

Appendices

Appendix A

This appendix contains additional material that supports the research and analysis presented in the Chapter 4 of this thesis. In this section, we highlight the salient features of the polar field behavior obtained in a 2D model incorporating the Babcock–Leighton α effect and in the 3D STABLE model with a single BMR placed at 15° latitude in the northern hemisphere. The time-latitude plots in Figures A.1 and A.2 reveal that the radial field first increases and then slowly decreases due to the supply of more leading (opposite) polarity flux towards the pole. Finally, it tends to saturate.

Notably, Figure A.1 clearly shows that as the meridional flow speed increases, the polar field strength also rises, primarily driven by the movement of trailing polarity flux toward the pole. On the other hand, in the STABLE model, as shown in Figure A.2, an increase in flow speed enhances the efficiency with which the trailing polarity flux is dragged toward the pole, leading to a significant increase in polar field strength. However, further increases in meridional flow cause both leading and trailing polarity flux to be directed toward the pole, ultimately resulting in a decrease in the polar field.

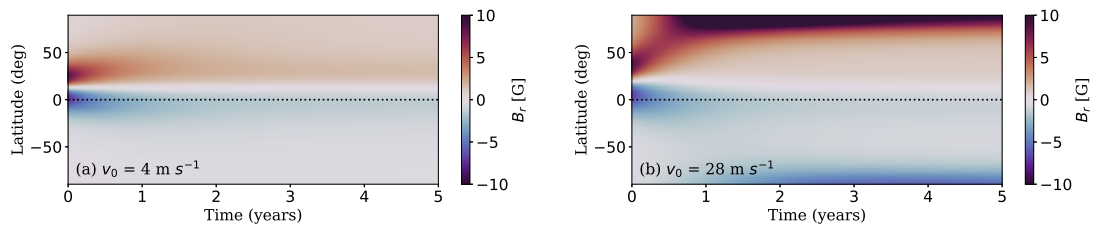


Figure A.1: Time-latitude plot of the radial field from the 2D model with Babcock–Leighton α for (a) $v_0 = 4 \text{ m s}^{-1}$ and (b) $v_0 = 28 \text{ m s}^{-1}$.

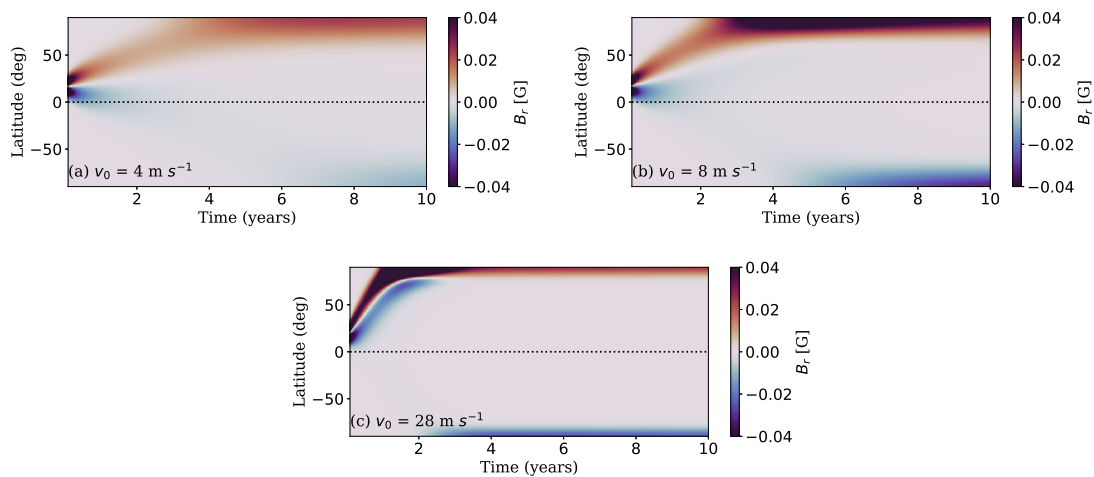


Figure A.2: Time-latitude plot of the radial field from the 3D STABLE model with a single BMR for (a) $v_0 = 4 \text{ m s}^{-1}$, (b) $v_0 = 8 \text{ m s}^{-1}$, and (c) $v_0 = 28 \text{ m s}^{-1}$.

Appendix B

This appendix contains additional material that supports the research and analysis presented in the Chapter 7 of this thesis.

The meridional flow is obtained from the following analytical form.

$$v_r(r, \theta) = v_0 \left(\frac{R_s}{r} \right)^2 \left[\frac{-1}{m+1} + \frac{c_1}{2m+1} \xi^m - \frac{c_2}{2m+p+1} \xi^{m+p} \right] \xi [2 \cos^2 \theta - \sin^2 \theta] \quad (\text{B.1})$$

$$v_\theta(r, \theta) = v_0 \left(\frac{R_s}{r} \right)^3 [-1 + c_1 \xi^m - c_2 \xi^{m+p}] \sin \theta \cos \theta, \quad (\text{B.2})$$

with

$$\begin{aligned} \xi(r) &= \frac{R_s}{r} - 1, \quad c_1 = \frac{(2m+1)(m+p)}{(m+1)p} \xi_p^{-m}, \\ c_2 &= \frac{(2m+p+1)m}{(m+1)p} \xi_p^{-(m+p)}, \quad \text{and } \xi_p = \frac{R_s}{r_p} - 1. \end{aligned} \quad (\text{B.3})$$

Here $m = 0.5$, $p = 0.25$, $v_0 = 10 \text{ m s}^{-1}$, and $r_p = 0.62R_s$. The boundary conditions are exactly taken from Chatterjee et al. (2004) and thus we do not repeat those here. For the initial magnetic field, we take

$$\begin{aligned} A &= 0 \quad \text{and} \\ B &= B_0 \sin(2\theta) \sin \left[\frac{\pi(r - 0.55R_s)}{(R_s - 0.55R_s)} \right]. \end{aligned} \quad (\text{B.4})$$

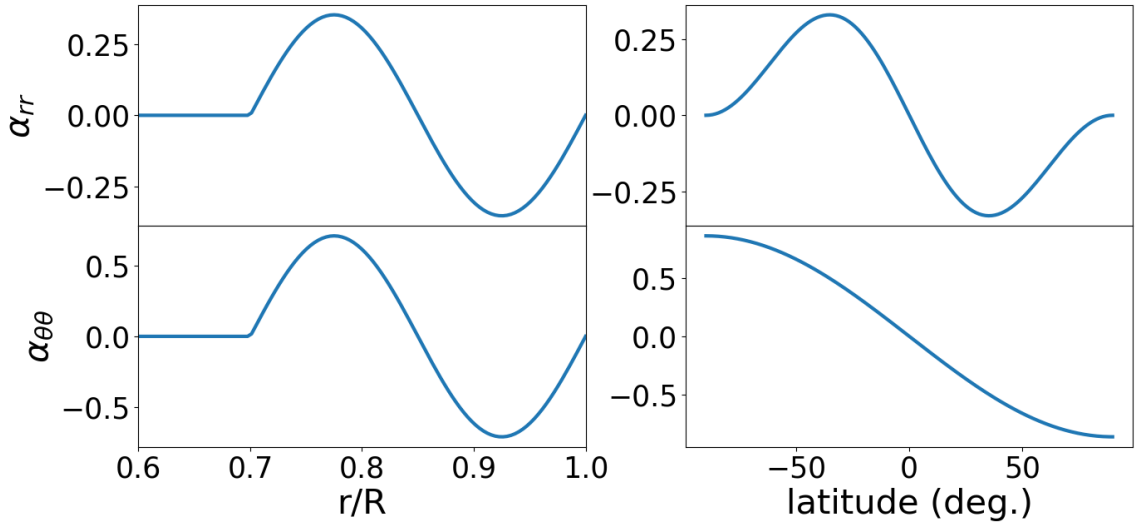


Figure B.1: Left: Radial variations of α_{rr} and $\alpha_{\theta\theta}$ in m s^{-1} at 45° latitude. Right: Latitudinal variations of the same at $r = 0.95R_s$. These are the profiles used in Set D; Eq. (7.12) with $\alpha_0 = 1 \text{ m s}^{-1}$.

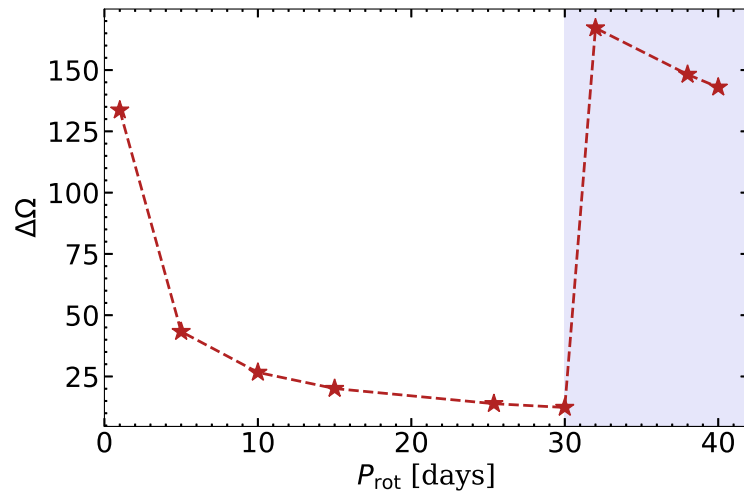


Figure B.2: Variation of differential rotation ($\Delta\Omega$) vs rotation period. The shaded area indicates the transition region to anti-solar differential rotation.

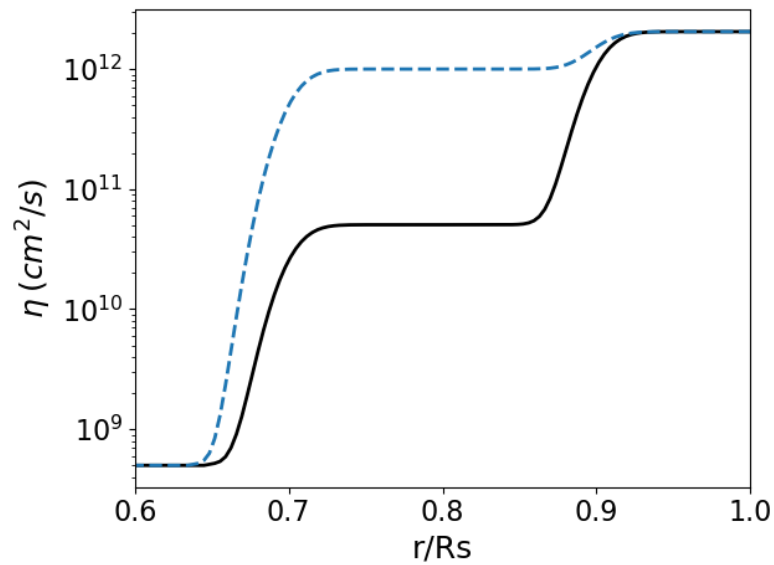


Figure B.3: Solid line: diffusivity profile η used in all the sets of simulations, except Set E for which the profile shown by the dashed line is used.

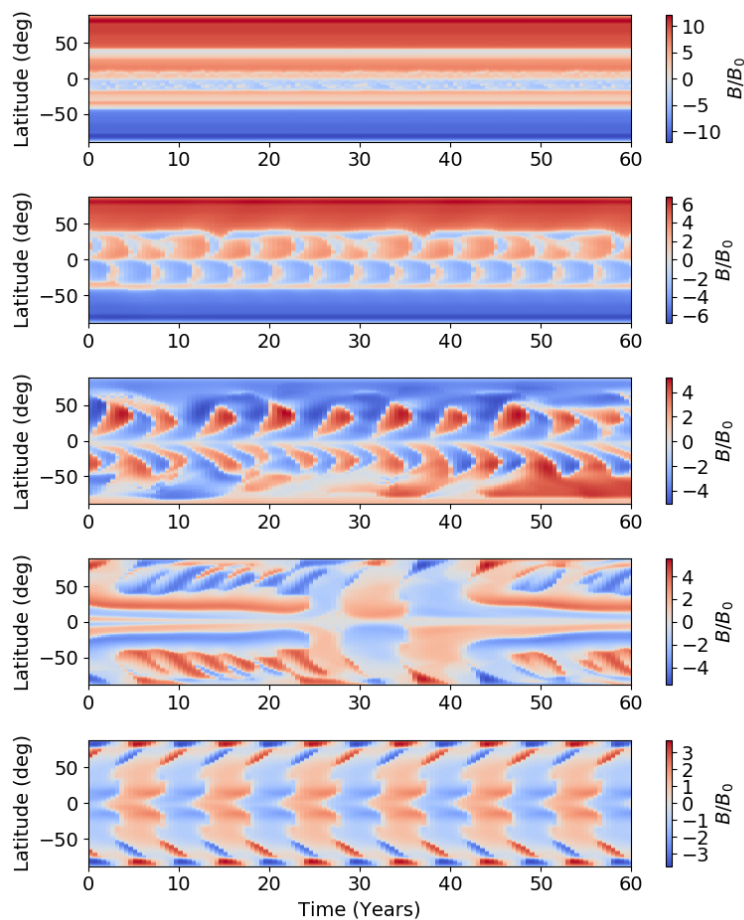


Figure B.4: Same as Fig. 7.5, but obtained from Runs E5, E17, E25, E32, E50 (top to bottom).

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List of Publications

1. Bidya Binay Karak, Aparna Tomar, **Vindya Vashishth** *, “Stellar dynamos with solar and antisolar differential rotations: Implications to magnetic cycles of slowly rotating stars”, *Monthly Notices of the Royal Astronomical Society (MNRAS)* 491 (3), 3155-3164 (2020)
2. Pawan Kumar, Bidya Binay Karak, **Vindya Vashishth**, “Supercriticality of the dynamo limits the memory of the polar field to one cycle”, *The Astrophysical Journal (ApJ)* 913 (1), 65 (2021)
3. **Vindya Vashishth**[†], Bidya Binay Karak, Leonid Kitchatinov, “Subcritical dynamo and hysteresis in a Babcock-Leighton type kinematic dynamo model”, *Research in Astronomy and Astrophysics (RAA)* 21 (10), 266 7 (2021)
4. **Vindya Vashishth**[‡], Bidya Binay Karak, Leonid Kitchatinov, “Dynamo modelling for cycle variability and occurrence of grand minima in Sun-like stars: rotation rate dependence”, *Monthly Notices of the Royal Astronomical Society (MNRAS)* 522 (2), 2601-2610 (2023)
5. **Vindya Vashishth** §, “Hysteresis near the transition of the large-scale dynamo in the presence of the small-scale dynamo”, *Solar Physics (SolPhy)* 299 (8), 115 (2024)
6. **Vindya Vashishth**[¶], Bidya Binay Karak, “The role of meridional flow in the gener-

*Presented in Chapter 7

†Presented in Chapter 2

‡Presented in Chapter 6

§Presented in Chapter 3

¶Presented in Chapter 4

ation of solar/stellar magnetic fields and cycles”, *The Astrophysical Journal (ApJ)* 974 (1), 6 (2024)

7. **Vindya Vashishth** **, Bidya Binay Karak, “Does the Babcock–Leighton dynamo operate in rapidly rotating sun-like stars?”, *Submitted, Monthly Notices of the Royal Astronomical Society (MNRAS)* (2024)

**Presented in Chapter 5

Conferences/Workshop attended

1. Presented an oral talk on **The role of meridional flow in the generation of solar/stellar magnetic fields and cycles**, at “Solar cycle variability: From understanding to making a prediction,” held from 14–18 October 2014, at ARIES, Nainital, Uttarakhand.
2. Presented poster on **The role of meridional flow in the generation of solar/stellar magnetic fields and cycles**, at “Space Climate 9 / ISEE Joint Symposium”, held from 01–04 October 2024, at Nagoya University, Nagoya, Japan.
3. Presented posters on **The role of meridional flow in the generation of solar/stellar magnetic fields and cycles**, and **Dynamo modelling for cycle variability and occurrence of grand minima in Sun-like stars**, at “IAU General Assembly Focus Meeting 8”, held from 06–15 August 2024, in Cape Town, South Africa.
4. Presented an oral talk on **Modelling the long-term variability of sun-like stars: From subcritical to supercritical dynamos**, and a poster on **Hysteresis near the transition of the large-scale dynamo in the presence of the small-scale dynamo** at the “IAU Symposium 365”, held from 21–25 August 2023 in Yerevan, Armenia.
5. Presented a poster on **Hysteresis near dynamo transition of the large-scale dynamo in the presence of the small-scale dynamo**, at the “41st Annual Meeting of the Astronomical Society of India (ASI)”, held from 01–05 March 2023, at IIT Indore, Madhya Pradesh.
6. Presented an oral talk on, **Modeling the occurrence of grand minima in sun-like**

stars using a dynamo model, at the “IAU General Assembly Focus Meeting 5”, held from 02–11 August 2022, in Busan, South Korea.

7. Presented a poster, on **Modelling the occurrence of grand minima in sun-like stars using a dynamo model**, at “40th Annual Meeting of the Astronomical Society of India (ASI)”, held from 25–29 March 2022, at IIT Roorkee, Uttarakhand.
8. Presented oral talk **Modelling the occurrence of grand minima in sun-like stars using a dynamo model** in the Workshop 3: Long-term Study of the Solar Activity at “41st Annual Meeting of the Astronomical Society of India (ASI)”, held on 24 March 2022, at IIT Roorkee, Uttarakhand.
9. Presented an oral talk, on **Changes of stellar cycle variability and frequency of grand minima with stellar rotation in dynamo models**, at the “ISSI Team 474 online meeting”, held on 21 February 2023 (Online).
10. Attended “NASA’s Living with a star, 17th Heliophysics Summer school”, on “Observational Heliophysics,” held from 17–21 July 2023 (Online).
11. Presented an oral talk on **Variability and grand minima in Solar and stellar dynamos**, at the “ISSI Team 474 online meeting”, held on 12 July 2023 (Online).
12. Presented an oral talk on, **Hysteresis of the large-scale dynamo in the presence of the small-scale dynamo**, at the “Pencil Code user meeting 2022–18th Annual Meeting for Pencil Code Developers and Users”, held from, 04–10 May 2022 (Online).
13. Attended “15th Quadrennial Solar-Terrestrial Physics Symposium (STP-15)”, held from 21–25 February 2022 (Online).
14. Presented oral talk on **Sub-Critical Dynamos and Hysteresis in the Babcock-Leighton Type Kinematic Dynamo Models**, at “The 2nd International Symposium on Space Science (ISSS-21)”, held on 15 November 2021 (Online).
15. Presented a poster, on **Sub-Critical Dynamos and Hysteresis in the Babcock-Leighton Type Kinematic Dynamo Models**, at International Conference (IIA-50)

on “Advances in Observations and Modelling of Solar Magnetism and Variability”, held from 01–04 March 2021 (Online).

16. Attended “39th Annual Meeting of the Astronomical Society of India (ASI)”, held from 18–23 February 2021 (Online).