PERSISTENCE OF WEAK MAGNETIC CYCLES DURING SOLAR GRAND MINIMA PHASES

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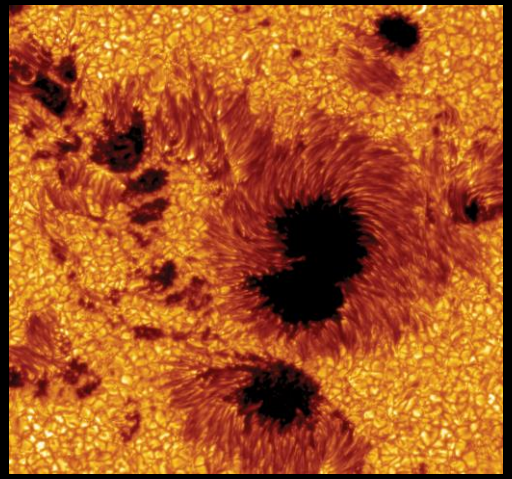
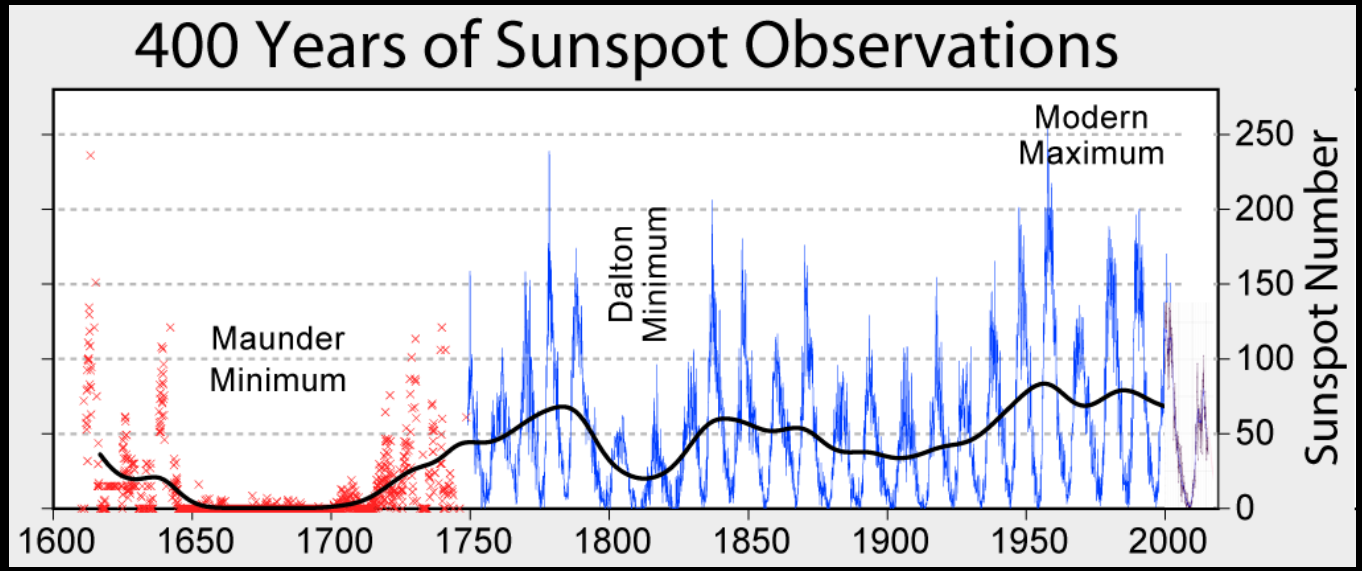


Credit: Encyclopedia Britannica

The Sun is a busy place,
Magnetically speaking!



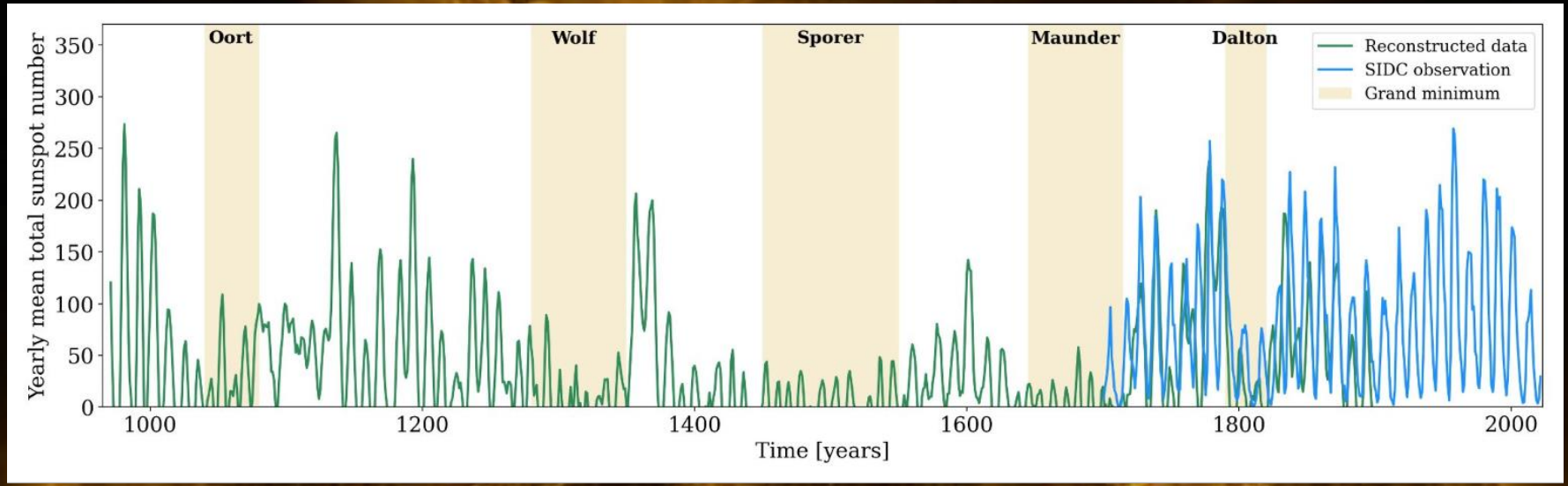
Credit: Wikipedia

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.

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



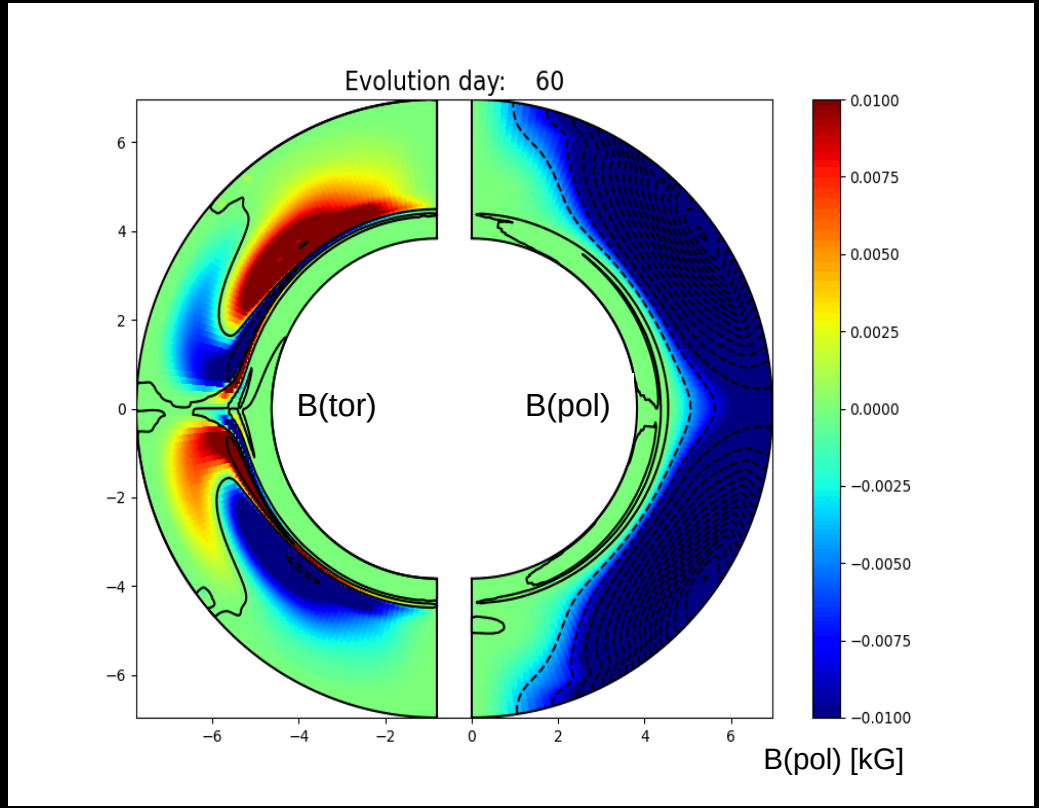
VizieR Online Data Catalog: 1000-year sunspot series (Usoskin et al., 2021)

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

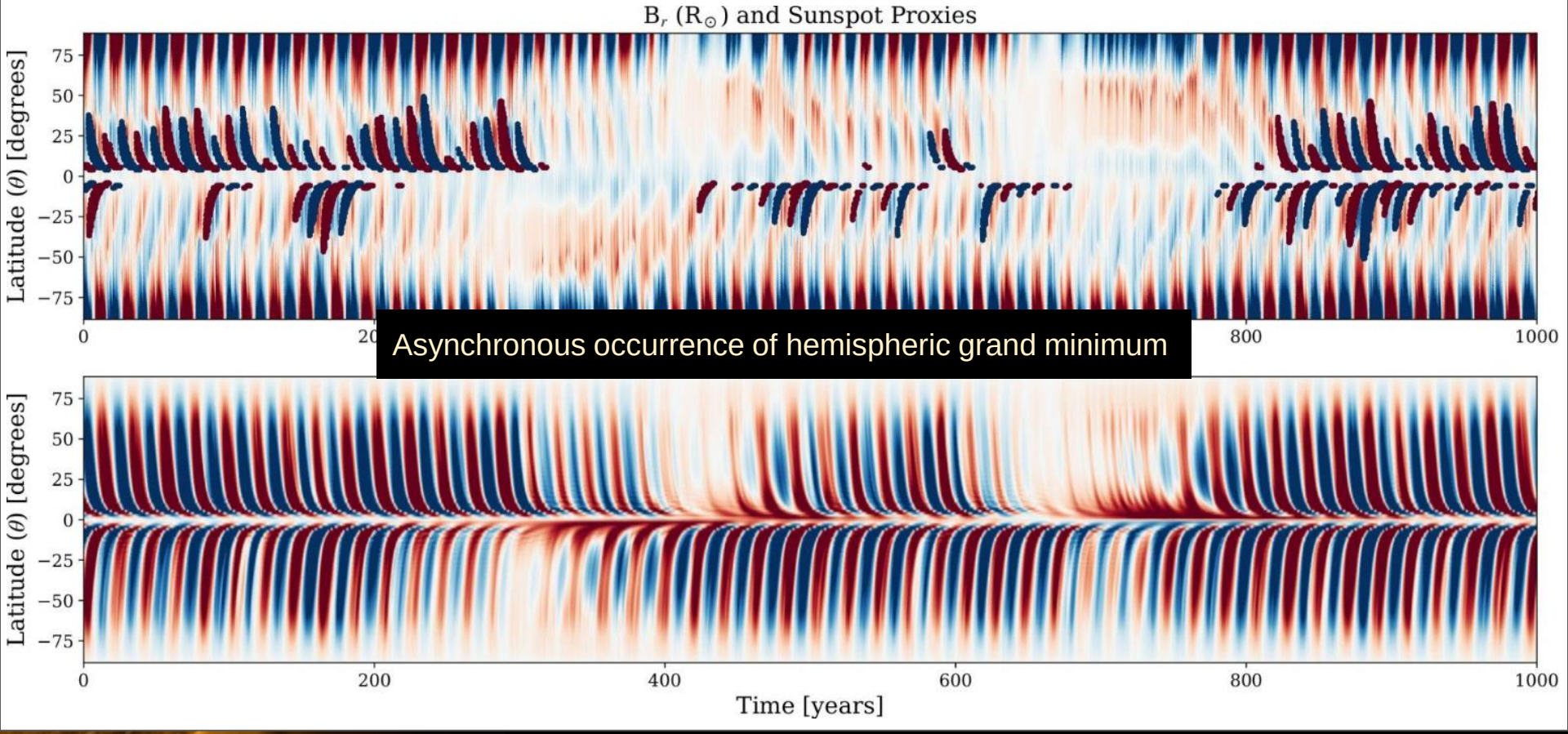
The global magnetic field of the Sun has two mutually coupled components -- the poloidal and toroidal fields.

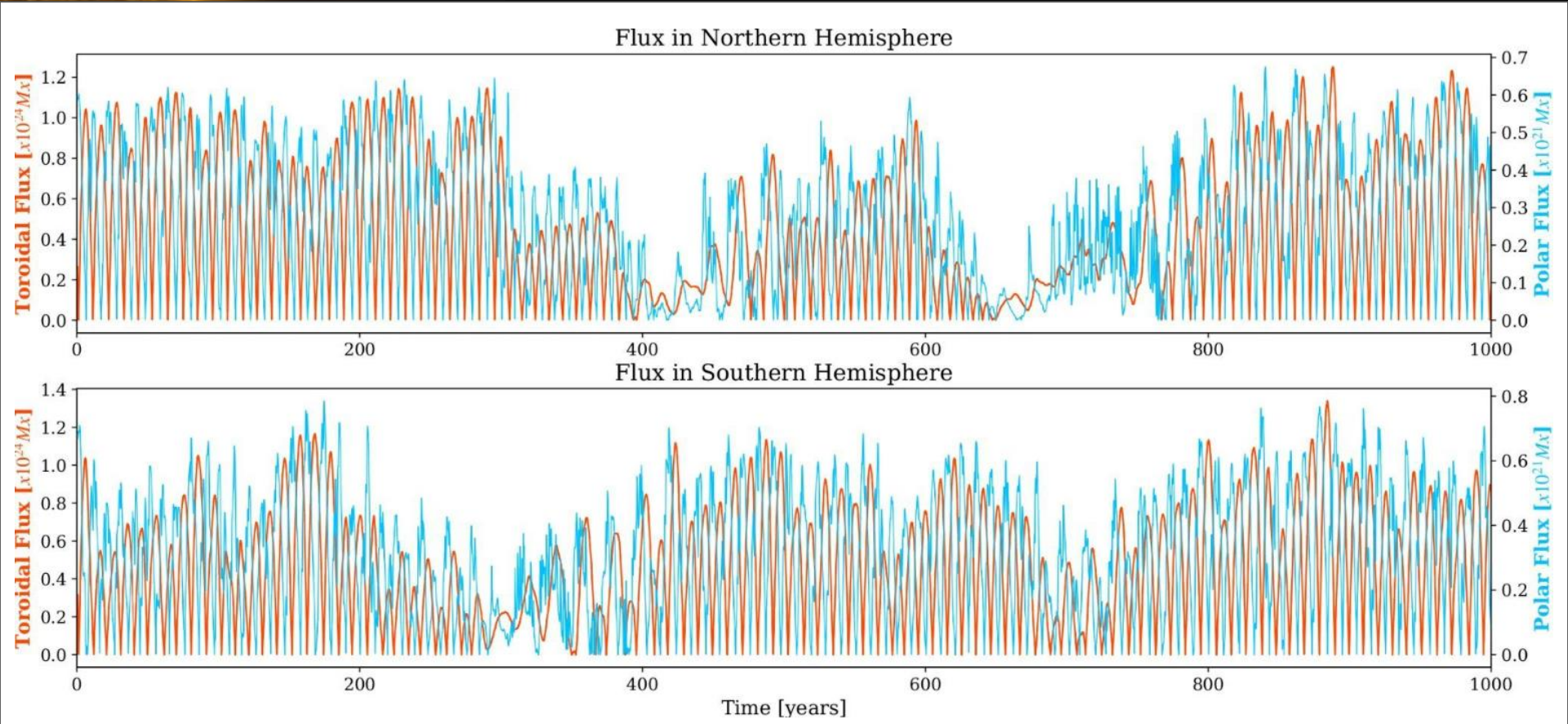
$$\mathbf{B} = B(r,\theta)e_\phi + \nabla \times [A(r,\theta)e_\phi]$$

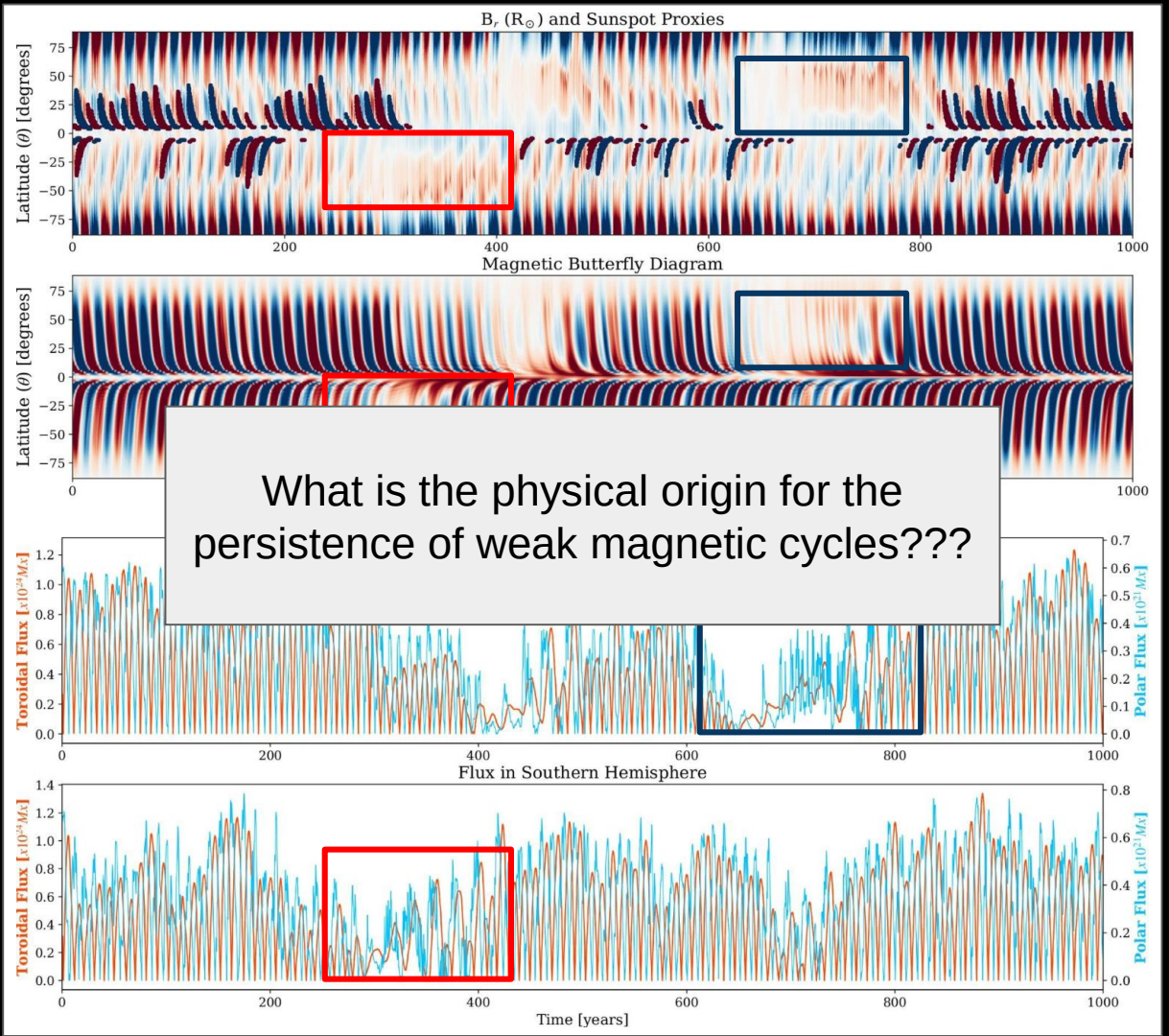
The dynamo is driven by non-linear, stochastically forced mean field and Babcock-Leighton poloidal sources.



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


B_r ($R_\odot$) and Sunspot Proxies
Latitude (θ) [degrees]
75
50
25
0
−25
−50
−75
0
800
1000
Asynchronous occurrence of hemispheric grand minimum
Latitude (θ) [degrees]
75
50
25
0
−25
−50
−75
0
200
400
600
800
1000
Time [years]


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]

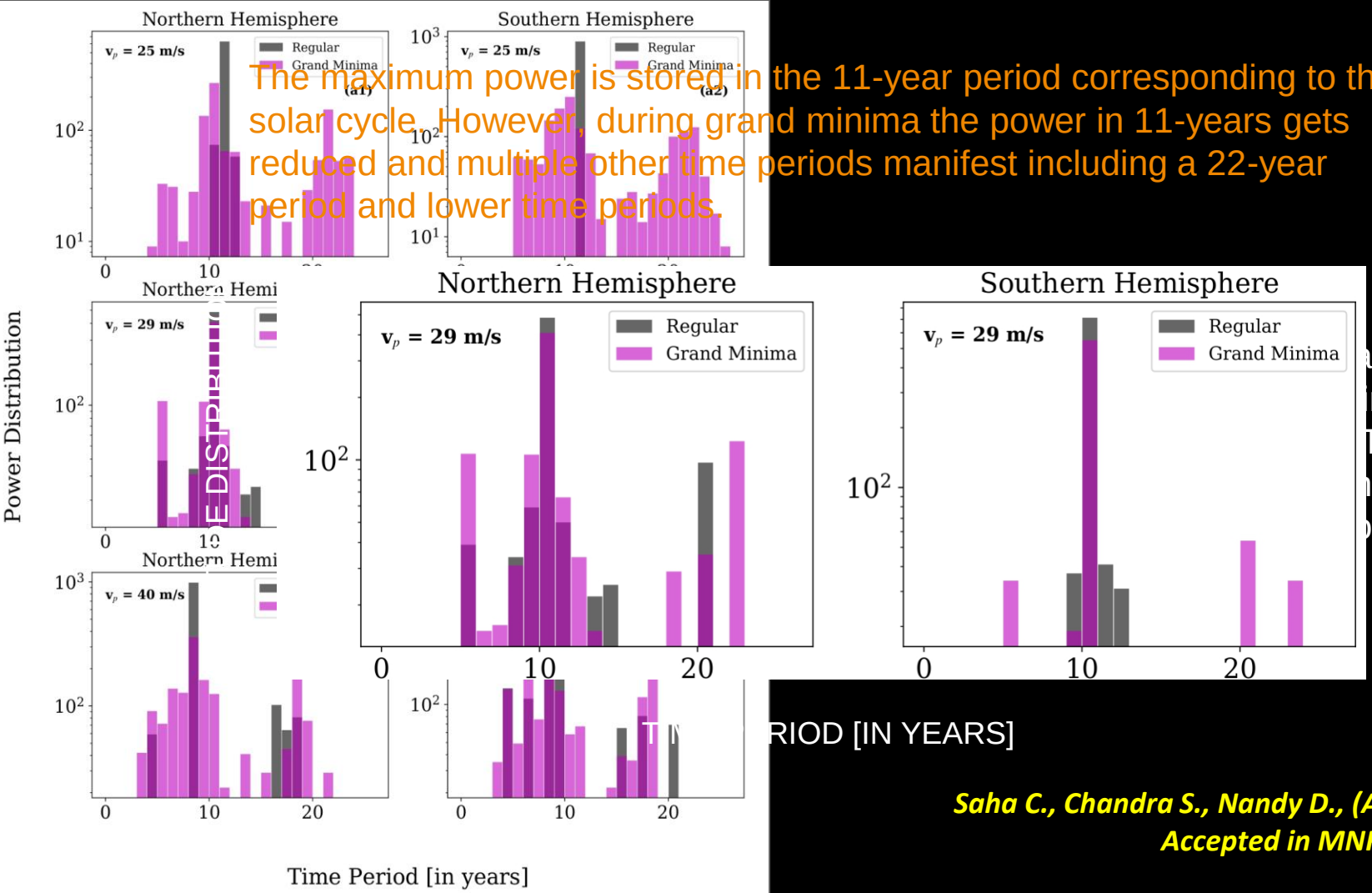


We perform long term dynamo simulations based on the framework by Hazra and Nandy ApJ (2014), Passos et al. A&A (2014)

Sunspot eruptions stop 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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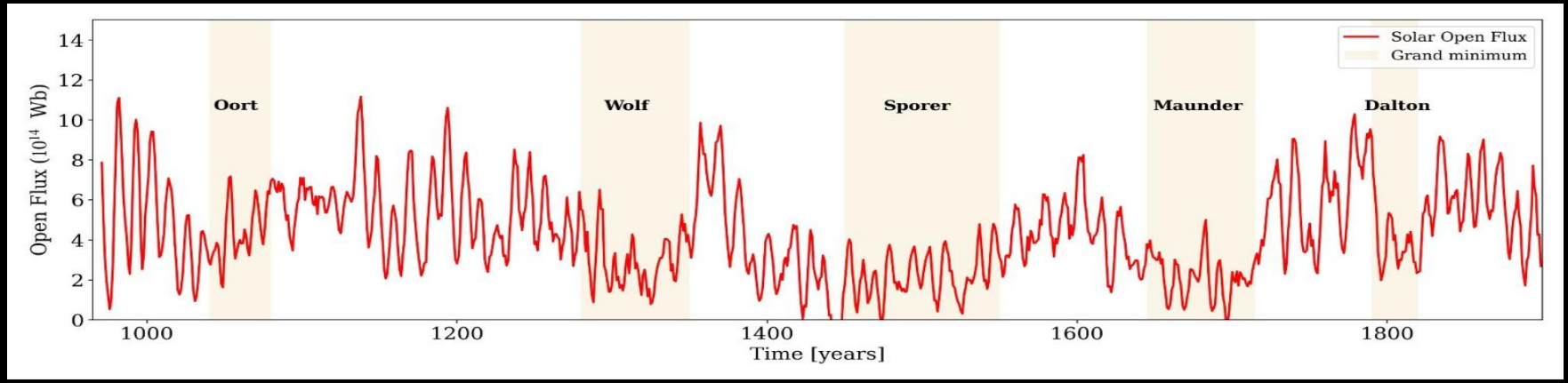
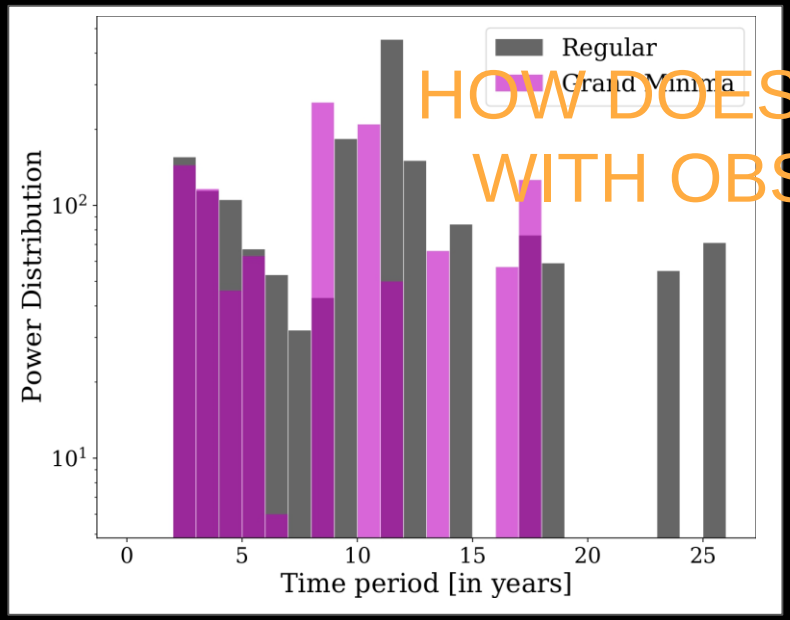
RIOD [IN YEARS]

Saha C., Chandra S., Nandy D., (Aug 2022, Accepted in MNRAS Lett.)



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.

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Future Work: The role of ephemeral regions

The relative roles of ephemeral magnetic regions and active regions in governing solar atmospheric dynamics and radiative output remains to be explored in detail, particularly during grand minima and maxima phases. With MURaM we can numerically simulate flux emergence spanning a range of flux content. From small scale ***ephemeral regions*** to larger active regions, we plan to study flux emergence and investigate the signatures it leaves on the chromosphere, a field that is not well understood. Further, under the conditions of a more realistic chromosphere, we will also plan to study the consequent impacts on the corona.

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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. *(See: Dash, Nandy and Usoskin 2022 arXiv:2208.12103)*

Acknowledgements: