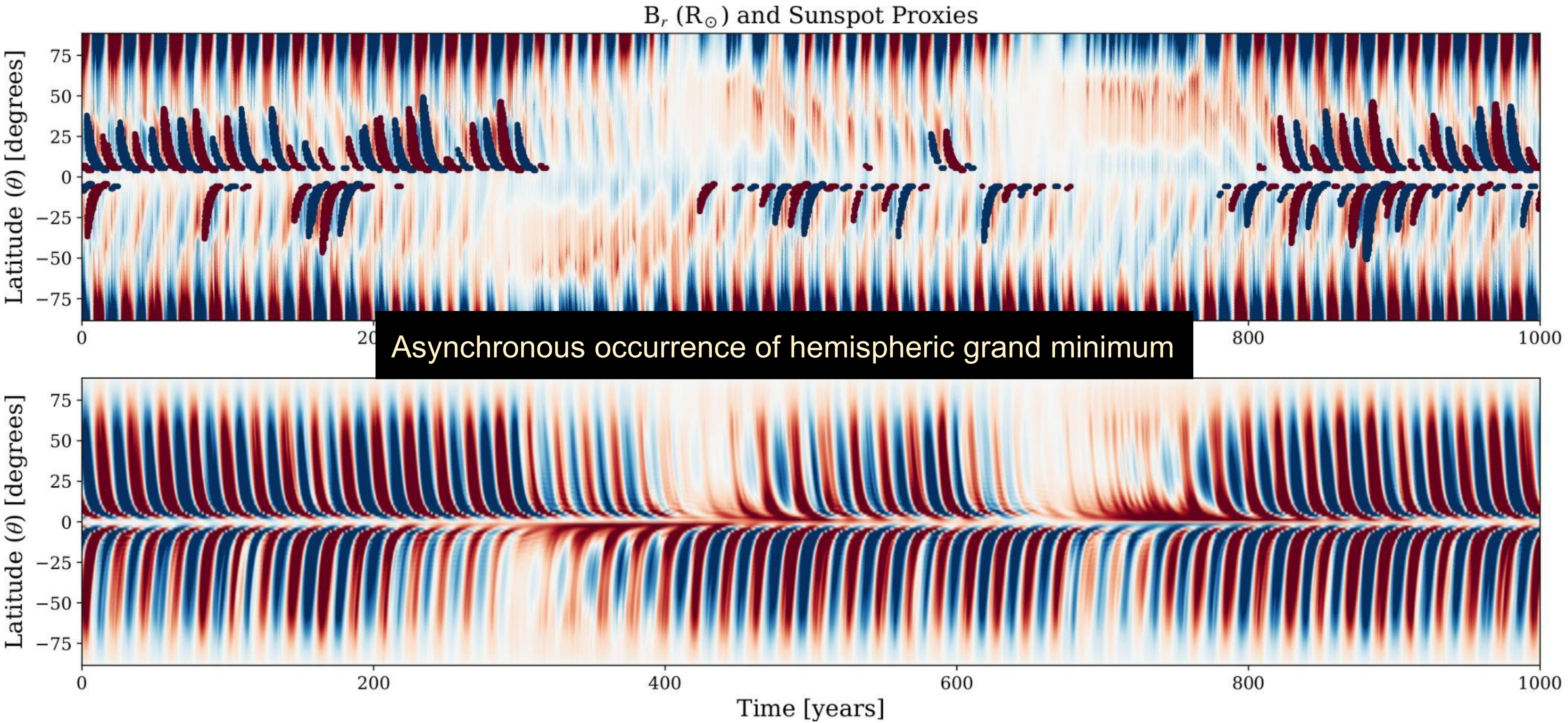


Toroidal field (B_ϕ)
Induction Profile

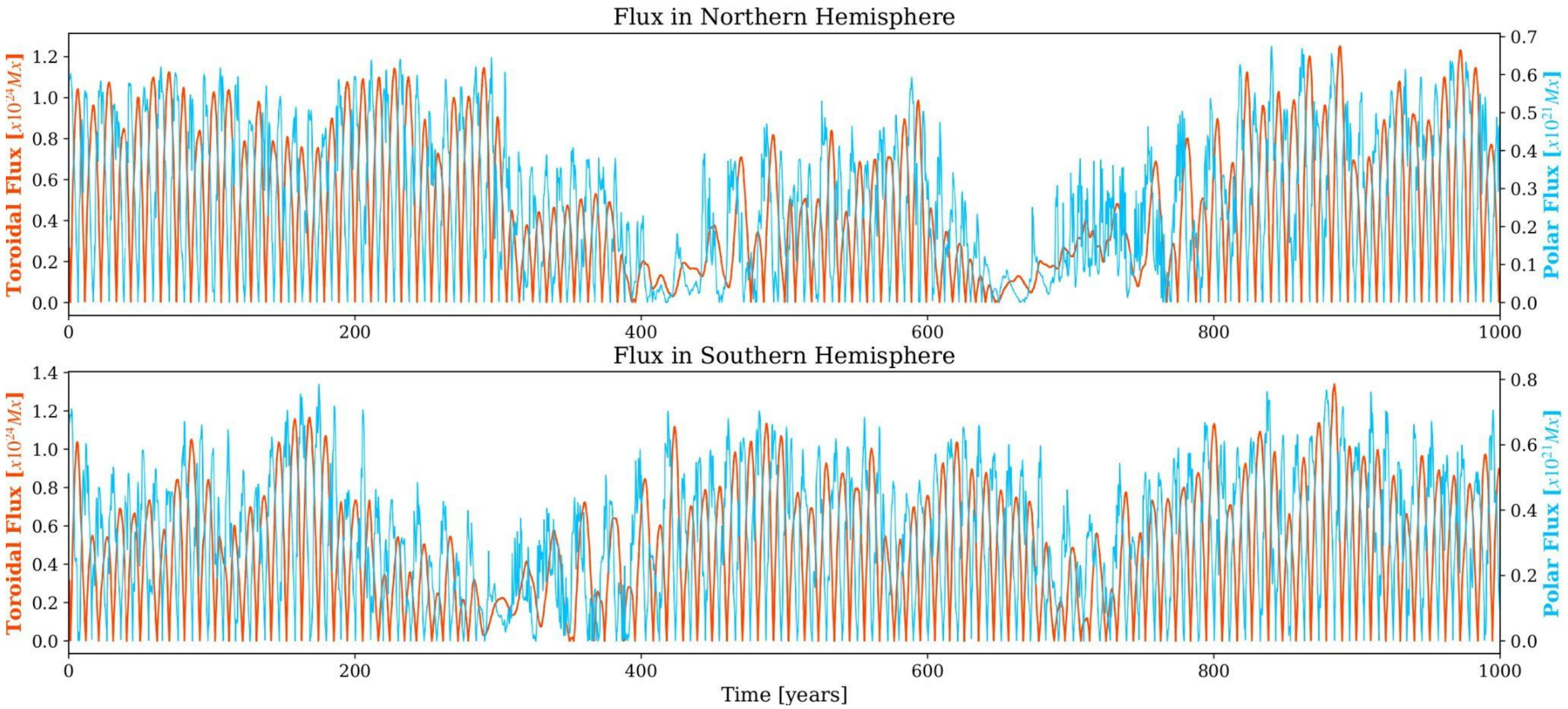
Diffusion profiles



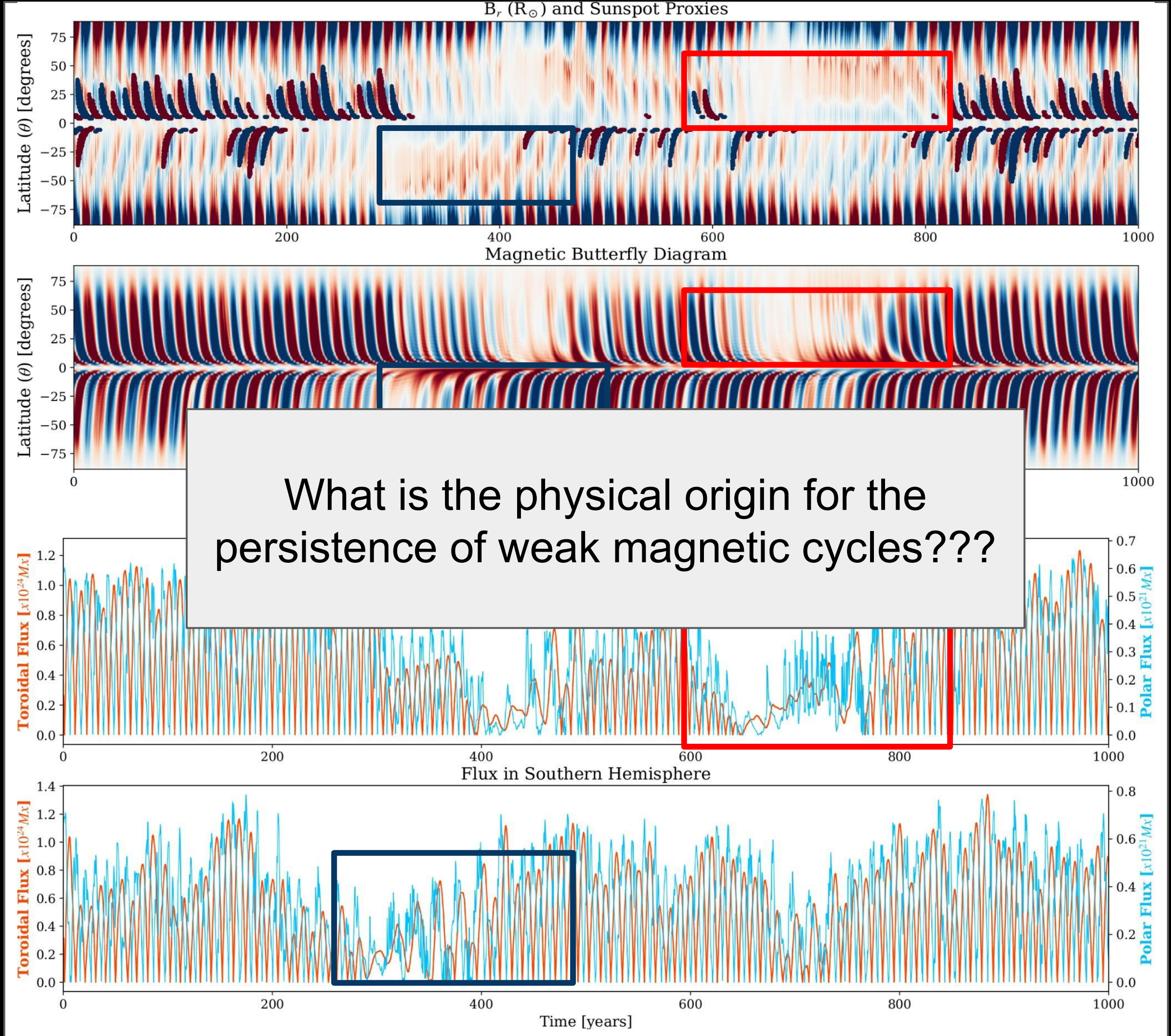
Nandy and Choudhuri *Science (2002)*
Chatterjee et al. *A&A (2004)*



Asynchronous occurrence of hemispheric grand minimum



Flux in Northern Hemisphere
Toroidal Flux [$x10^{24}Mx$]
Polar Flux [$x10^{21}Mx$]
Flux in Southern Hemisphere
Toroidal Flux [$x10^{24}Mx$]
Polar Flux [$x10^{21}Mx$]
Time [years]



What is the physical origin for the persistence of weak magnetic cycles???

We perform long term simulations using the solar dynamo model inspired by Passos et al. A&A (2014), Hazra and Nandy MNRAS (2019)

Sunspot eruptions stops in certain phases both in the Northern and Southern Hemispheres

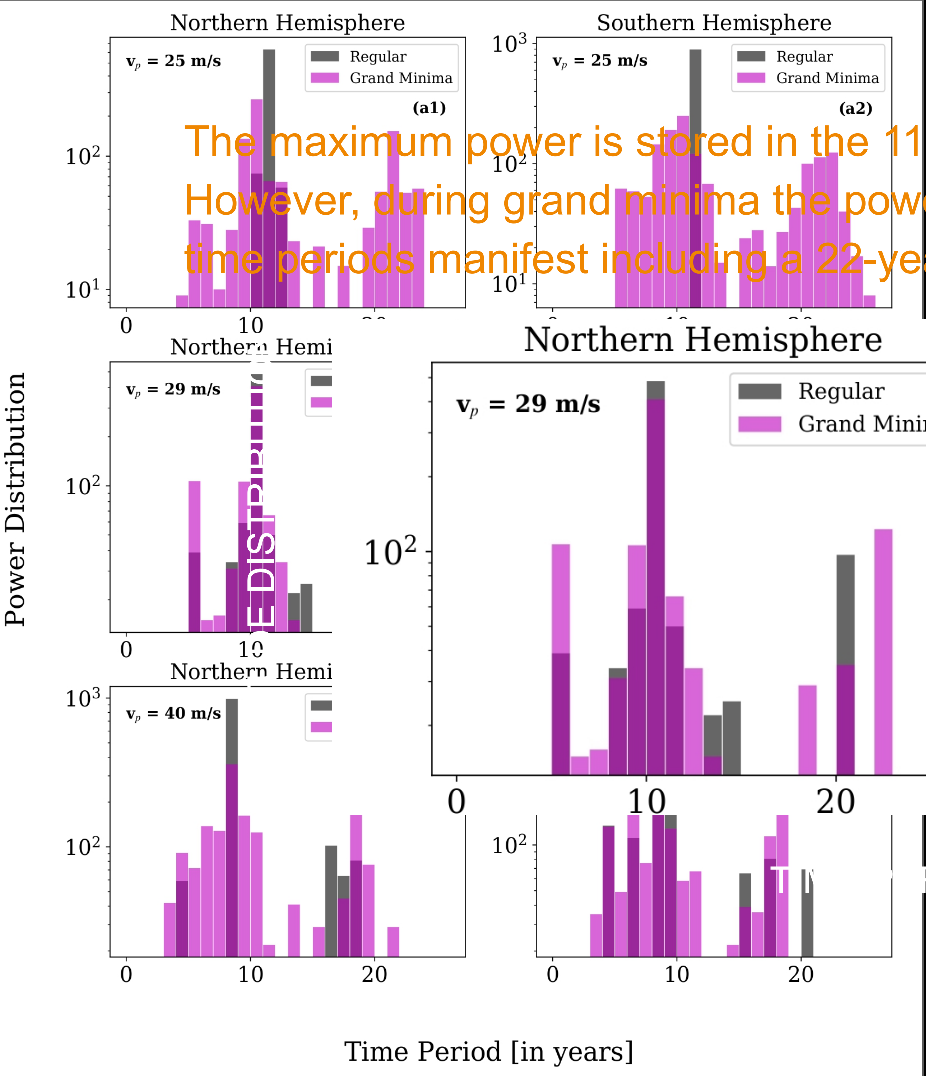
⇩

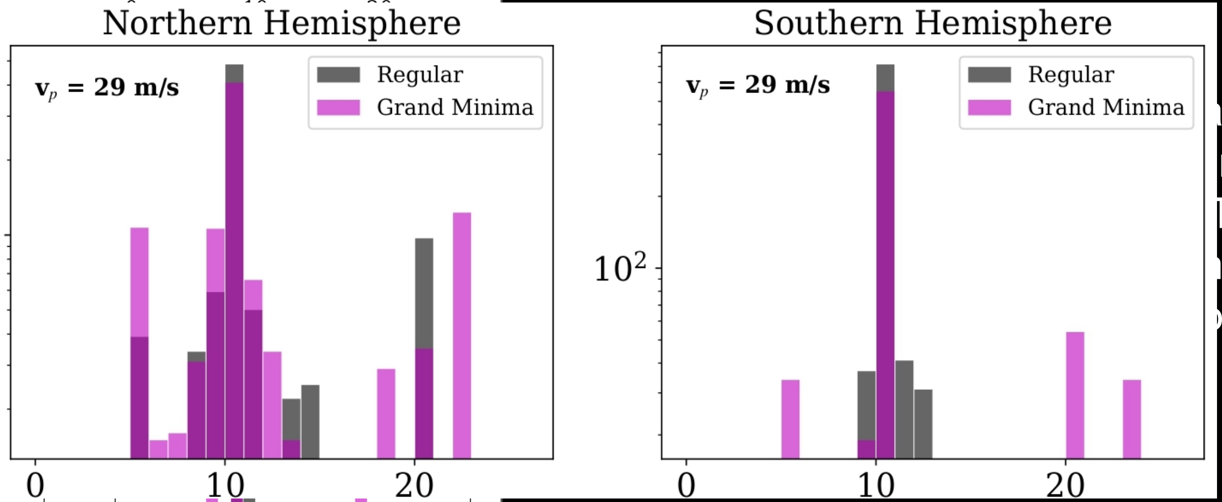
Although regular sunspot eruptions stop, we see persistent weak magnetic activity in the poloidal and toroidal fields.

⇩

We further analyse the periodicities during grand minima episodes.

The maximum power is stored in the 11-year period corresponding to the solar cycle. However, during grand minima the power in 11-years gets reduced and multiple other time periods manifest including a 22-year period and lower time periods.





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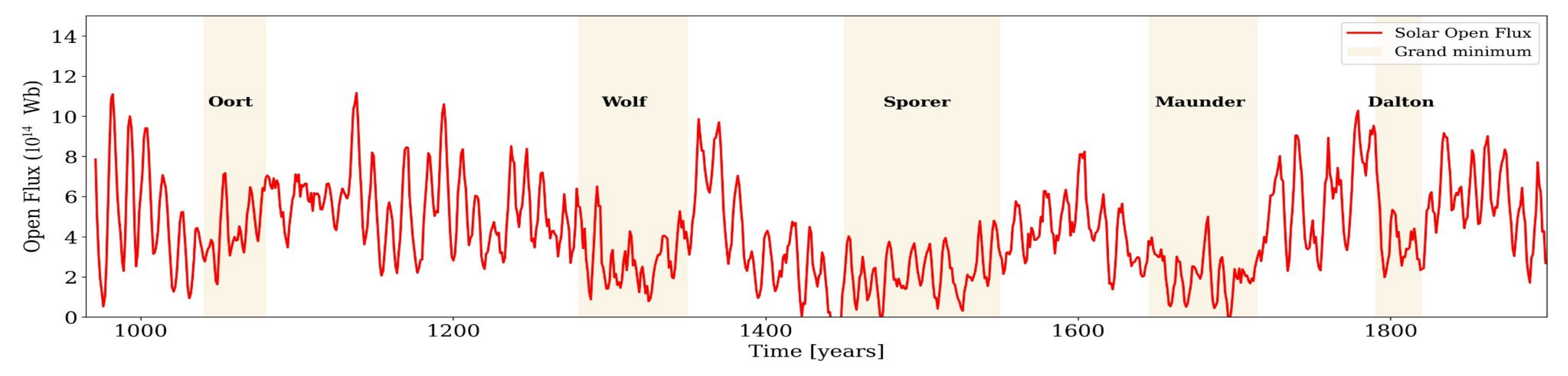
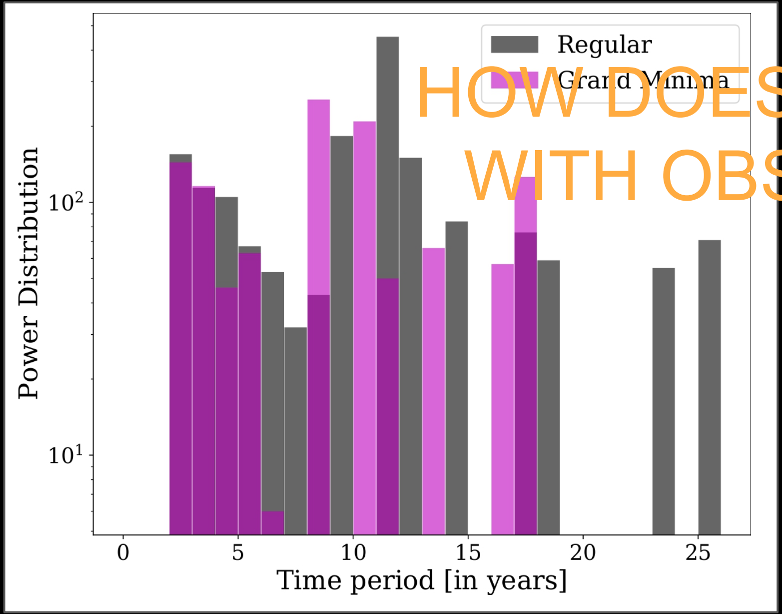
Saha C., Chandra S., Nandy D., MNRAS Lett. Vol 517 (Nov 2022)



Usoskin et al., 2021



HOW DOES THIS COMPARE WITH OBSERVATIONS??

On analysing reconstructed open polar flux data (*VizieR Online Data Catalog,* 2021), we find a similar redistribution of power across different timescales. The 11-year periodicity becomes less prominent while high frequency cycles manifest.

Saha C., Chandra S., Nandy D., MNRAS Lett. Vol 517 (Nov 2022)

The Takeaways

- Meridional circulation and a weak mean field α in the SCZ can sustain weak, magnetic cycles in the large-scale polar field amplitude even during grand minima.
- Specifically, our simulations reveal high frequency cycles in the solar convection zone, which are causally connected to the meridional circulation timescales.
- Periods around 22 years manifest during grand minima episodes, which we attribute to the fact that the last dominant polarity of the polar field before entry into grand minima phases dominates with a jump of one cycle during the low activity mode.
- Analysis of solar open flux reconstruction hints at the presence of similar periodic trends, lending independent support to our results.

Acknowledgements:

Sanghita Chandra: chandra@mps.mpg.de

@SanghitaChandra

Persistence of Weak Magnetic Cycles During Solar Grand Minima Episodes