Harmonically forced and synchronized dynamos

Frank Stefani

with thanks to

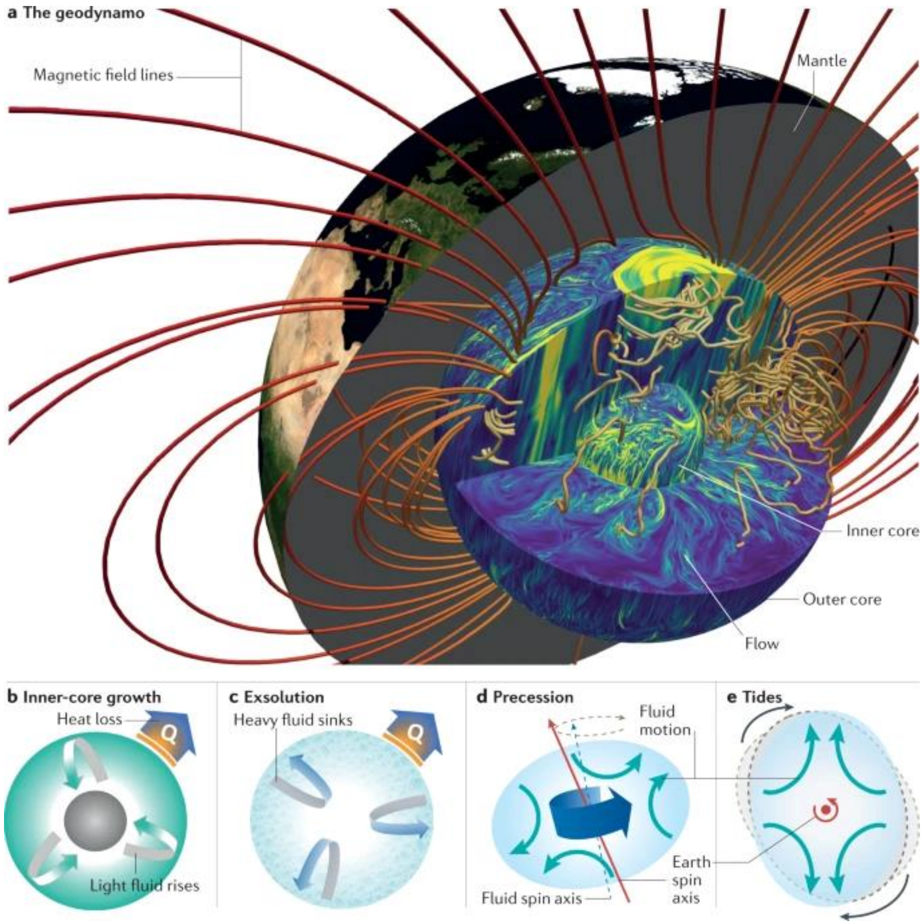
Gerrit M. Horstmann, Laurène Jouve, Martins Klevs, George Mamatsashvili, Tom Weier

19th MHD Days
AIP Potsdam
2-4 Dec 2024

HZDR
HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

Precession, tides, et cetera: Highly recommendable reviews

M. Le Bars, D. Cébron, P. Le Gals: Flows driven by libration, precession, and tides. Annu. Rev. Fluid Mech. 47 (2015)

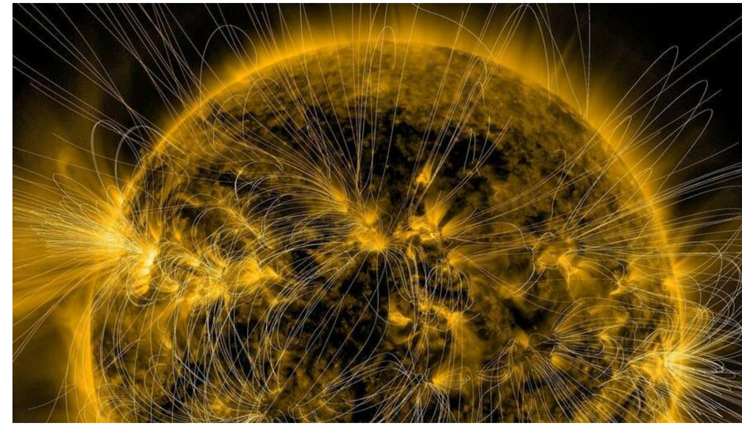


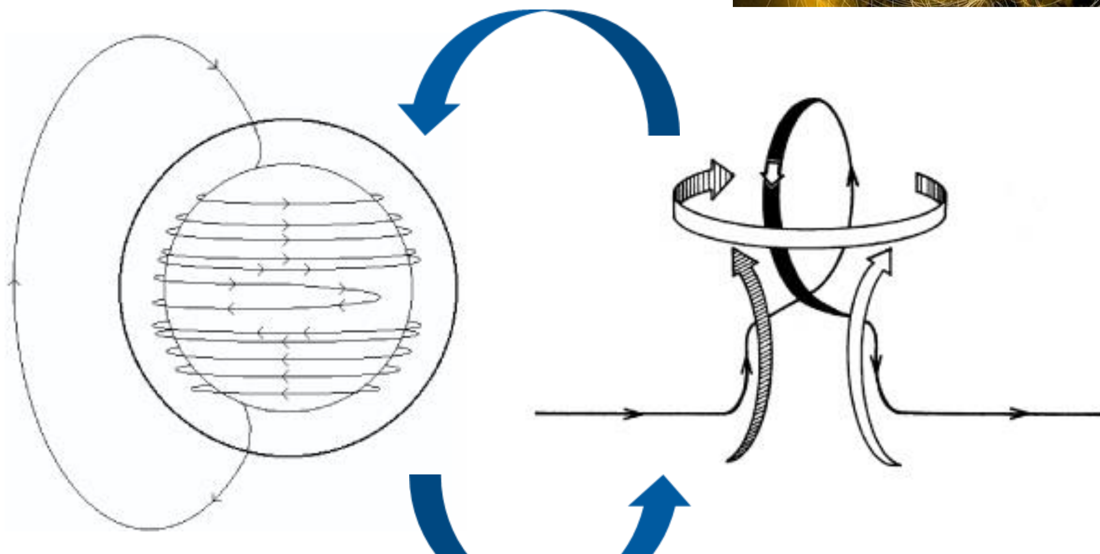
M. Landeau, A. Fournier, H.-C. Nataf, D. Cébron, N. Schaeffer: Sustaining Earth's magnetic dynamo. Nature Rev. Earth Environ. 3 (2022), 255

The solar dynamo: Basics

Any solar dynamo needs:

- some Ω effect to wind up toroidal field from poloidal field
- some α effect to regenerate poloidal field from toroidal field





Ω **effect** α **effect**

Parker, Astrophys J. 122, 293 (1955)

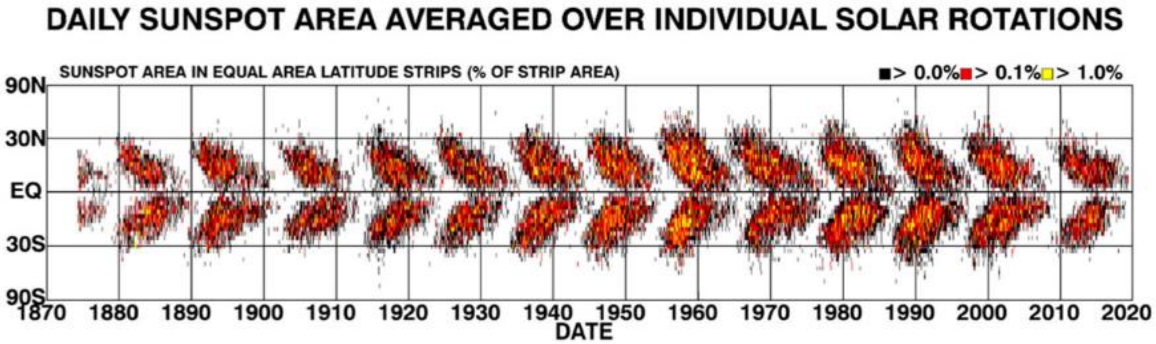
DRESDEN concept HZDR

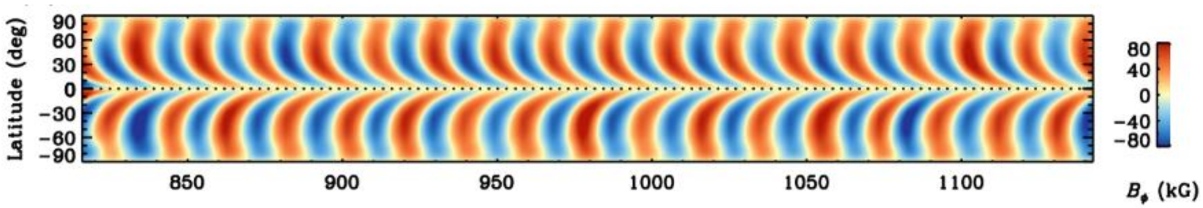
The solar dynamo: conventional wisdom

With appropriate models, e.g. Babcock-Leighton (including meridional circulation), and some parameter fitting, one “readily” obtains

- a reasonable period of the Hale cycle (22 years)
- a reasonable shape of the butterfly diagram of sunspots

http://www.solarcyclescience.com/solarcycle.html

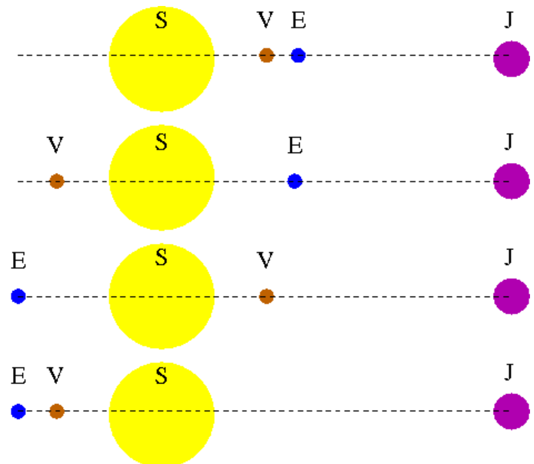




Karak, B.B., Miesch, M., ApJ 847 (2017), 69

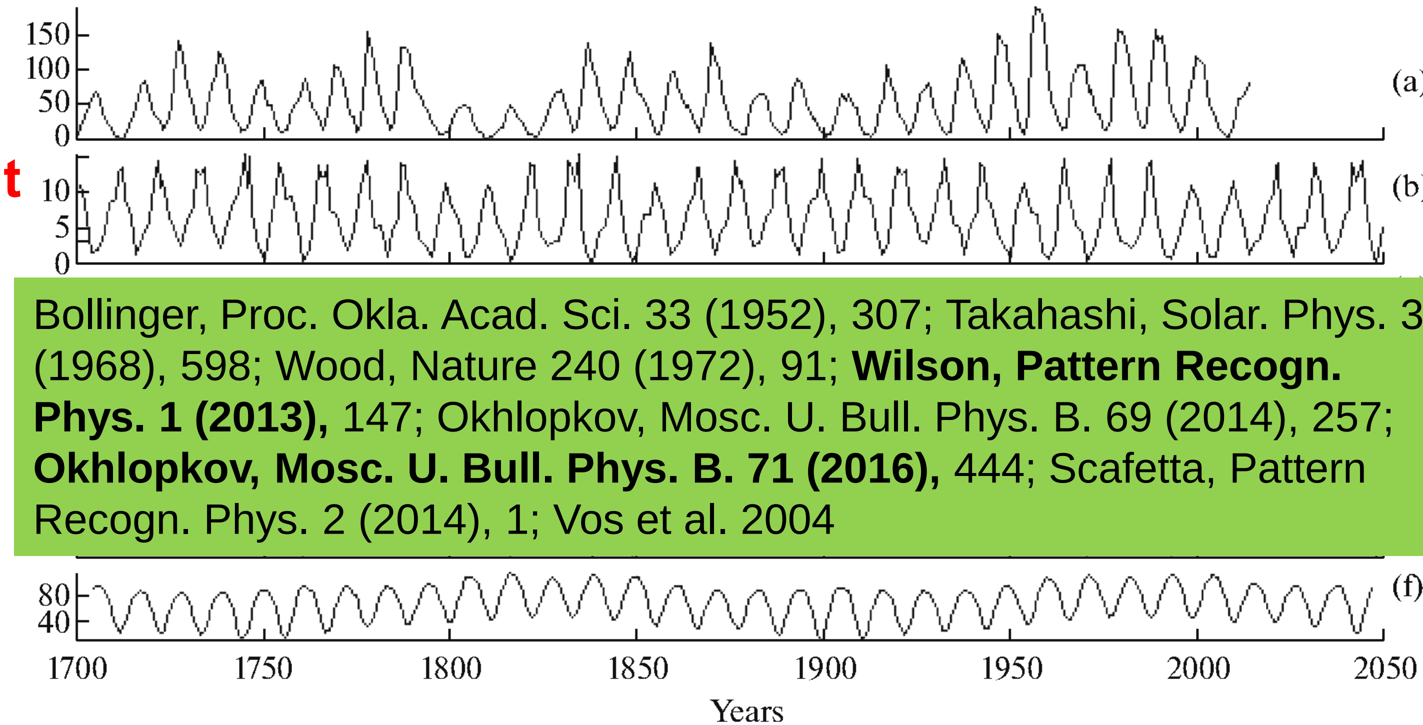
First indication for phase stability and clocking

Conspicious parallelity of the solar Schwabe cycle with 11.07-yr spring-tide period of the tidally dominant Venus-Earth-Jupiter system (despite weak tidal forces → 1 mm tidal height!)



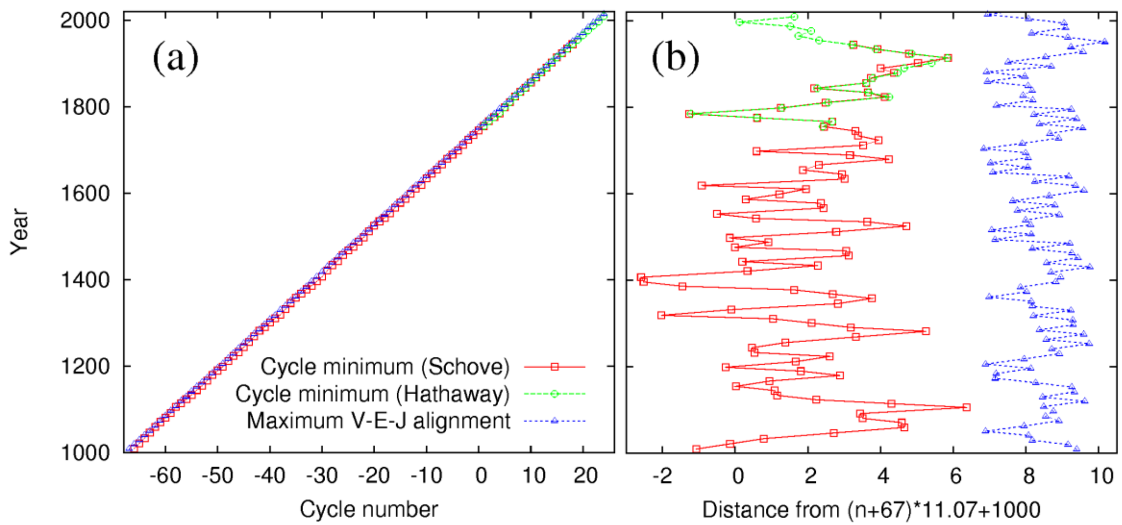
Sunspots

VEJ alignment index



Bollinger, Proc. Okla. Acad. Sci. 33 (1952), 307; Takahashi, Solar. Phys. 3 (1968), 598; Wood, Nature 240 (1972), 91; **Wilson, Pattern Recogn. Phys. 1 (2013),** 147; Okhlopkov, Mosc. U. Bull. Phys. B. 69 (2014), 257; **Okhlopkov, Mosc. U. Bull. Phys. B. 71 (2016),** 444; Scafetta, Pattern Recogn. Phys. 2 (2014), 1; Vos et al. 2004

First indication for phase stability and clocking



Schove, D.J.: J. Geophys. Res. 60 (1955), 127; Hathaway, D.H., Liv. Rev. Sol. Phys. 7 (2010)

Strong indication for a clocked process, in contrast to a random walk process

F. S. et al., Solar Physics 294 (2019)

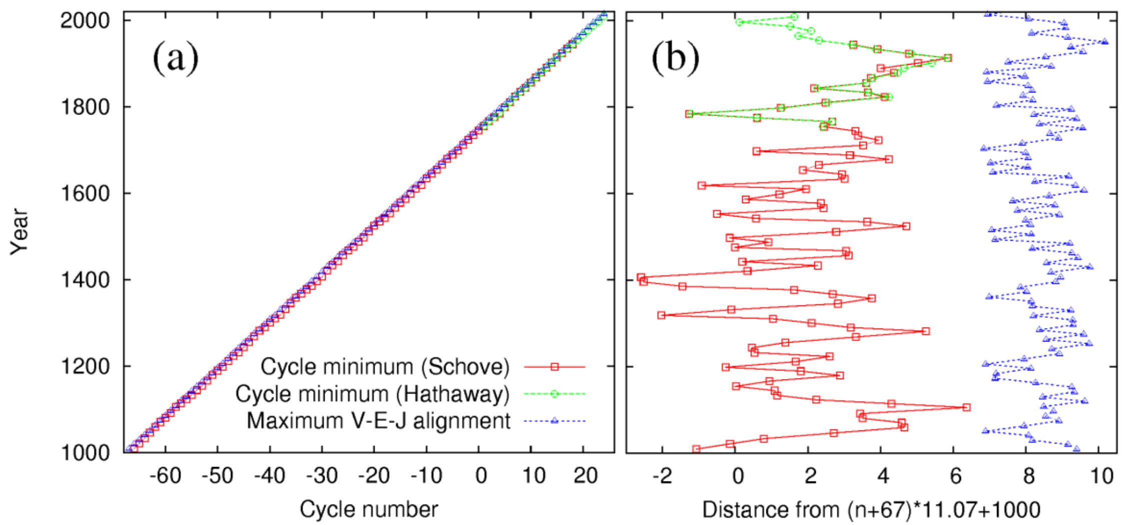
Schove's data (derived mainly from aurorae borealis) are often criticized ("9 per century rule")

I. Usoskin, Living Rev. Sol. Phys. 14, 3 (2017); H.-C. Nataf, Solar Physics 297 (2022), 107

However: ^{10}Be and ^{14}C data give similar cycles.

F. S. et al., Astron. Nachr. 341 (2020), 600

First indication for phase stability and clocking



Schove, D.J.: J. Geophys. Res. 60 (1955), 127; Hathaway, D.H., Liv. Rev. Sol. Phys. 7 (2010)

Strong indication for a clocked process, in contrast to a random walk process

F. S. et al., Solar Physics 294 (2019)

Schove's data (derived mainly from aurorae borealis) are often criticized ("9 per century rule")

I. Usoskin, Living Rev. Sol. Phys. 14, 3 (2017); H.-C. Nataf, Solar Physics 297 (2022), 107

However: ^{10}Be and ^{14}C data give similar cycles.

F. S. et al., Astron. Nachr. 341 (2020), 600

Phase stability of the Schwabe cycle: the state of the debatte

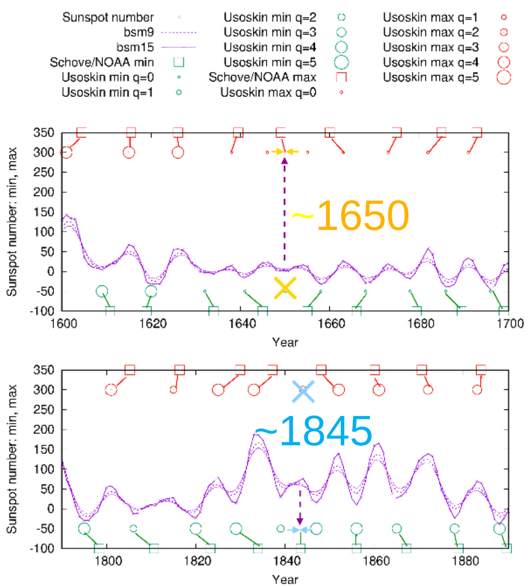
Stefani et al., Solar Physics 294 (2019) → Criticized by → Nataf, Solar Physics 297 (2022), 107

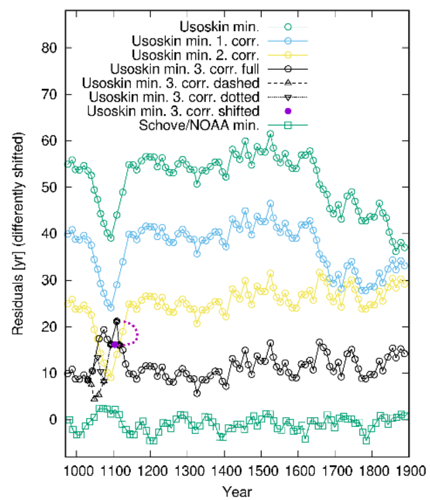
Nataf, Solar Physics 297 (2022), 107 → Criticized by → Scafetta, Solar Physics 298 (2023), 24

Scafetta, Solar Physics 298 (2023), 24 → answer → Nataf, Solar Physics 298 (2023), 33

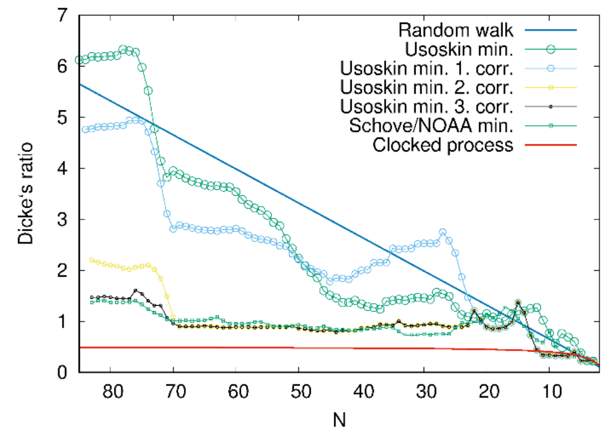
Weisshaar et al., A&A 671 (2023), A87: **No evidence for synchronization of the solar cycle by a "clock"** → Criticized by → Stefani, Beer, Weier, **No evidence for absence of solar dynamo synchro-nization,** promptly rejected by Editor of A&A → Solar Physics 298, 83 (2023)

^{14}C-Data: two very plausible corrections → clocked process down to AD 1140





Residuals



Dicke-Ratio

Phase stability of the Schwabe cycle: the state of the debatte

Stefani et al., Solar Physics 294 (2019)

Criticize…

…297 (2022), 107

Nataf, Solar Physics 298 (2023), 3…

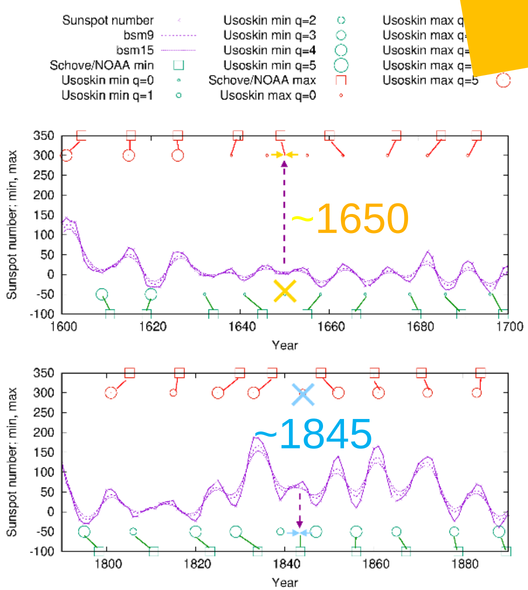
…s 298 (2023), 24

Weisshaar et al., A&A 671 (2023), A…
No evidence for synchronization…
the solar cycle by a “clock”

…o evidence for …mo synchro-… …Editor of …, 83 (2023)

^{14}C-Data: two very plausible cor…

…140



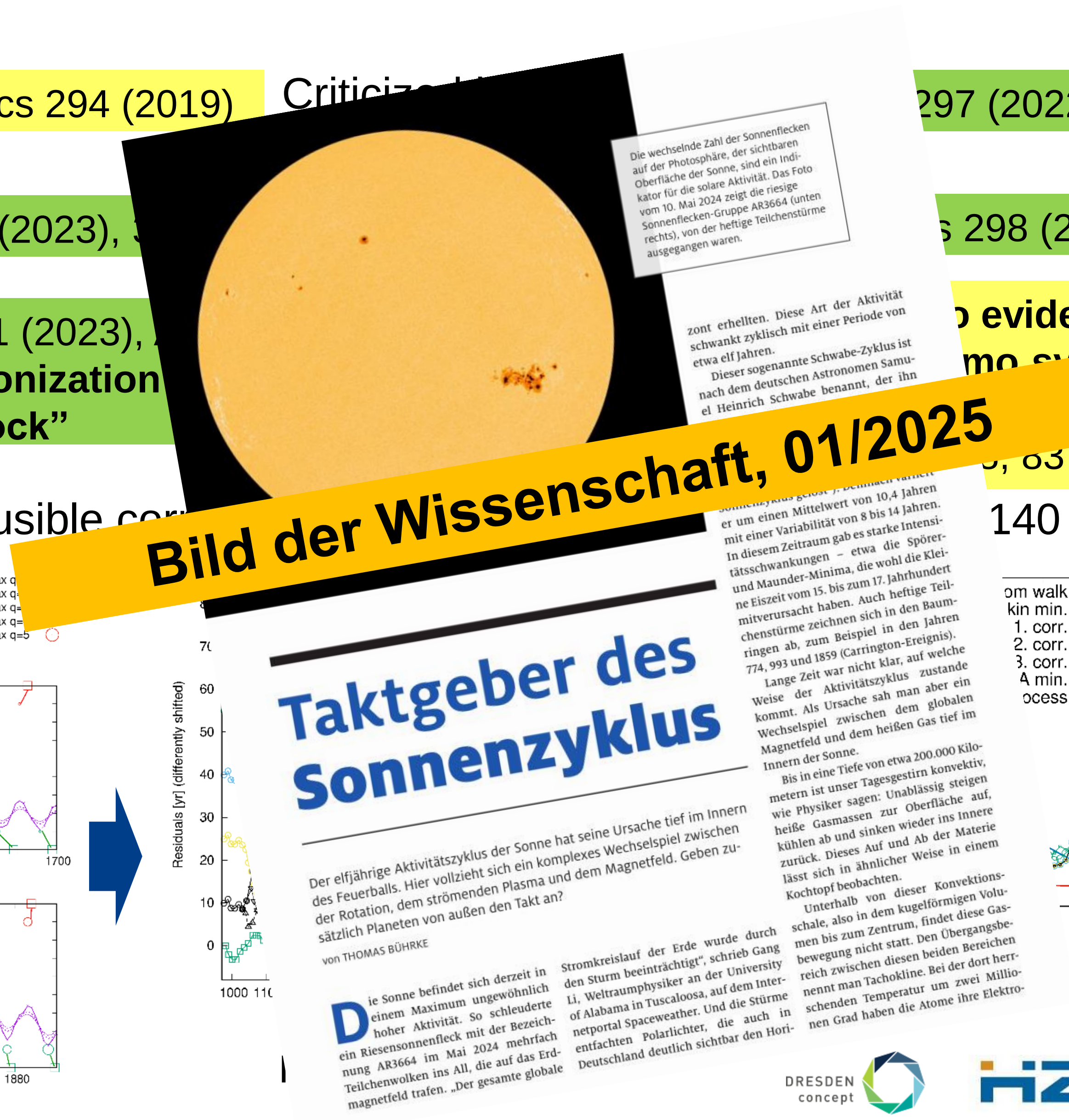


Bild der Wissenschaft, 01/2025

Die wechselnde Zahl der Sonnenflecken auf der Photosphäre, der sichtbaren Oberfläche der Sonne, sind ein Indikator für die solare Aktivität. Das Foto vom 10. Mai 2024 zeigt die riesige Sonnenflecken-Gruppe AR3664 (unten rechts), von der heftige Teilchenstürme ausgegangen waren.

Taktgeber des Sonnenzyklus

Der elfjährige Aktivitätszyklus der Sonne hat seine Ursache tief im Innern des Feuerballs. Hier vollzieht sich ein komplexes Wechselspiel zwischen der Rotation, dem strömenden Plasma und dem Magnetfeld. Geben zusätzlich Planeten von außen den Takt an?

von THOMAS BÜHRKE

Die Sonne befindet sich derzeit in einem Maximum ungewöhnlich hoher Aktivität. So schleuderte ein Riesensonnenfleck mit der Bezeichnung AR3664 im Mai 2024 mehrfach Teilchenwolken ins All, die auf das Erdmagnetfeld trafen. „Der gesamte globale Stromkreislauf der Erde wurde durch den Sturm beeinträchtigt“, schrieb Gang Li, Weltraumphysiker an der University of Alabama in Tuscaloosa, auf dem Internetportal Spaceweather. Und die Stürme entfachten Polarlichter, die auch in Deutschland deutlich sichtbar den Horizont erhellten. Diese Art der Aktivität schwankt zyklisch mit einer Periode von etwa elf Jahren.

Dieser sogenannte Schwabe-Zyklus ist nach dem deutschen Astronomen Samuel Heinrich Schwabe benannt, der ihn … er um einen Mittelwert von 10,4 Jahren mit einer Variabilität von 8 bis 14 Jahren. In diesem Zeitraum gab es starke Intensitätsschwankungen – etwa die Spörer- und Maunder-Minima, die wohl die Kleine Eiszeit vom 15. bis zum 17. Jahrhundert mitverursacht haben. Auch heftige Teilchenstürme zeichnen sich in den Baumringen ab, zum Beispiel in den Jahren 774, 993 und 1859 (Carrington-Ereignis).

Lange Zeit war nicht klar, auf welche Weise der Aktivitätszyklus zustande kommt. Als Ursache sah man aber ein Wechselspiel zwischen dem globalen Magnetfeld und dem heißen Gas tief im Innern der Sonne.

Bis in eine Tiefe von etwa 200.000 Kilometern ist unser Tagesgestirn konvektiv, wie Physiker sagen: Unablässig steigen heiße Gasmassen zur Oberfläche auf, kühlen ab und sinken wieder ins Innere zurück. Dieses Auf und Ab der Materie lässt sich in ähnlicher Weise in einem Kochtopf beobachten.

Unterhalb von dieser Konvektionsschale, also in dem kugelförmigen Volumen bis zum Zentrum, findet diese Gasbewegung nicht statt. Den Übergangsbereich zwischen diesen beiden Bereichen nennt man Tachokline. Bei der dort herrschenden Temperatur um zwei Millionen Grad haben die Atome ihre Elektro-

DRESDEN concept

HZDR

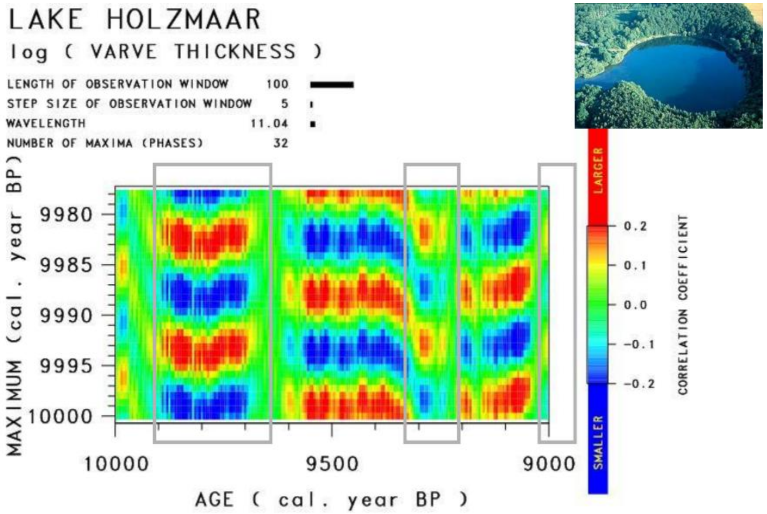
Second indication for phase stability and clocking

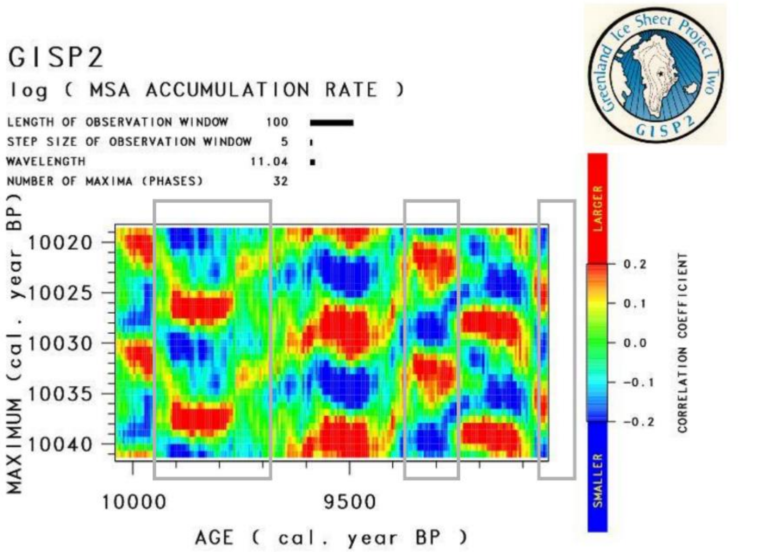
Phase diagrams for algae data from lake Holzmaar und algae-produced Methanesulfonate (MSA) in Greenland ice core GISP2 show 11.04-years cycle with very similar band structures.

Bands are separated by apparent 5.5-years-phase jumps, resulting from nonlinear transfer function (due to optimality condition of algae growth)

Strong evidence for a 11.04(?)-years-cycle, that was phase-stable over 1000 years!

H. Vos et al., in “Climate in Historical Times: Towards a Synthesis of Holocene Proxy Data and Climate Models”, GKSS School of Environmental Research, p. 293 (2004)

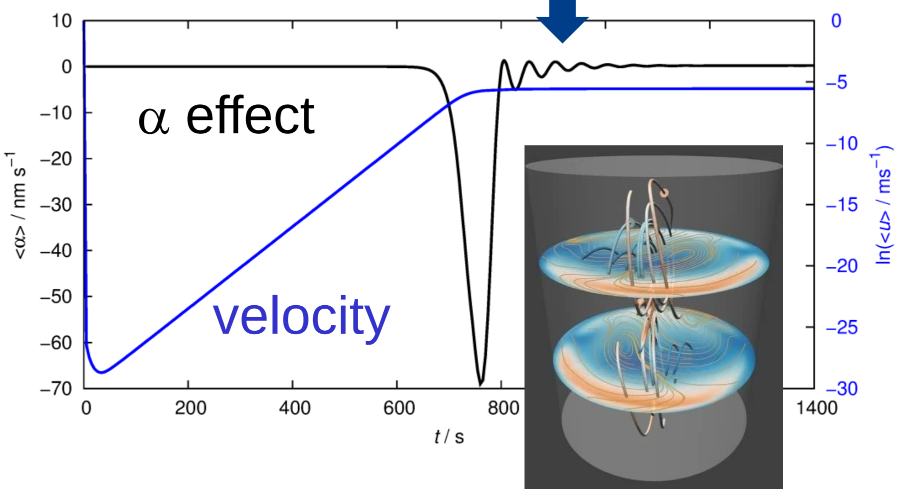


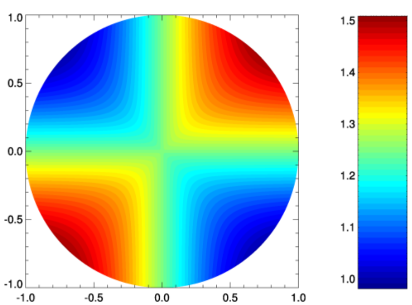


F. S. et al., Astron. Nachr. 341 (2020), 600

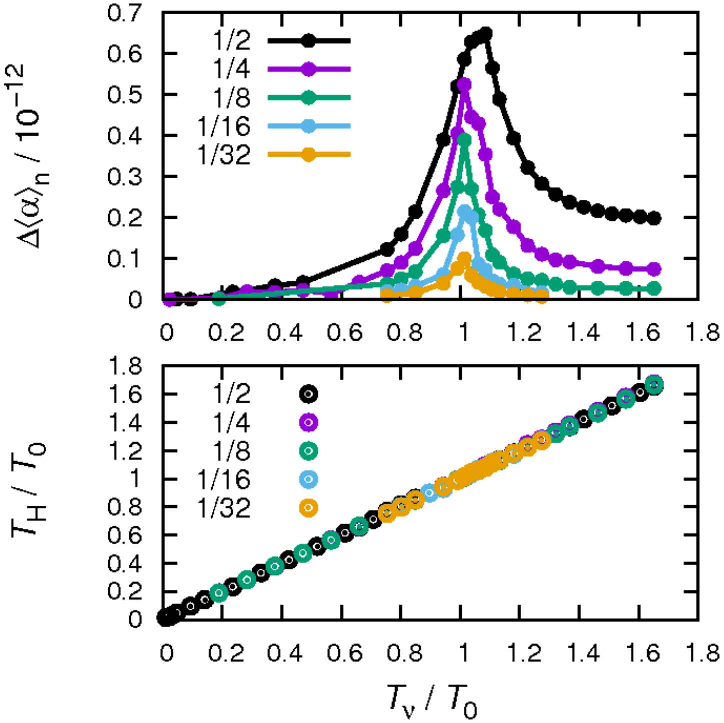
Original idea: tidal forces might synchronize α to 11.07 years

Current driven Tayler instability (with azimuthal wave number m=1) tends to undergo intrinsic helicity oscillations…





…which can be easily synchronized by tidal (m=2) perturbations (of the VEJ-system)



N. Weber et al., NJP 17 (2015), 113013; F. S. et al., Solar Phys. 291 (2016), 2197; Solar Physics 294 (2019), 60

A simple ODE model of a synchronized dynamo

$$\dot{A}(t) = \alpha(t)B(t) - \tau^{-1}A(t)$$

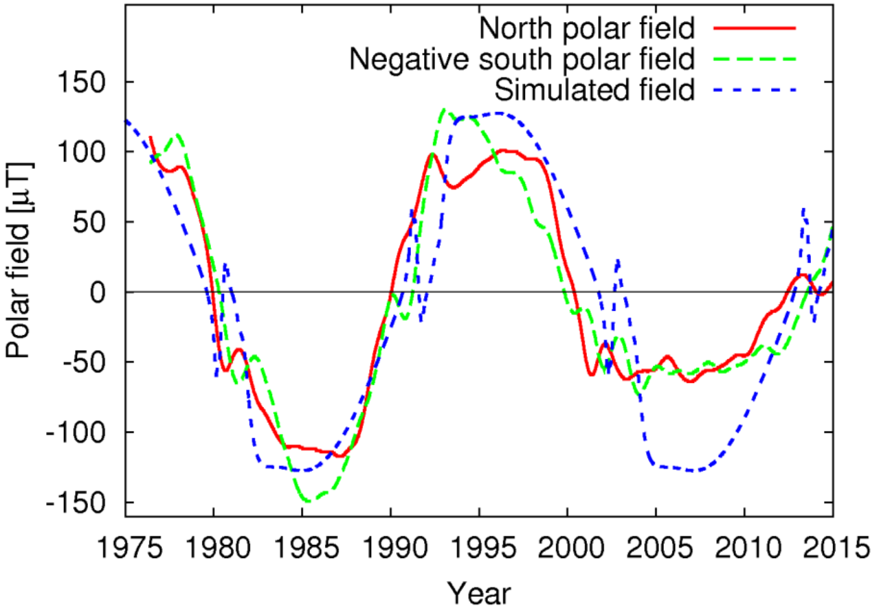
$$\dot{B}(t) = \omega A(t) - \tau^{-1}B(t)$$

$$\alpha(t) = \frac{c}{1+gB^2(t)} + \frac{pB^2(t)}{1+hB^4(t)}\sin(2\pi t/T_\nu)$$

Oscillatory α term with period of 11.07 years and resonant dependence on the field strength

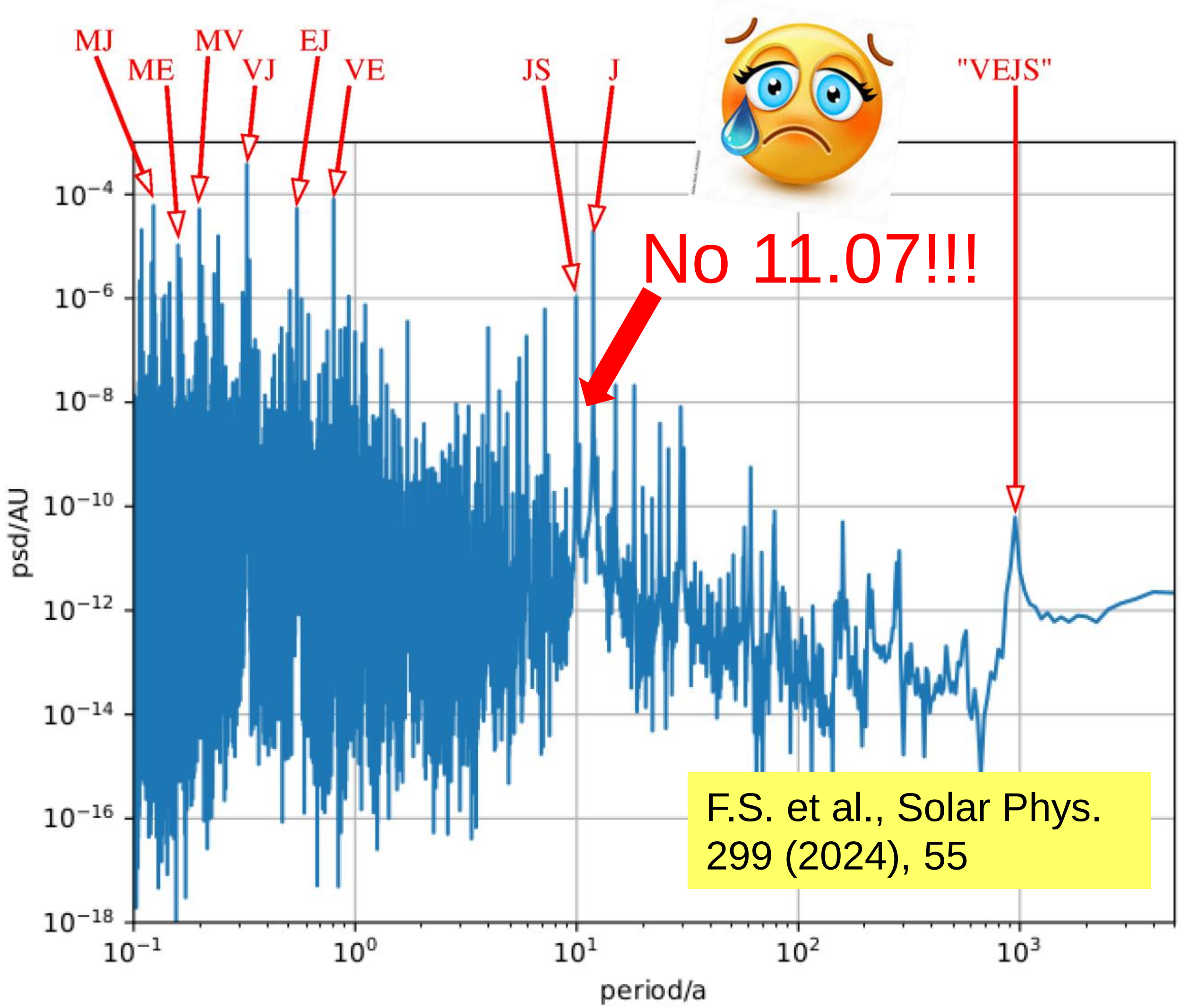
Constant α term with quenching

…parametric resonance yields a 22.14 years solar cycle!



F.S. et al, Solar Phys. 291 (2016), 2197

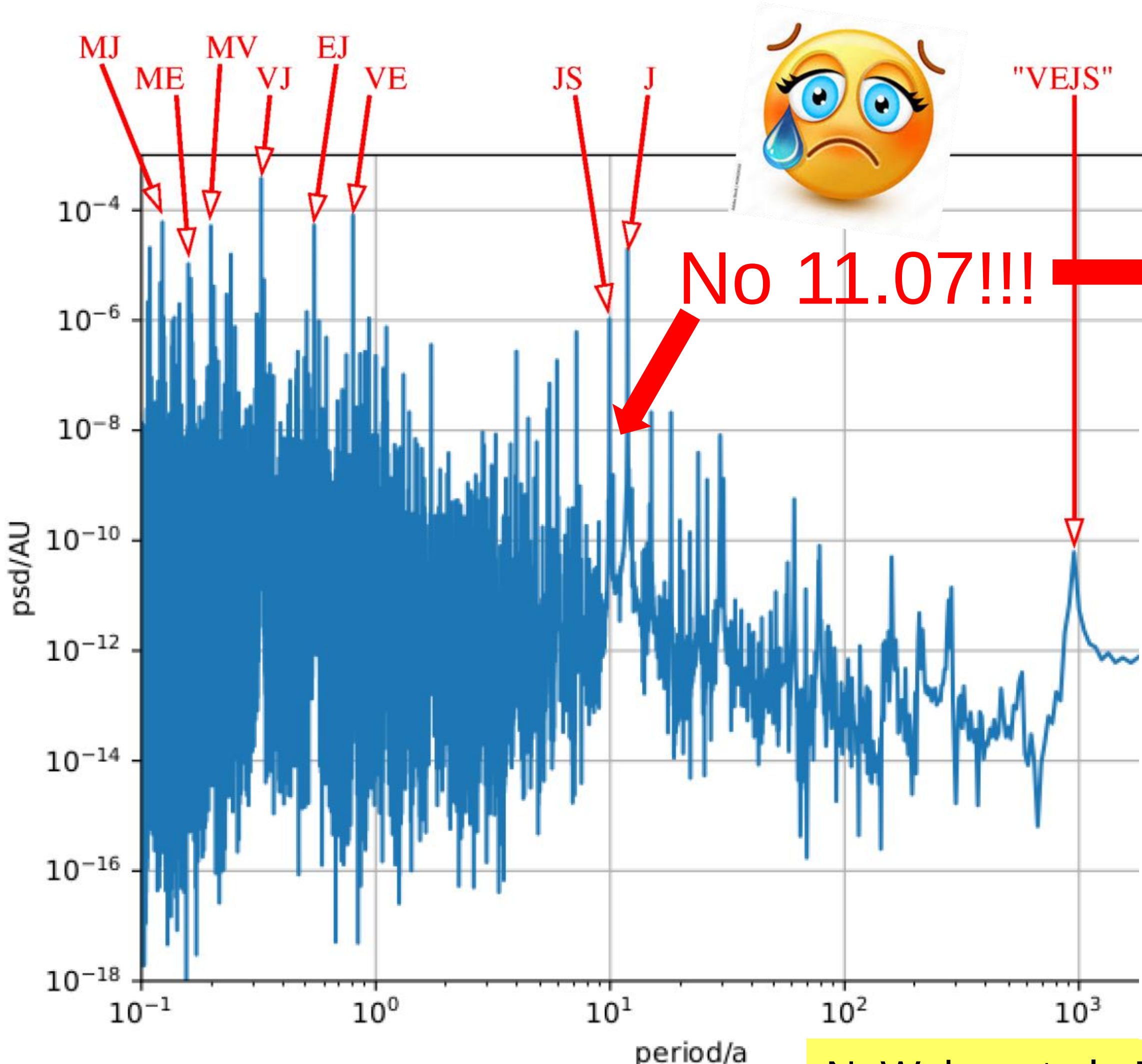
However: No 11.07-yr peak in the spectrum of tidal potential…



F.S. et al., Solar Phys. 299 (2024), 55

H.-C. Nataf, Solar Phys. 297, 107 (2022),
R.G. Cionco et al., Solar Phys. 298, 70 (2023)

However: No 11.07-yr peak in the spectrum of tidal potential…



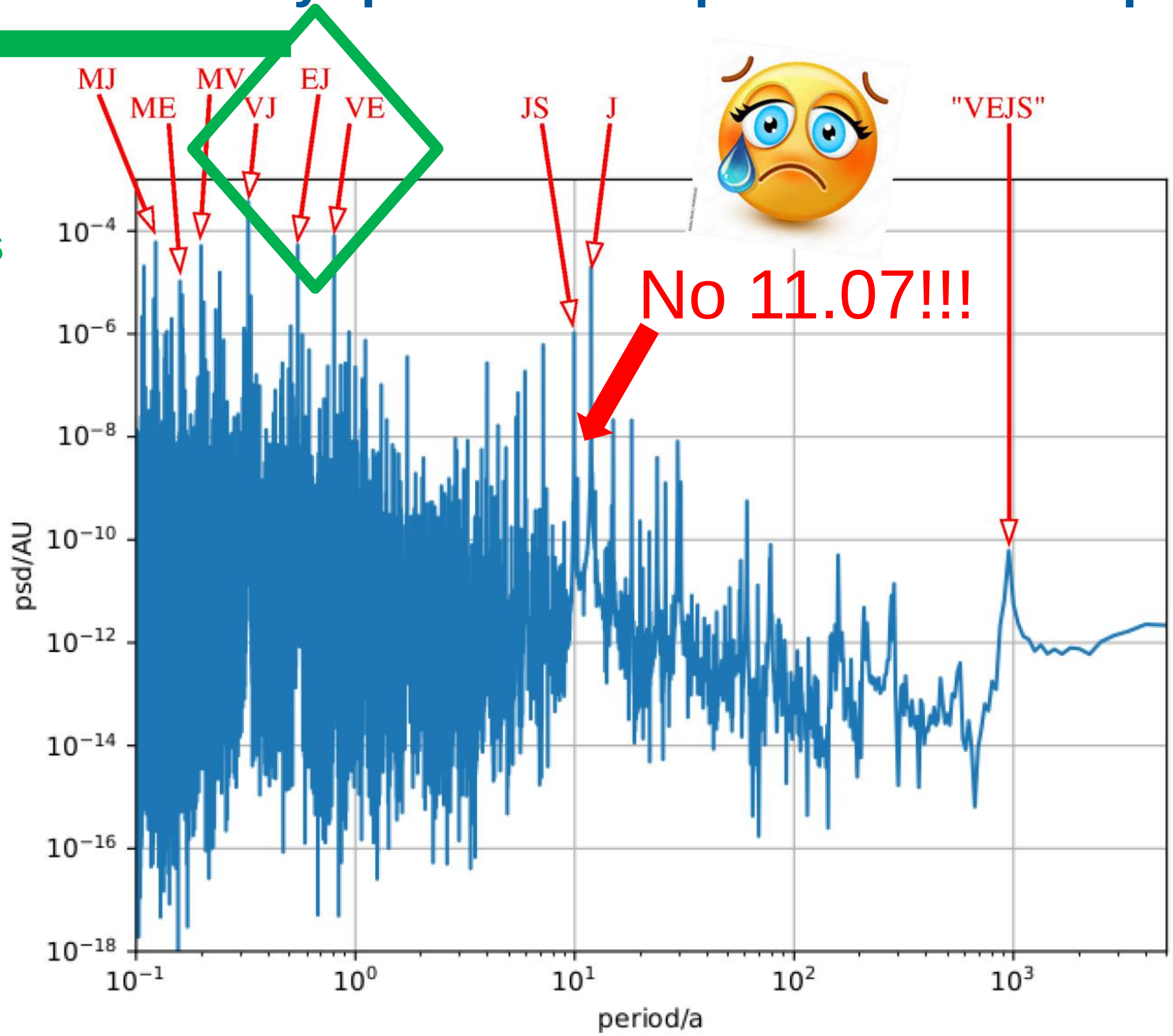
This puts into question the entire concept of **direct helicity synchronization** (e.g., of the Tayler instability) by tidal forces as previously discussed in…

H-.C. Nataf, Solar Phys. 297, 107 (2022),
R.G. Cionco et al., Solar Phys. 298, 70 (2023)

N. Weber et al., New J. Phys 17, 113013 (2015); F. Stefani et al. Solar Phys. 291 (2016), 294 (2019), 296 (2021)

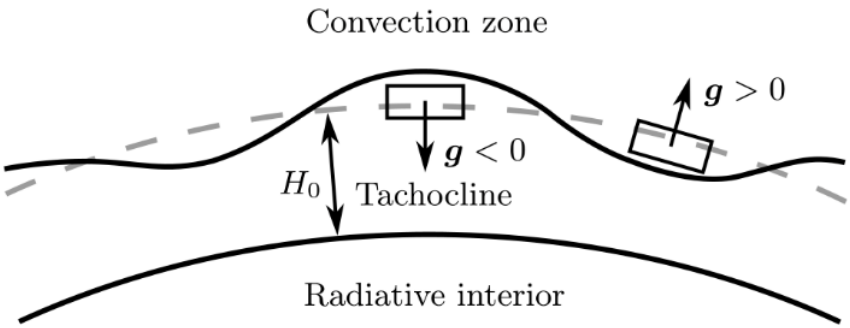
However: No 11.07-yr peak in the spectrum of tidal potential…

So, let's first focus on those periods



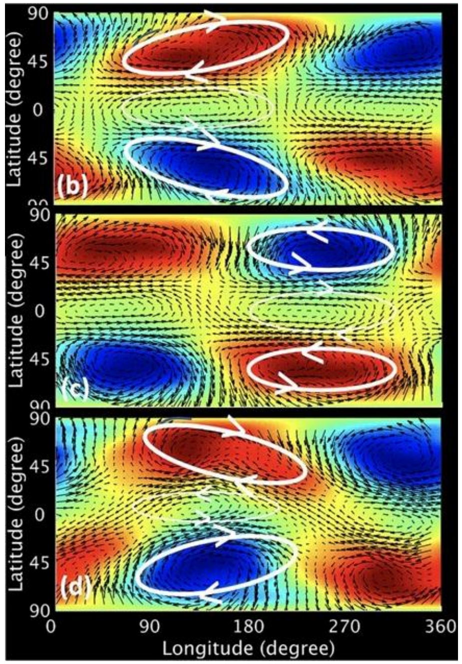
H-.C. Nataf, Solar Phys. 297, 107 (2022),
R.G. Cionco et al., Solar Phys. 298, 70 (2023)

New ansatz: Tidal synchronization of magneto-Rossby waves



magneto-Rossby

waves



Shallow water approximation with azimuthal magnetic field under the influence of tidal forces, using some (not well-known) wave damping factor λ

M. Dikpati, S.W. McIntosh, Space Weather 18 (2020), e2018SW002109

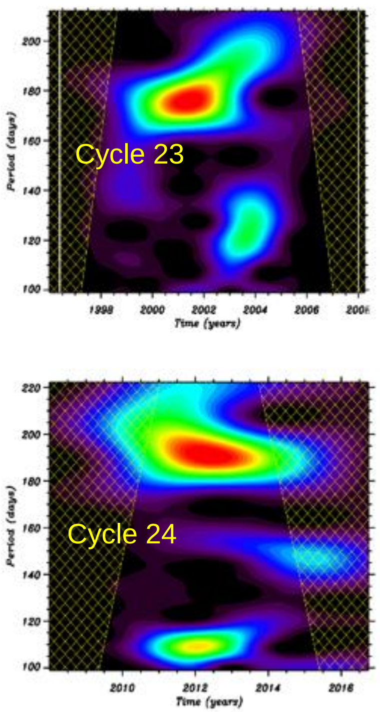
G. Horstmann et al., Astrophys. J. 944 (2023), 48

New ansatz: Tidal synchronization of magneto-Rossby waves

$$\Box_{v_A}^2 v - C_0^2 \Box_{v_A} \Delta v + f_0^2 \frac{\partial^2 v}{\partial t^2} - C_0^2 \beta \frac{\partial}{\partial x}\frac{\partial v}{\partial t} + 2\lambda \frac{\partial}{\partial t} \Box_{v_A} v - \lambda C_0^2 \Delta \frac{\partial v}{\partial t} + \lambda^2 \frac{\partial^2 v}{\partial t^2} = f_0 \frac{\partial}{\partial x}\frac{\partial^2 V}{\partial t^2} - \lambda \frac{\partial}{\partial y}\frac{\partial^2 V}{\partial t^2} - \frac{\partial}{\partial t}\frac{\partial}{\partial y}\Box_{v_A} V$$

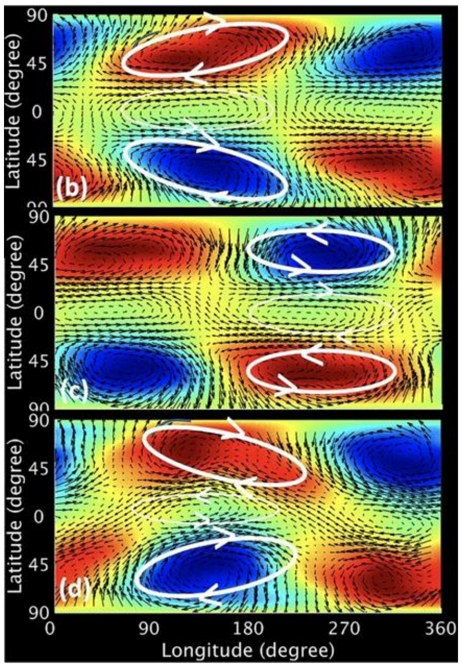
$$= \left[f_0 \Omega + 2\Omega^2 - \frac{2 v_A^2}{R_0^2} + \frac{2 f_0 \Omega}{R_0} y \right] \frac{4K\Omega}{R_0} \sin\left(\frac{2x}{R_0} - 2\Omega t\right) + \frac{4K\lambda\Omega^2}{R_0} \cos\left(\frac{2x}{R_0} - 2\Omega t\right)$$

Rieger-type periods



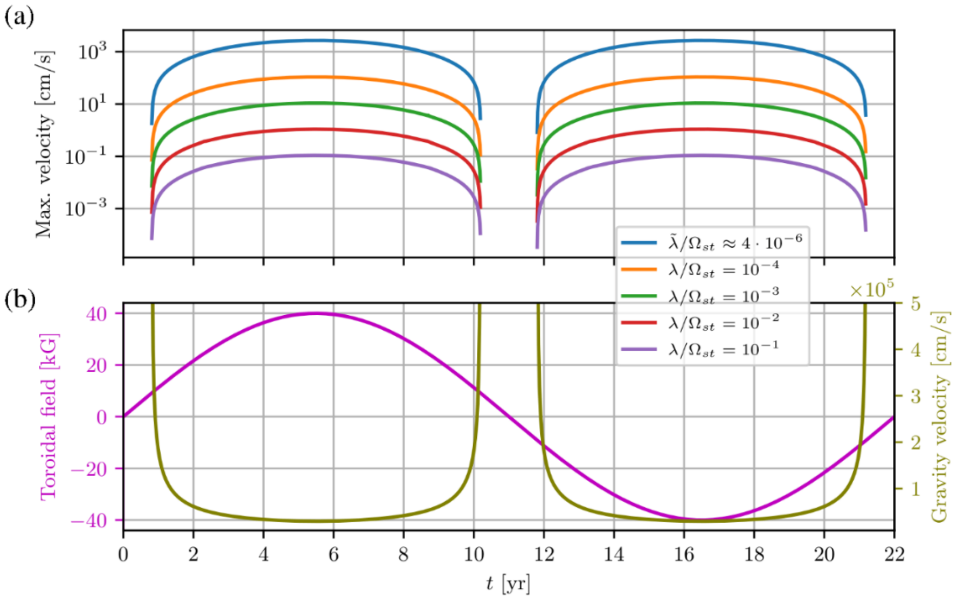
E. Gurgenashvili et al., A&A 653, A146 (2021)

magneto-Rossby waves



M. Dikpati, S.W. McIntosh, Space Weather 18 (2020), e2018SW002109

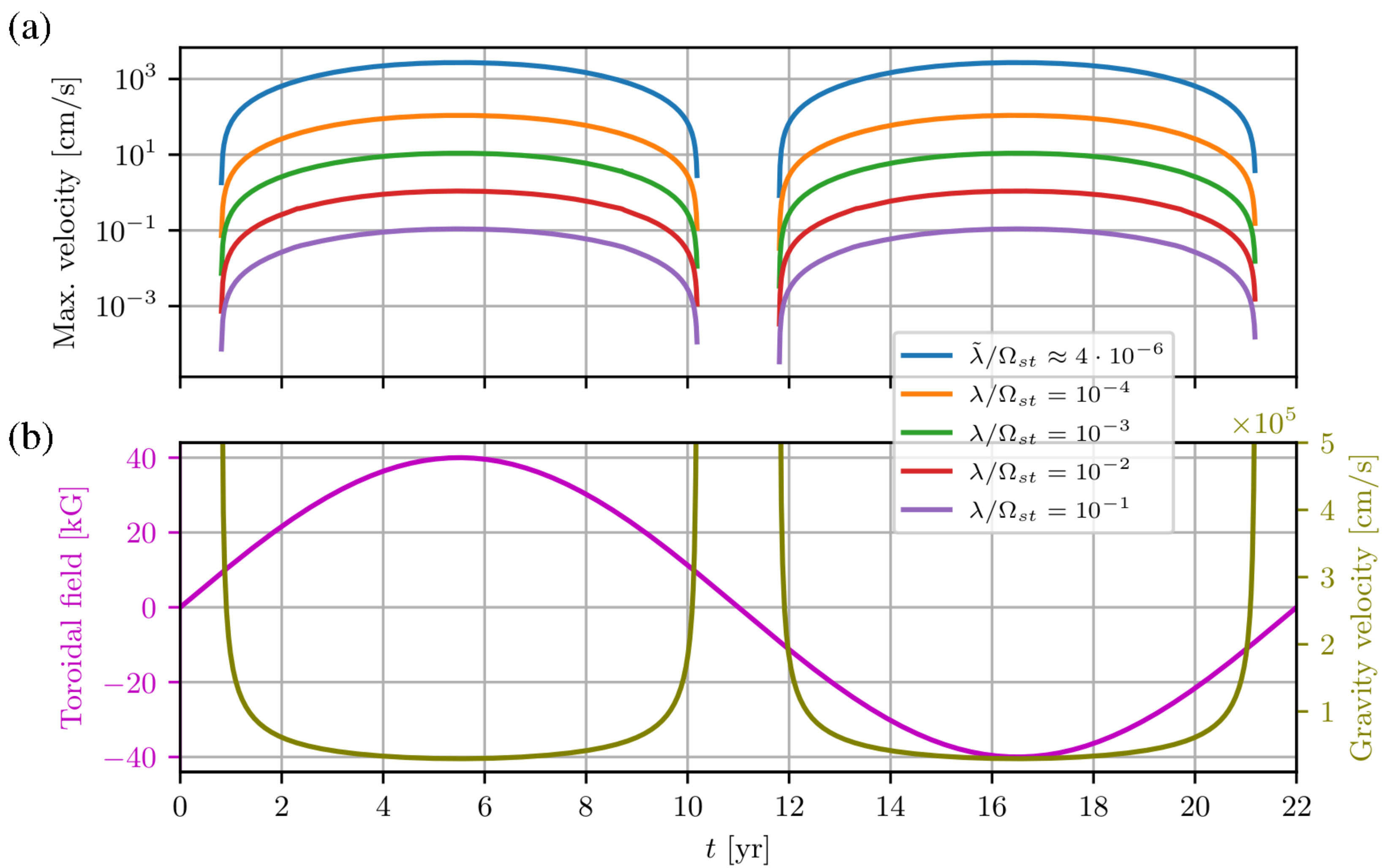
Analytical solution



Example: Venus-Jupiter spring tide, period 118 days; wave **velocities of up to 1-100 m/s are possible** for realistic tides

G. Horstmann et al., Astrophys. J. 944 (2023), 48; F.S. et al., Solar Phys. 299 (2024), 55

λ-dependent reaction on the 118-day spring tide of Venus-Jupiter

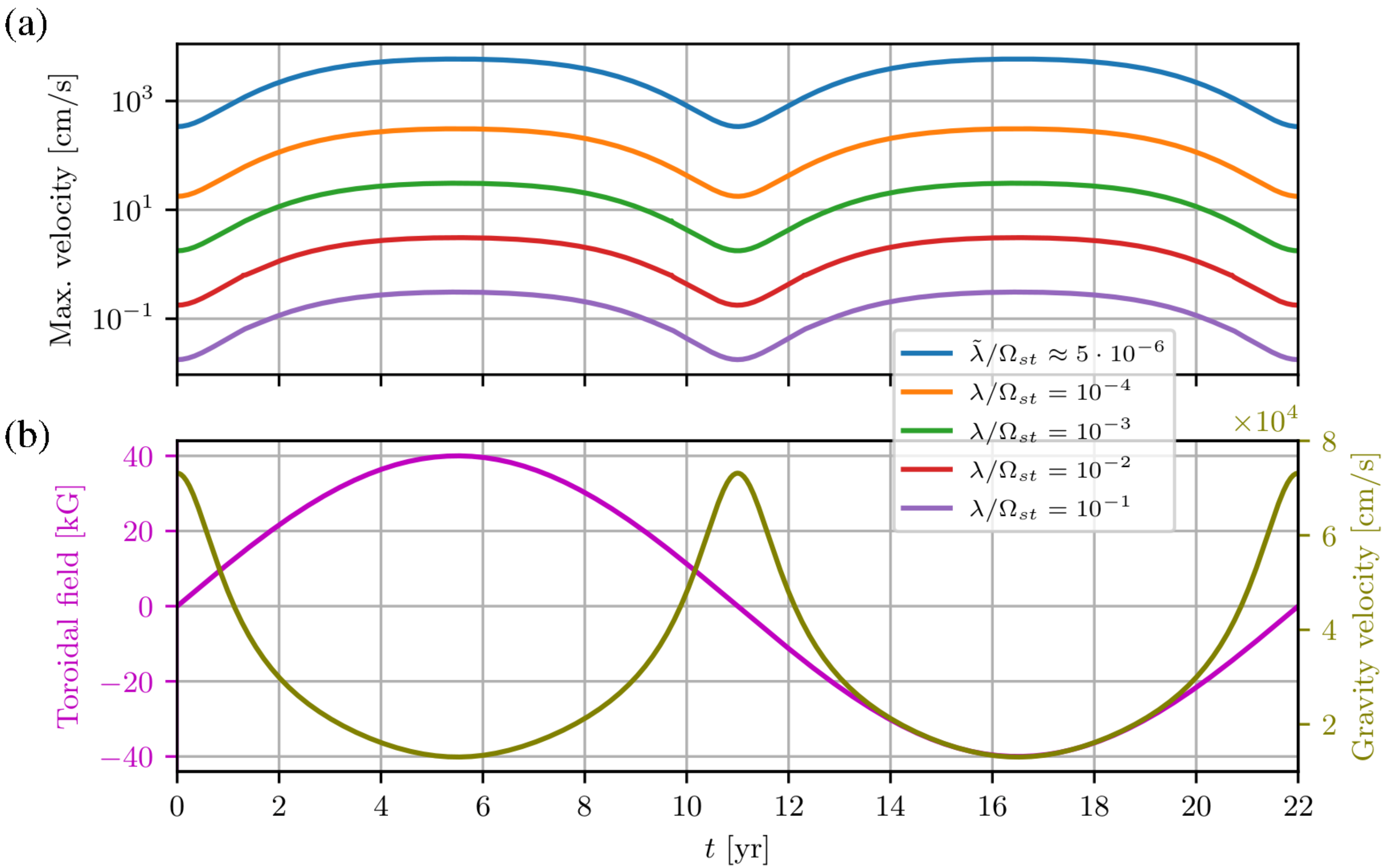


Simplified assumption:

$$V = K\left(\frac{1}{2} + \frac{y}{R_0}\right)\left[1 + \cos\left(\frac{2x}{R_0} + \Omega_{\rm st} t\right)\right]$$

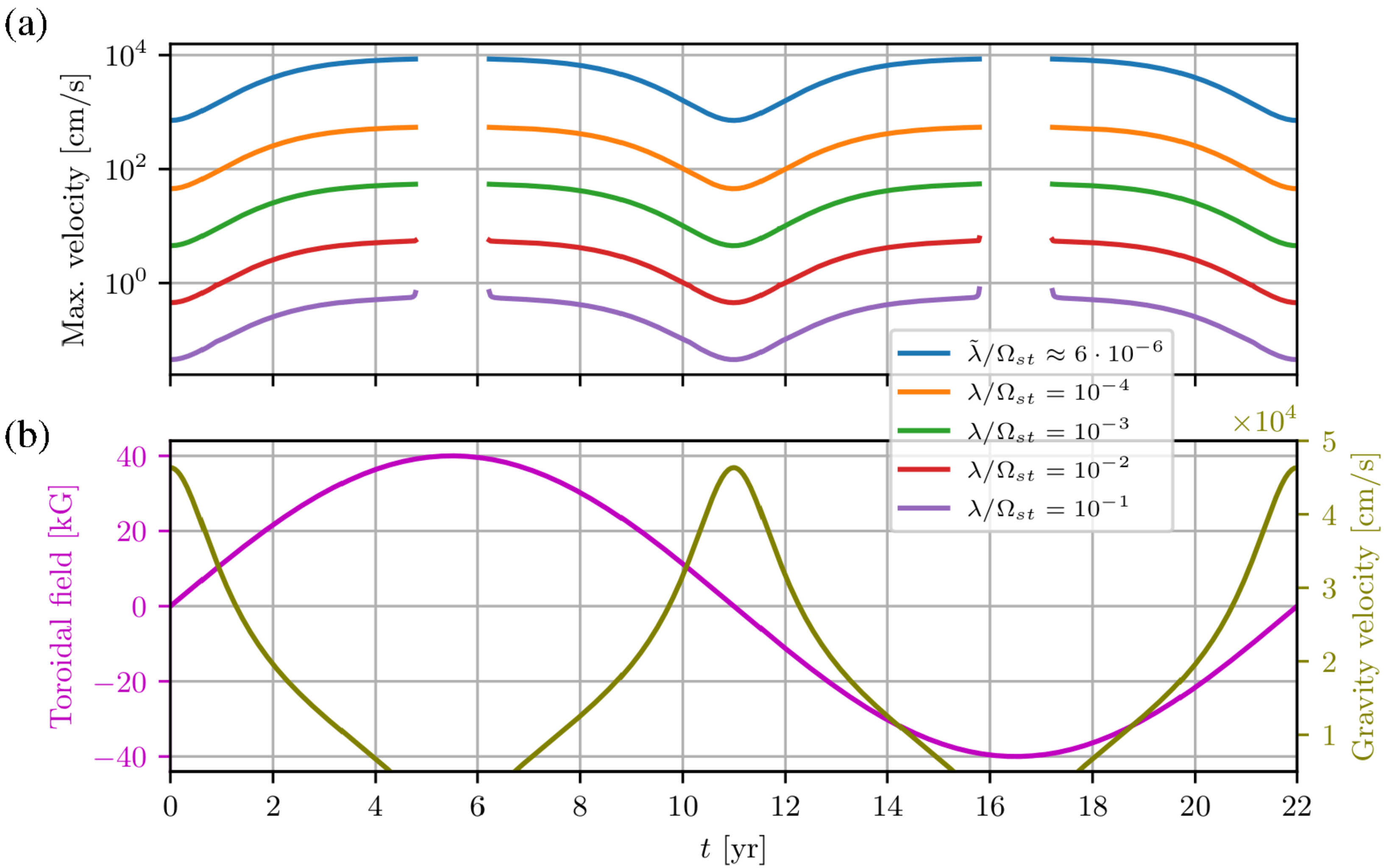
F.S. et al., Solar Phys. 299 (2024), 55

λ-dependent reaction on the 199-day spring tide of Earth-Jupiter



Simplified assumption: $$V = K\left(\frac{1}{2} + \frac{y}{R_0}\right)\left[1 + \cos\left(\frac{2x}{R_0} + \Omega_{st} t\right)\right]$$

λ-dependent reaction on the 292-day spring tide of Earth-Venus

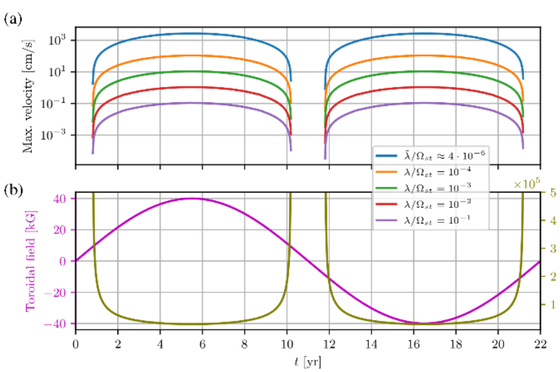


Simplified assumption:

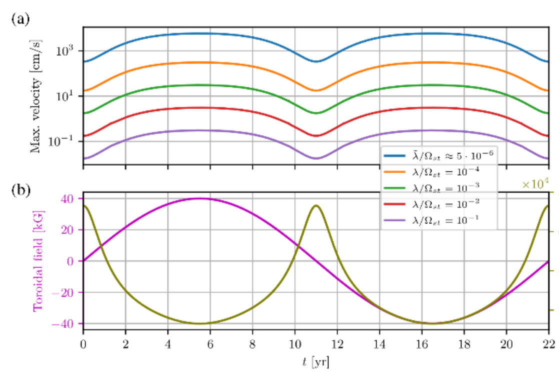
$$V = K\left(\frac{1}{2} + \frac{y}{R_0}\right)\left[1 + \cos\left(\frac{2x}{R_0} + \Omega_{\rm st} t\right)\right]$$

Nice, but where does the 11.07-yr come from?

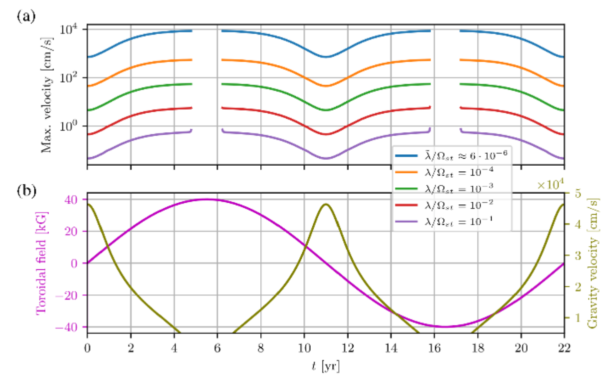
Venus-Jupiter spring tide with period 118 days

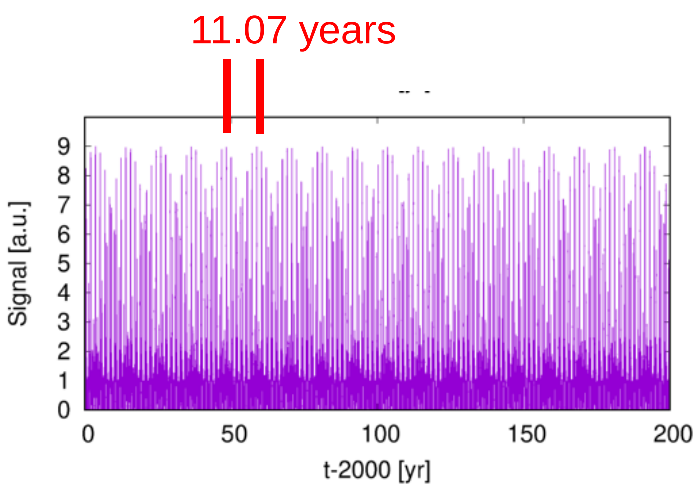


Earth-Jupiter spring tide with period 199 days



Venus-Earth spring tide with period 292 days





$$s(t) = \left[\cos\left(2\pi \cdot \frac{t - t_{VJ}}{0.5 \cdot P_{VJ}}\right) + \cos\left(2\pi \cdot \frac{t - t_{EJ}}{0.5 \cdot P_{EJ}}\right) + \cos\left(2\pi \cdot \frac{t - t_{VE}}{0.5 \cdot P_{VE}}\right)\right]^2$$

Any dynamo-relevant effect (helicity, α-effect, zonal flow, pressure…) will be a **quadratic functional** of the waves. This comprises a significant axisymmetric part with **11.07-year** period.

F.S. et al., Solar Physics 299 (2024), 51

DRESDEN concept

HZDR

A „realistic“ 2D α–Ω-dynamo model with meridional circulation…

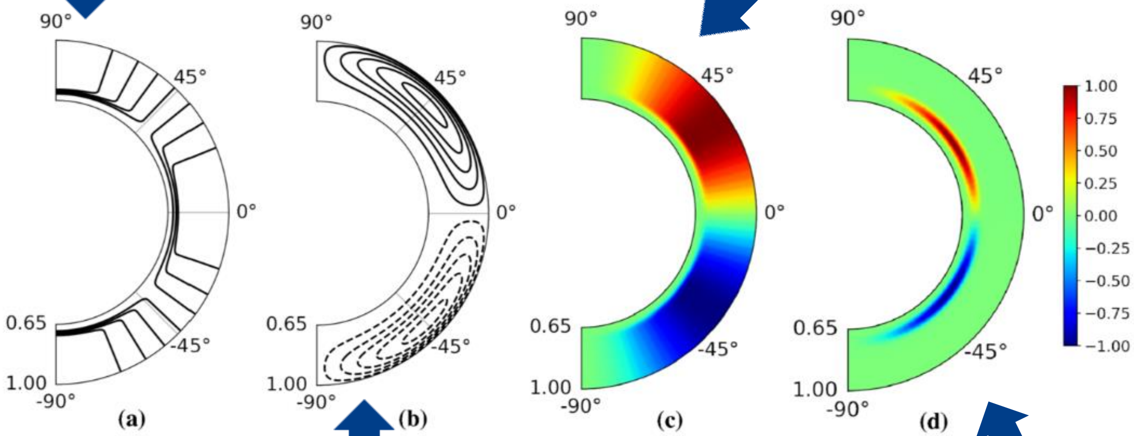
$$\frac{\partial B}{\partial t} = \tilde{\eta} D^2 B + \frac{1}{s}\frac{\partial (sB)}{\partial r}\frac{\partial \tilde{\eta}}{\partial r} - R_{\mathrm{m}} s \boldsymbol{u}_{\mathrm{p}} \cdot \nabla \left(\frac{B}{s}\right) + C_\Omega s (\nabla \times (A \boldsymbol{e}_\phi)) \cdot \nabla \Omega ,$$

$$\frac{\partial A}{\partial t} = \tilde{\eta} D^2 A - \frac{R_{\mathrm{m}}}{s} \boldsymbol{u}_{\mathrm{p}} \cdot \nabla (sA) + C_\alpha^{\mathrm{c}} \alpha^{\mathrm{c}} B + C_\alpha^{\mathrm{p}} \alpha^{\mathrm{p}} B ,$$

$$C_\Omega = \Omega_{\mathrm{eq}} \mathrm{R}_\odot^2 / \eta_{\mathrm{t}} ,$$
$$R_{\mathrm{m}} = u_0 \mathrm{R}_\odot / \eta_{\mathrm{t}} ,$$
$$C_\alpha^{\mathrm{c}} = \alpha_{\max}^{\mathrm{c}} \mathrm{R}_\odot / \eta_{\mathrm{t}} ,$$
$$C_\alpha^{\mathrm{p}} = \alpha_{\max}^{\mathrm{p}} \mathrm{R}_\odot / \eta_{\mathrm{t}} .$$

$$\Omega(r,\Theta) = C_\Omega \left\{ \Omega_{\mathrm{c}} + \frac{1}{2}\left[1 + \mathrm{erf}\left(\frac{r - r_{\mathrm{c}}}{d}\right)\right](1 - \Omega_{\mathrm{c}} - c_2 \cos^2\Theta) \right\}$$

$$\alpha^{\mathrm{c}}(r,\Theta,t) = C_\alpha^{\mathrm{c}} \frac{3\sqrt{3}}{4} \sin^2\Theta \cos\Theta \left[1 + \mathrm{erf}\left(\frac{r - r_{\mathrm{c}}}{d}\right)\right]\left[1 + \frac{|\boldsymbol{B}(r,\Theta,t)|^2}{B_0^2}\right]^{-1}$$



$$\alpha = \alpha^{\mathrm{c}} + \alpha^{\mathrm{p}}$$

Assumed to result from wave helicity

$$\boldsymbol{u}_{\mathrm{p}} = \nabla \times (\psi(r,\Theta) \boldsymbol{e}_\phi)$$

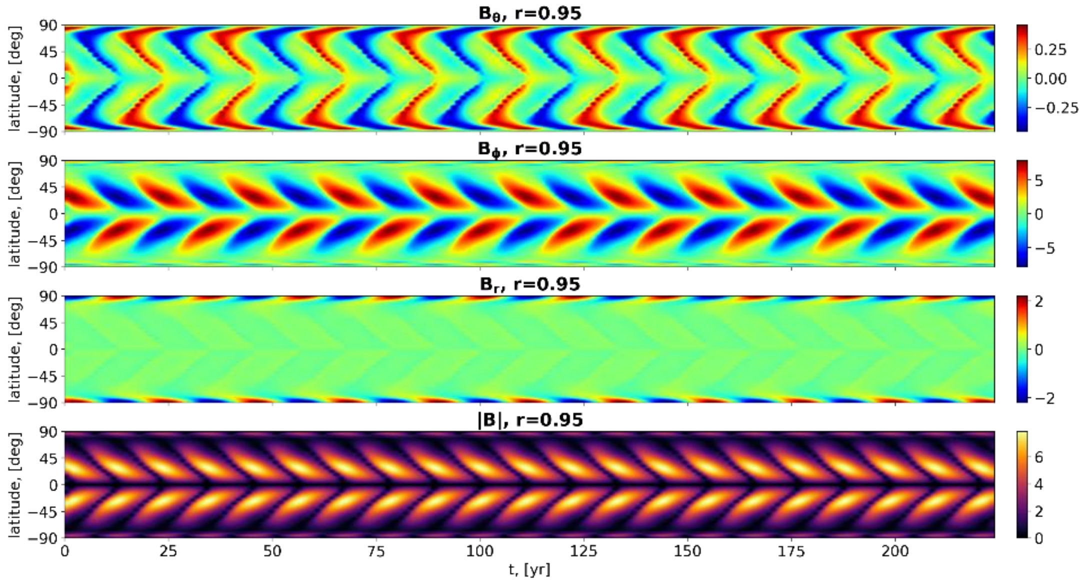
$$\psi(r,\Theta) = R_{\mathrm{m}} \left\{ -\frac{2}{\pi} \frac{(r - r_{\mathrm{b}})^2}{(1 - r_{\mathrm{b}})} \sin\left(\pi \frac{r - r_{\mathrm{b}}}{1 - r_{\mathrm{b}}}\right) \cos\Theta \sin\Theta \right\}$$

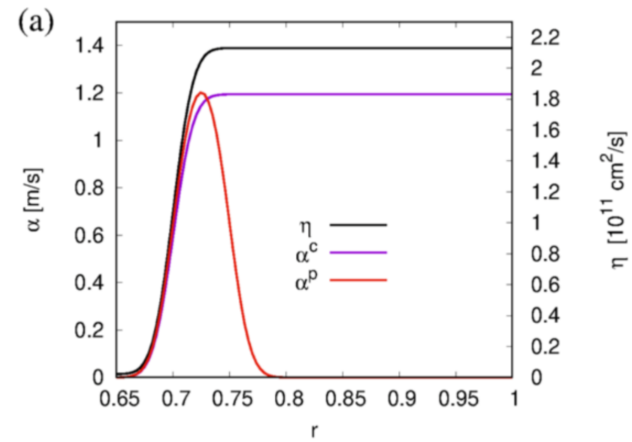
$$\alpha^{\mathrm{p}}(r,\Theta,t) = C_\alpha^{\mathrm{p}} \frac{1}{\sqrt{2}} \sin^2\Theta \cos\Theta \left[1 + \mathrm{erf}\left(\frac{r - r_{\mathrm{c}}}{d}\right)\right]\left[1 - \mathrm{erf}\left(\frac{r - r_{\mathrm{d}}}{d}\right)\right] \times \frac{2|\boldsymbol{B}(r,\Theta,t)|^2}{1 + |\boldsymbol{B}(r,\Theta,t)|^4} \sin(2\pi t / T_{\mathrm{f}}) ,$$

11.07 yr

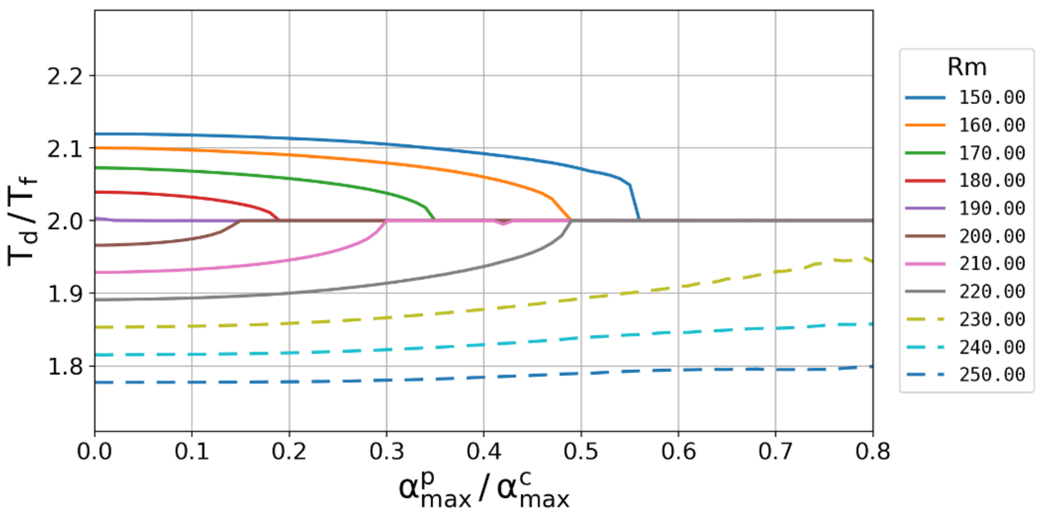
M. Klevs, F. Stefani., L. Jouve, Solar Phys. 298, 90 (2023)

…shows again parametric resonance





Much higher conductivity in the tachocline than in the convection zone

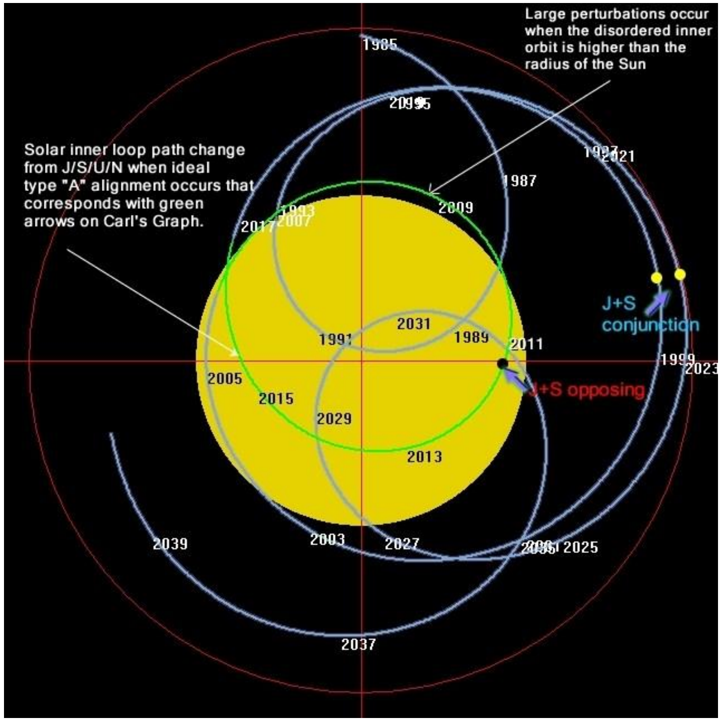


For a reasonable value α_0=1.3 m/s, we need just **~dm/s** for the synchronized α to entrain the entire dynamo

DRESDEN concept

HZDR

Suess/de Vries cycle: A beat period between 22.14 and 19.86 yr ?



Tidal forcing → **22.14 years**

Sun around barycenter → **19.86 years**

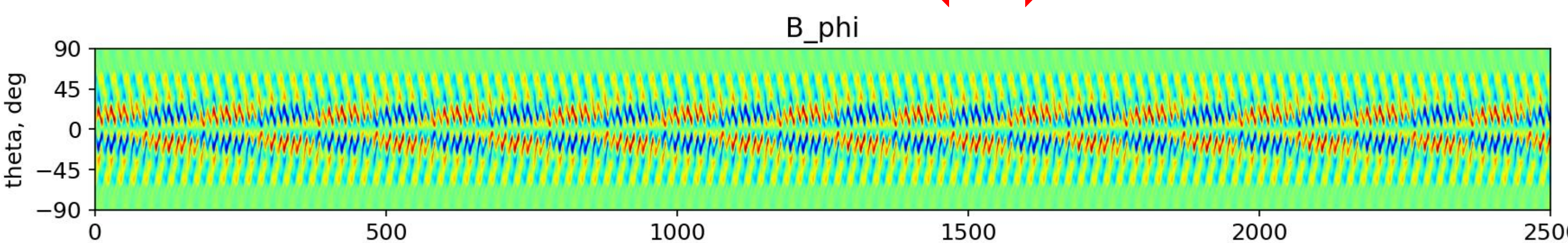
(with unclear spin-orbit coupling

Talk by J. Shirley

Beat period: **193 years**

19.86 x 22.14/(22.14-19.86)

193 years: Suess-de Vries cycle



DRESDEN concept

HZDR

A little regression to an 1D α–Ω-model (with periodic α term):

$$\frac{\partial B(\theta,t)}{\partial t} = \omega(\theta,t)\frac{\partial A(\theta,t)}{\partial \theta} - \frac{\partial^2 B(\theta,t)}{\partial \theta^2} - \kappa B^3(\theta,t)$$

$$\frac{\partial A(\theta,t)}{\partial t} = \alpha(\theta,t)B(\theta,t) - \frac{\partial^2 A(\theta,t)}{\partial \theta^2},$$

Loss parameter with angular momentum periodicity ~19.86 yr

$$\omega(\theta,t) = \omega_0(1 - 0.939 - 0.136\cos^2(\theta) - 0.1457\cos^4(\theta))\sin(\theta)\,,$$

$$\alpha(\theta,t) = \alpha^p(\theta,t) + \alpha^c(\theta,t)$$

$$\alpha^p(\theta,t) = \alpha_0^p \sin(2\pi t/11.07)\mathrm{sgn}(90^\circ - \theta)\frac{B^2(\theta,t)}{(1 + q_\alpha^p B^4(\theta,t))} \text{ for } 55^\circ < \theta < 125^\circ$$

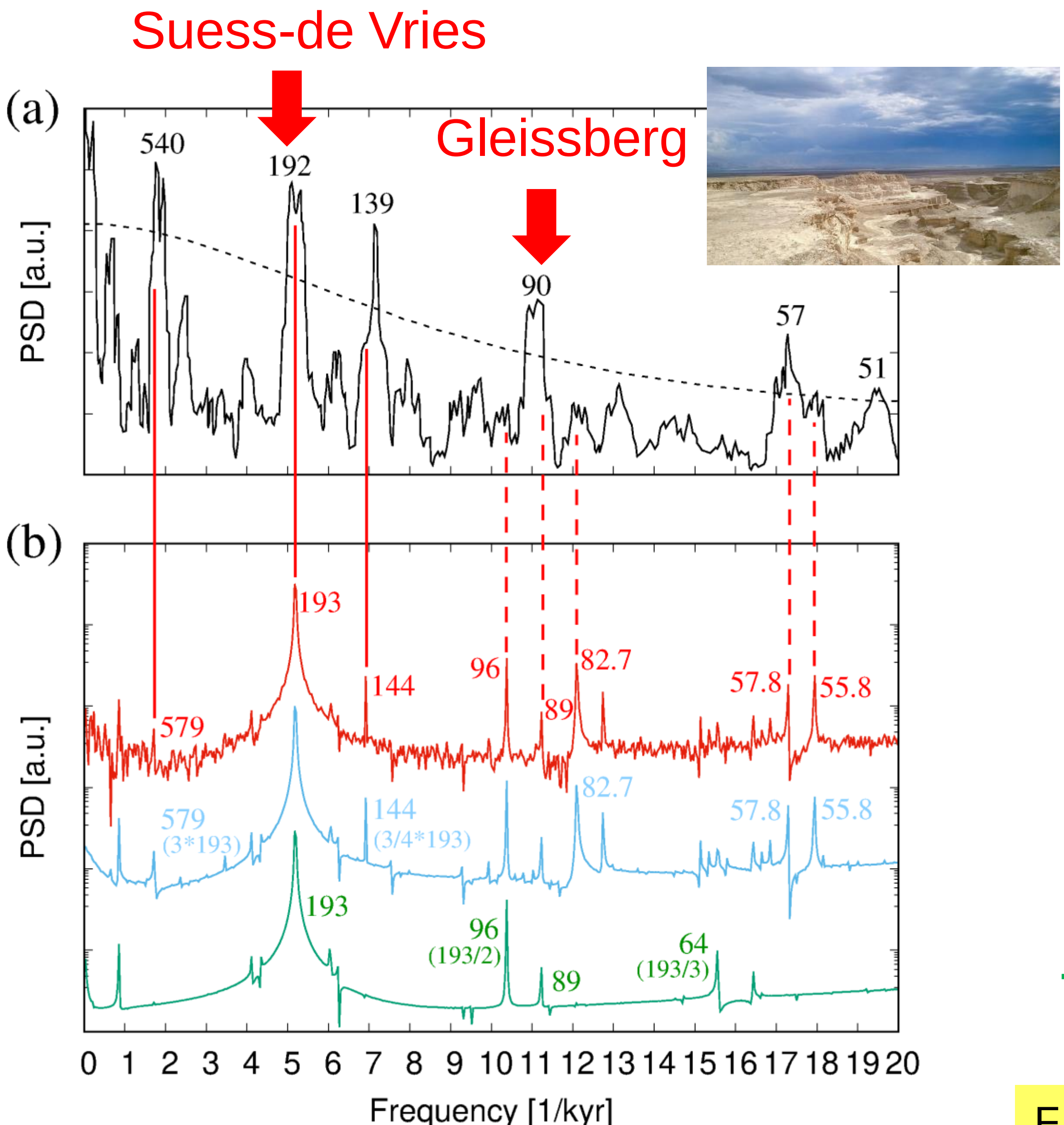
$$\alpha^c(\theta,t) = \alpha_0^c\big(1 + \xi(t)\big)\sin(2\theta)/\big(1 + q_\alpha^c B^2(\theta,t)\big)$$

Noise with strength D

F.S. et al., Solar Physics 294 (2019), 60,
Solar Physics 296, 88 (2021)

Comparison: numerical results - sediment data (Lake Lisan)

!



Yearly sediment thicknesses over 8500 years (climate archive)

S. Prasad et al., Geology 32, 581 (2004)

1D α–Ω-dynamo model

…with some noise

…all planets

…only Jupiter and Saturn

F.S. et al., Solar Physics 296, 88 (2021); 299 (2024), 55

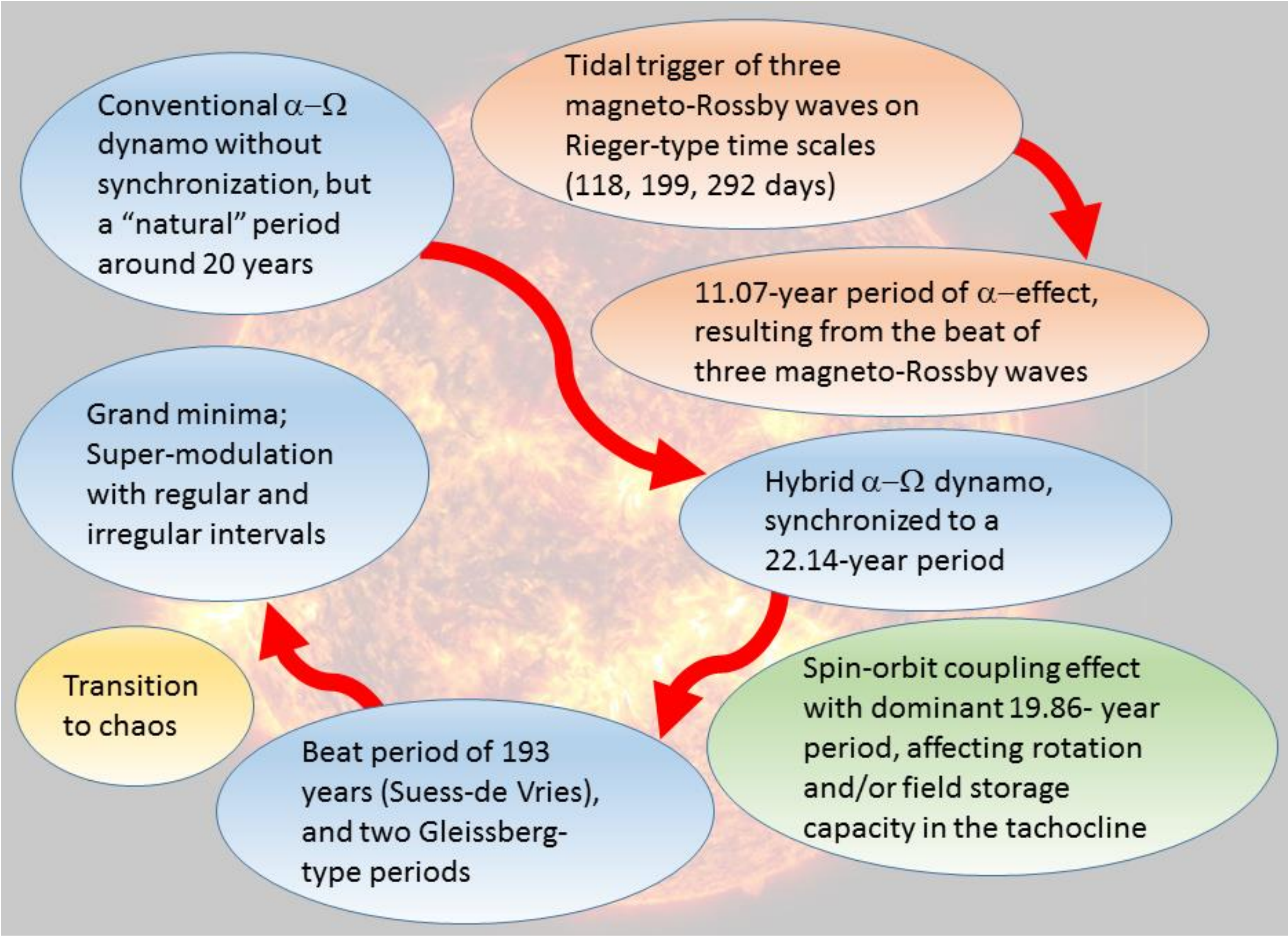
Summary

- General principle: Energy is „harvested“ on the shortest possible time-scales
- **Various dynamo periods emerge as beat periods**
- Three tidally triggered magneto-Rossby waves on Rieger-type time-scale → Schwabe/Hale
- Hale+Barycentric motion → Suess-de Vries (+Gleissberg)
- **Self-consistency: The sharp Suess-de Vries peak at 193 years could hardly be explained without phase-stability of the primary Hale cycle at 22.14 years**

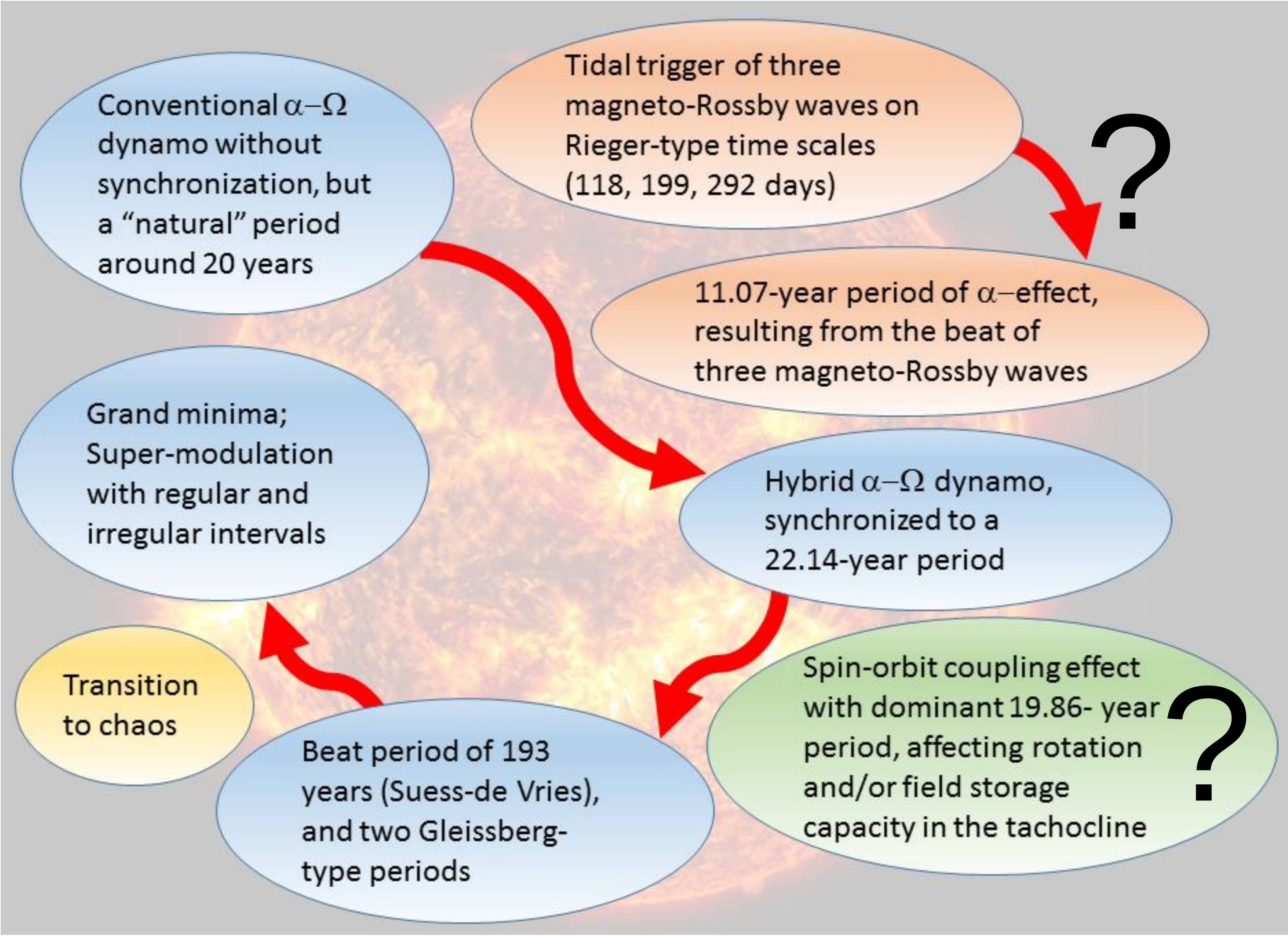
DRESDEN concept

HZDR

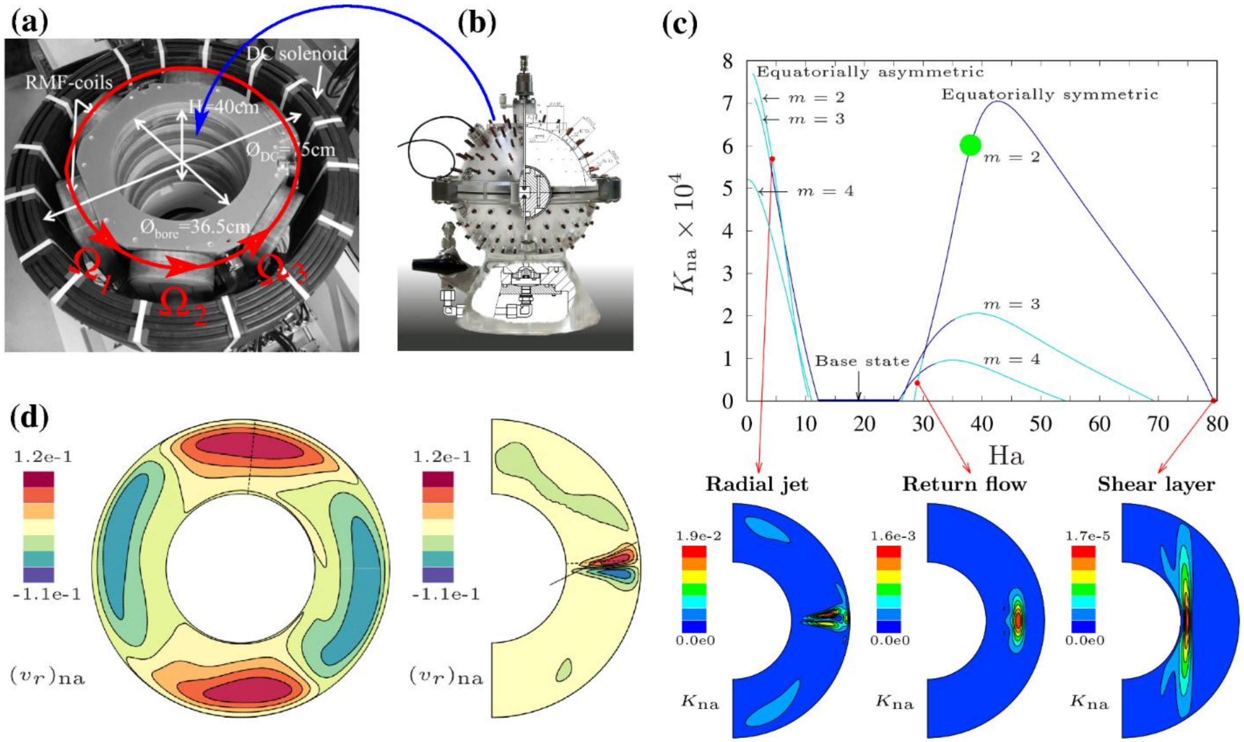
Summary


Conventional α−Ω dynamo without synchronization, but a "natural" period around 20 years
Tidal trigger of three magneto-Rossby waves on Rieger-type time scales (118, 199, 292 days)
11.07-year period of α−effect, resulting from the beat of three magneto-Rossby waves
Grand minima; Super-modulation with regular and irregular intervals
Hybrid α−Ω dynamo, synchronized to a 22.14-year period
Spin-orbit coupling effect with dominant 19.86- year period, affecting rotation and/or field storage capacity in the tachocline
Transition to chaos
Beat period of 193 years (Suess-de Vries), and two Gleissberg-type periods

Summary and open problems



Our plan for an experiment with tidal excitation of three waves



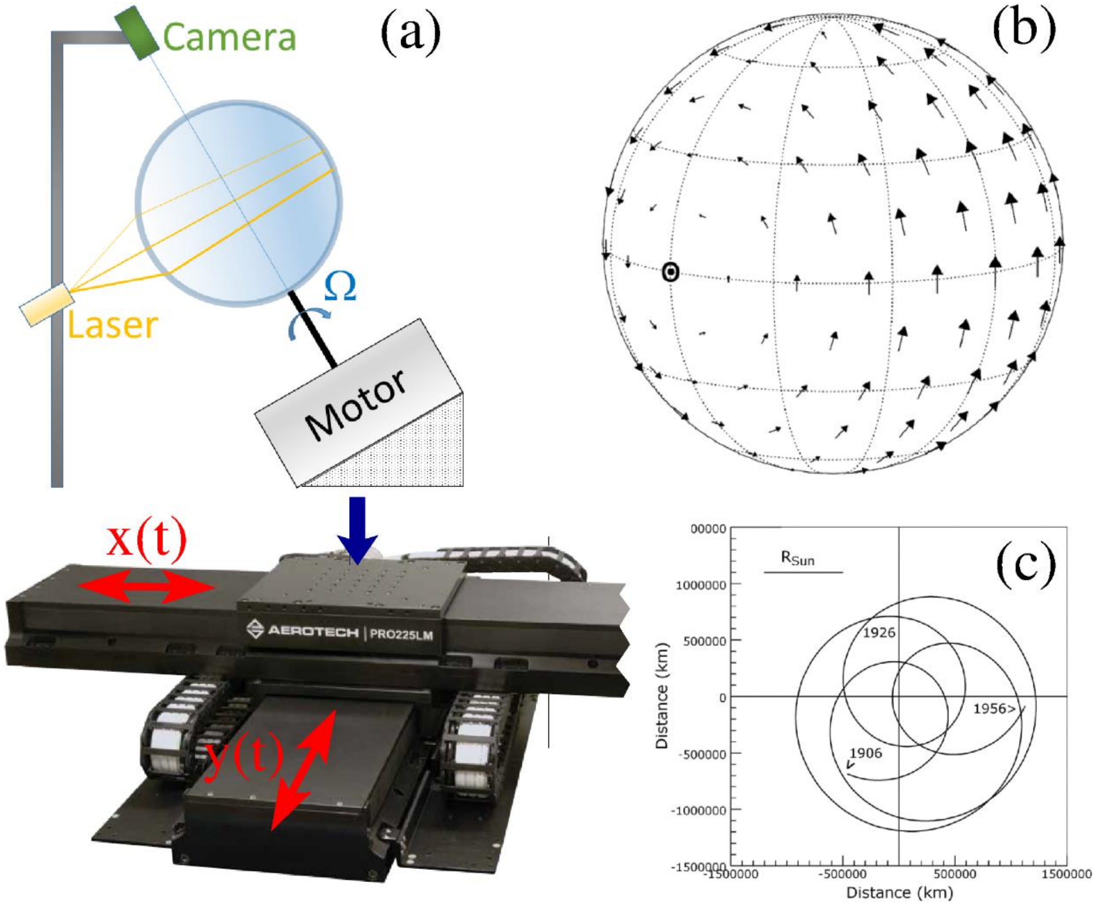
Jüstel et al.,
Phys. Fluids 34,
104115 (2022)

Ogbonna et al.,
Phys. Fluids 32,
124119 (2020)

Excitation of three waves with azimuthal wave number m=2 (c,d) in a magnetized spherical Couette flow HEDGEHOG (b) by tide-like forces generated in the MultiMag facility (a)

Study of beat period in the emerging zonal flow
(and the α-Effect)

Our plan for an experiment on spin-orbit coupling



Rosette-shaped barycentric motion (c) and inclined rotation axis lead to spin-orbit coupling

Emerging torque has typical m=1 structure (b) well known from precession

J. Shirley, Planet. Space Sci. 141, 1 (2017), 1339

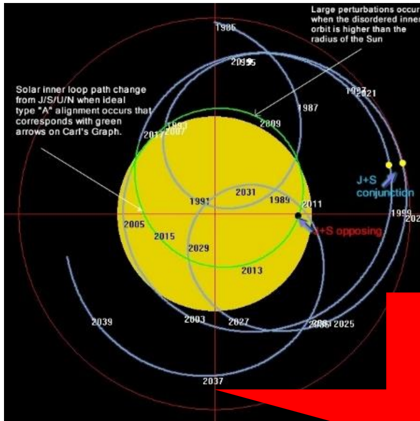
Theory is yet underexplored, parameters still to be constrained by observation
→ Improved theory + experiment (a)

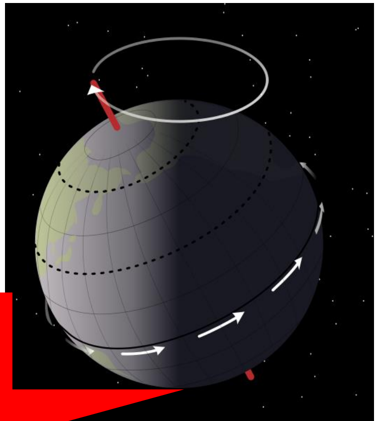
Talk by J. Shirley

DRESDEN concept HZDR

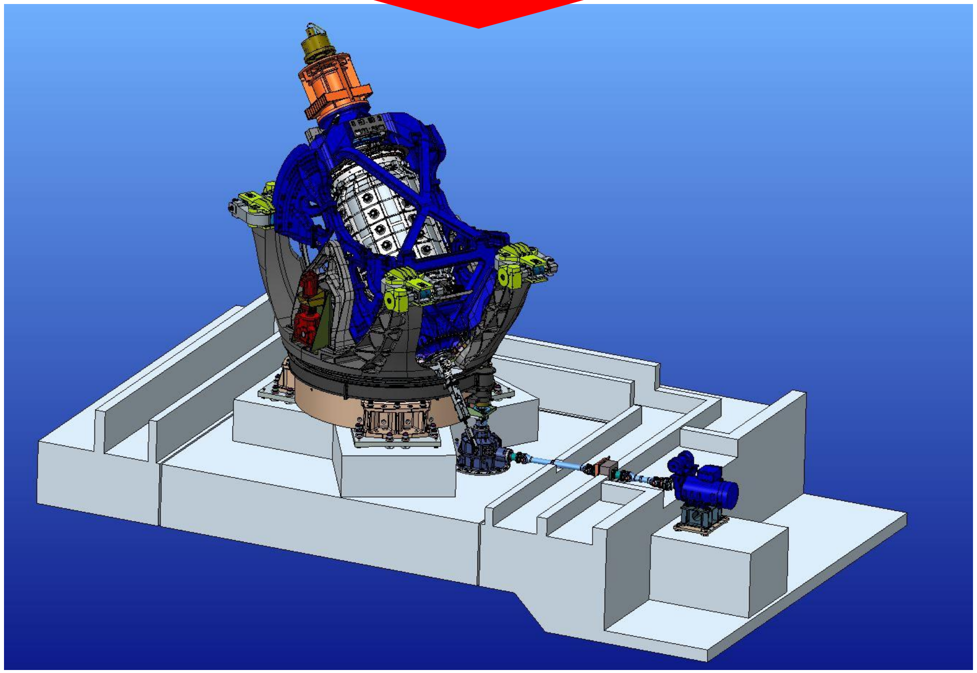
Precession driven DRESDYN dynamo: Two motivations

Sun:
Similarity of forcing term from spin-orbit coupling with that of precession

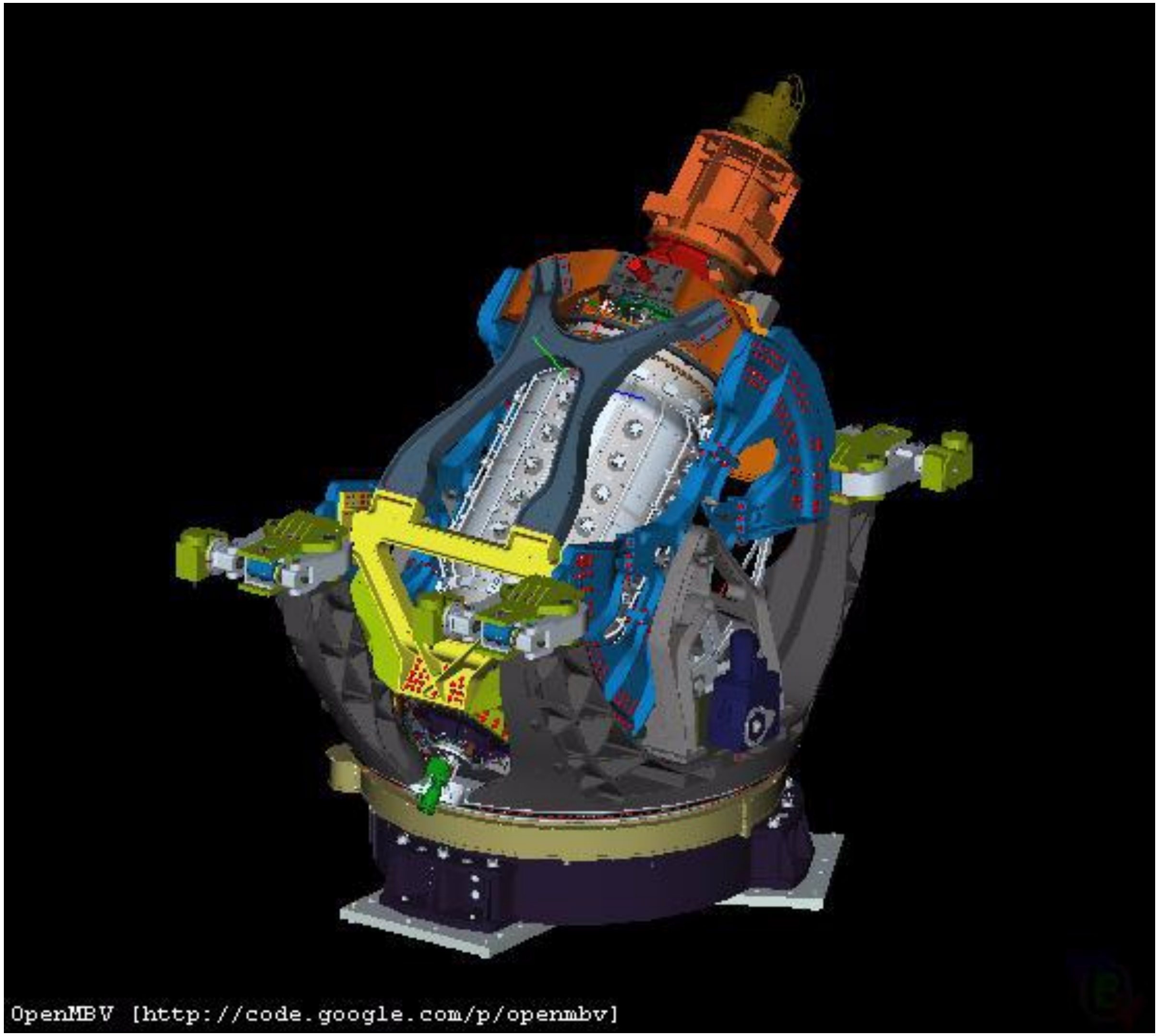




Earth:
Role of various Milankovic cycles on geomagnetic field (and its reversal statistics)



Precession driven dynamo experiment

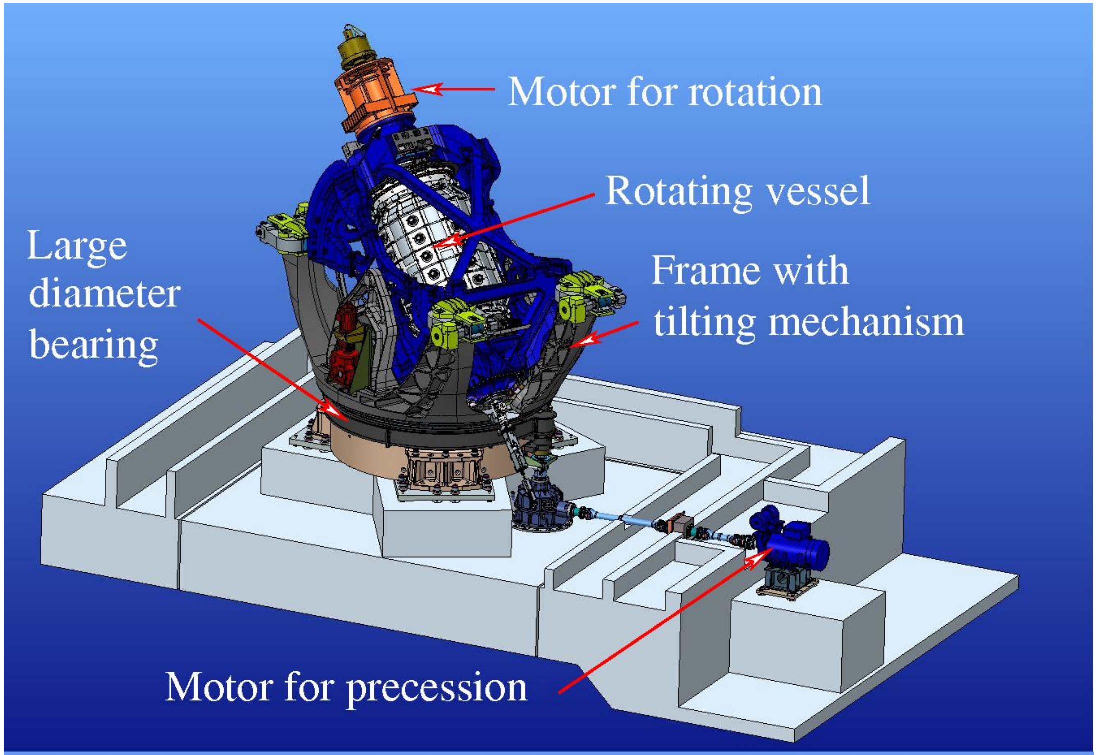


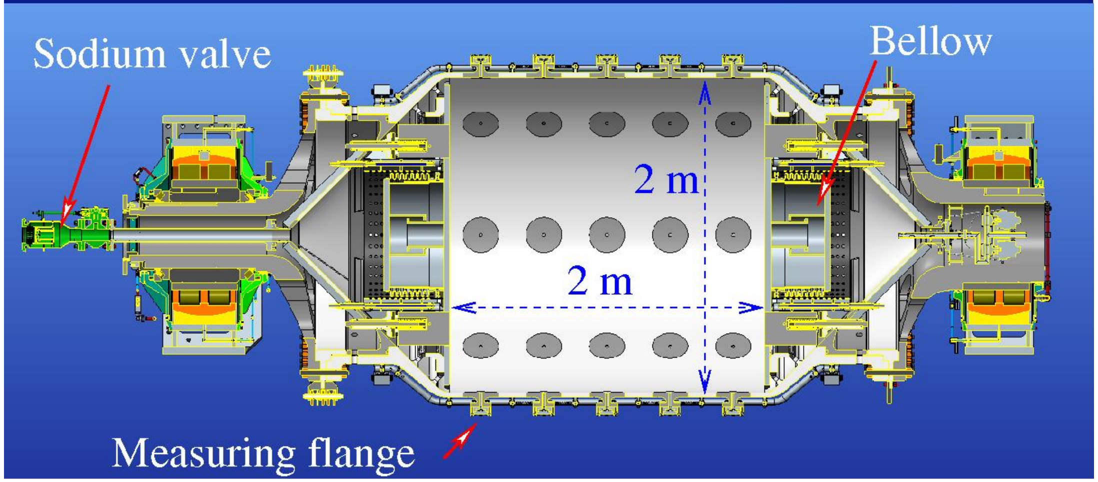
Slow motion (factor 10)

Precession driven dynamo experiment

Key parameters:

- Cylinder with 2 m diameter and 2 m height, 8 tons of liquid sodium
- Cylinder rotation: 10 Hz (will need some 800 kW motor power)
- Turntable rotation: 1 Hz
- Magnetic Reynolds number ~ 700
- Gyroscopic torque onto the basement: 8 MNm !





“Fundamental” problems due to huge gyroscopic torque

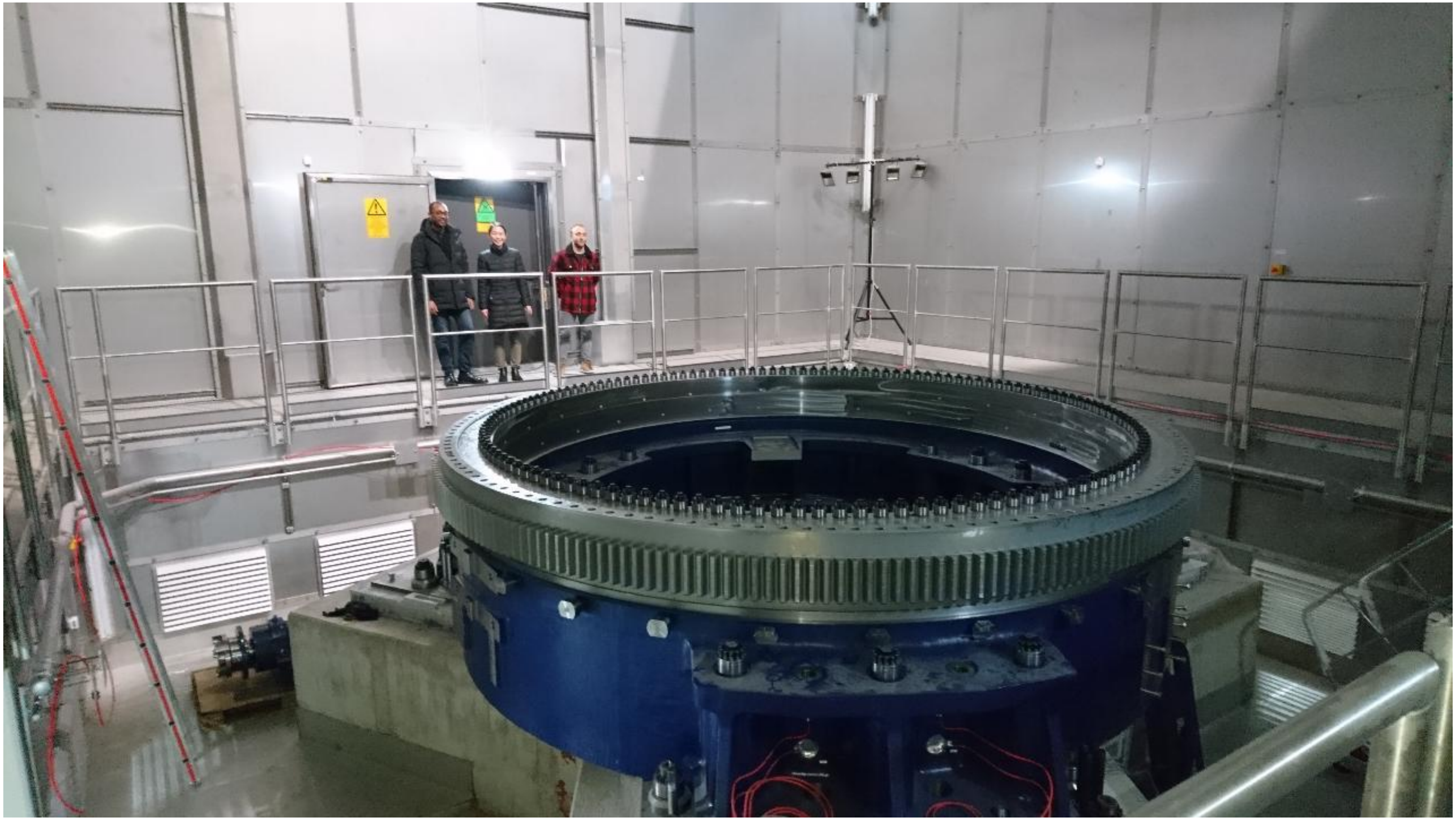
April 2013: drilling 7 holes (22 m deep)

July 2013: Constructing the ferroconcrete basement

May 2015: The tripod for the dynamo within the containment (with stainless steel “wallpaper”)

DRESDEN concept HZDR

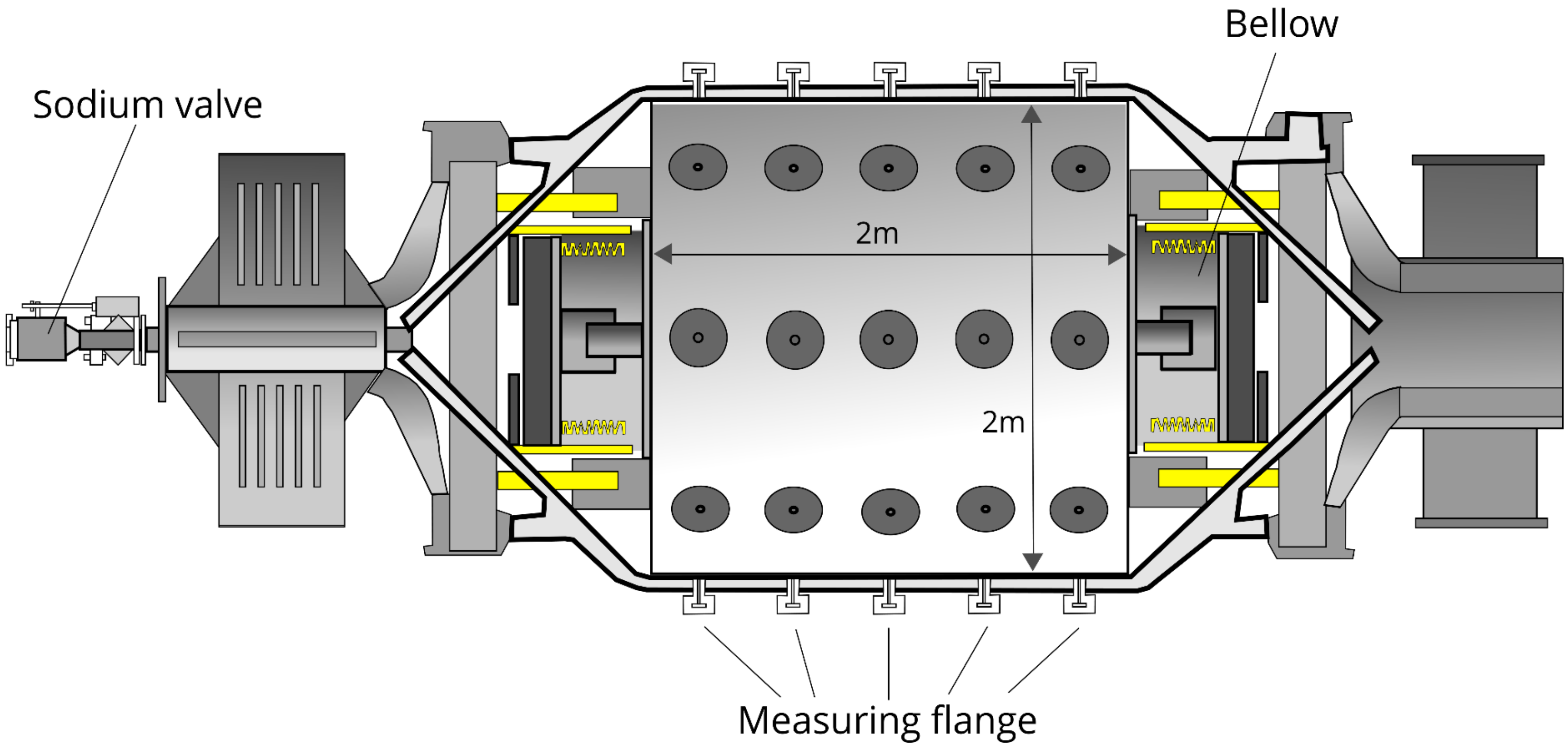
Large ball bearing installed (12/2018)



DRESDEN concept HZDR

Traverse and pylons (01/2019)

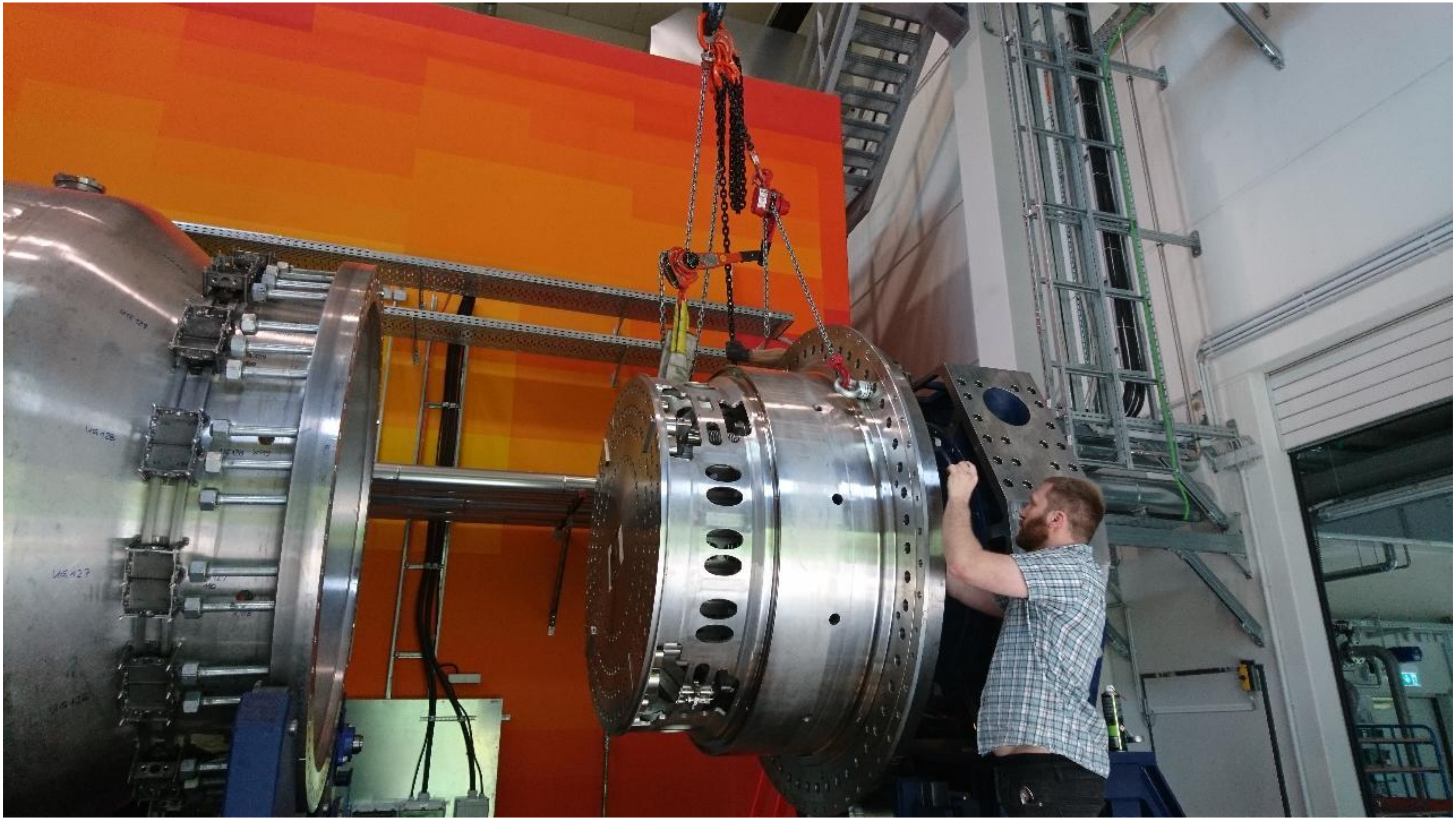
Rotation vessel with bearings



Pressure test (with 35 bar) of the rotation vessel (3/2019)

The vessel arrives at HZDR (July 3, 2020)

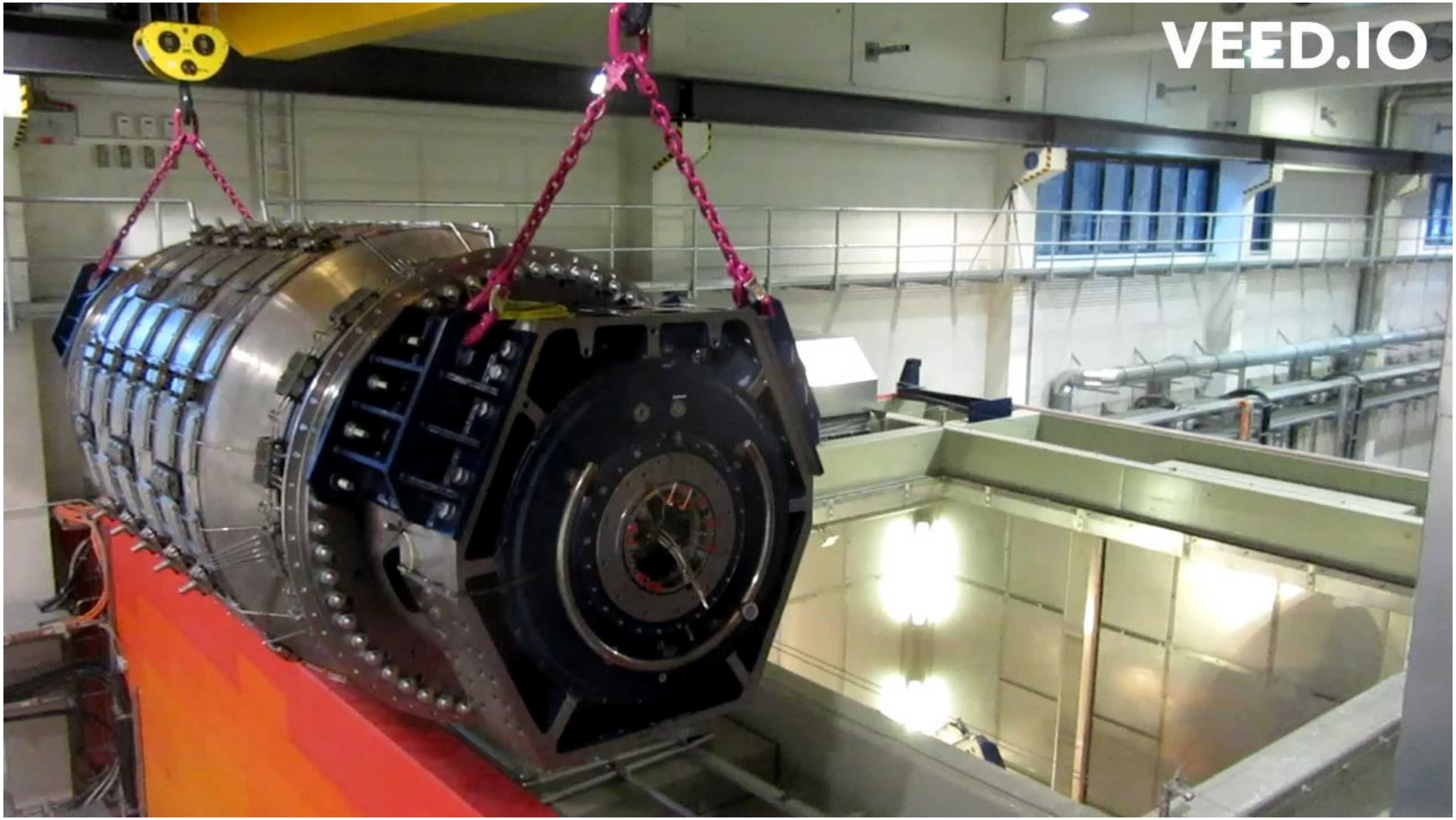
Assembly of the first conical end and the bearing (May 2022)



DRESDEN concept

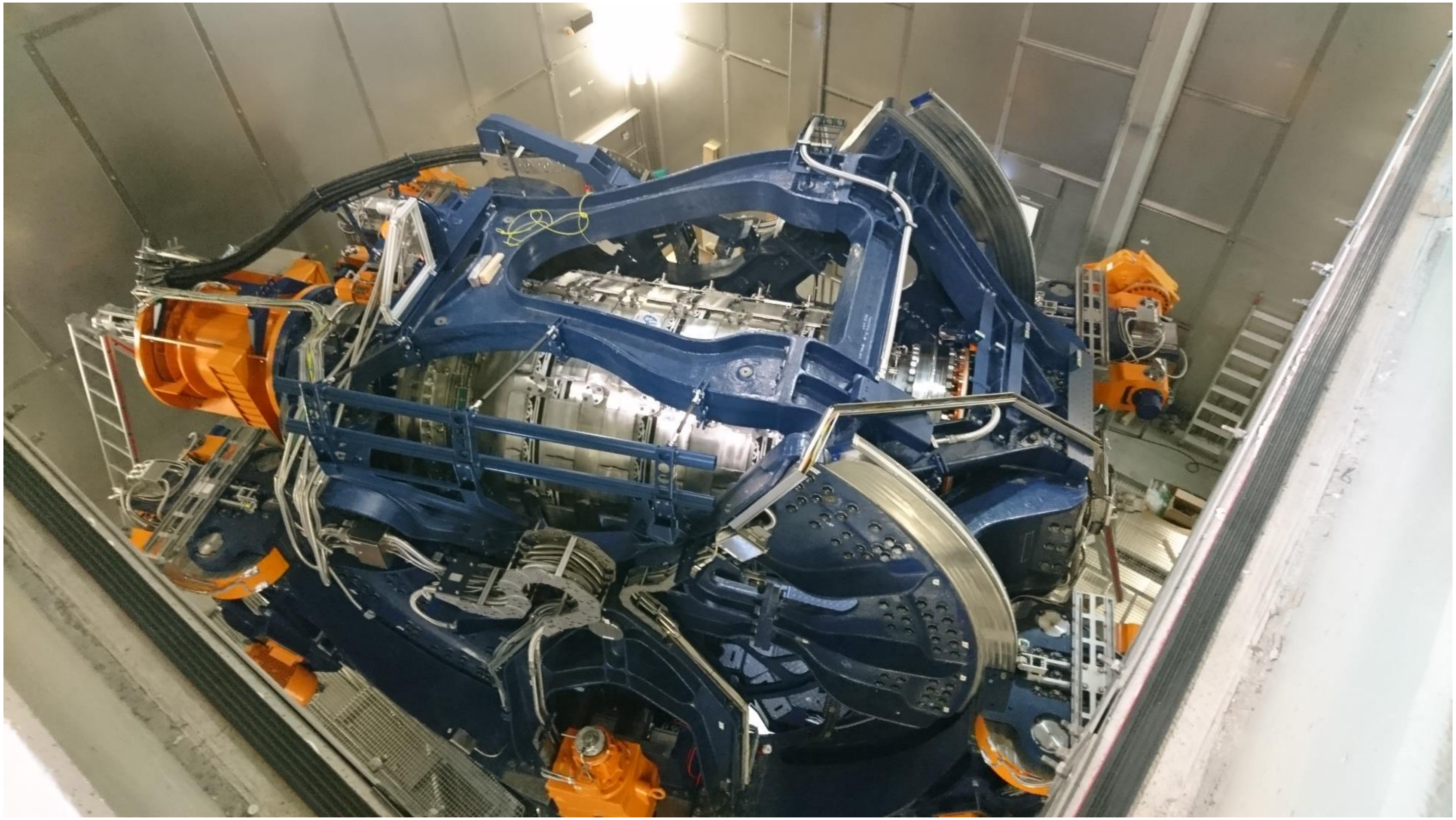
HZDR

And then came January 17, 2024…

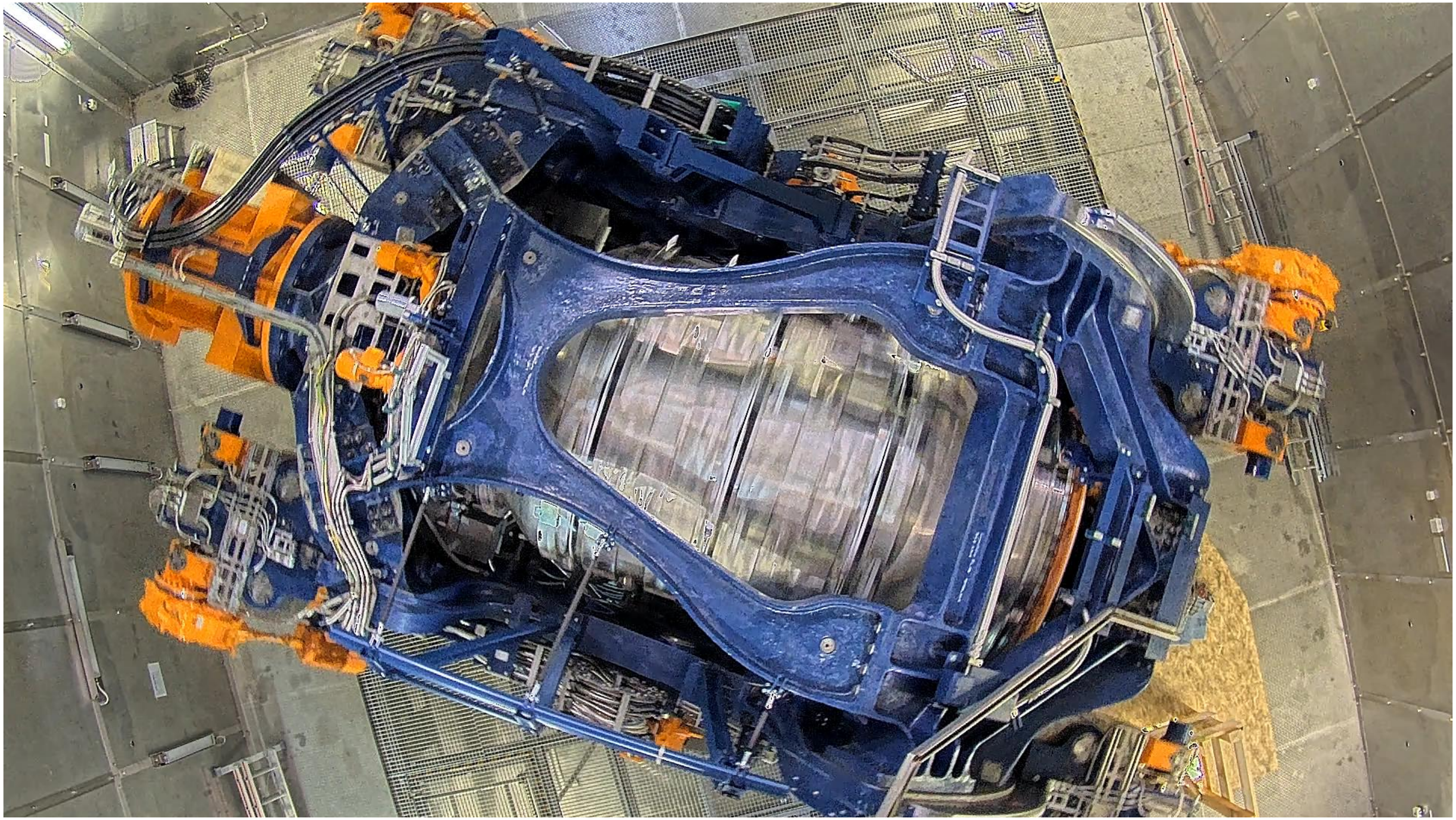


DRESDEN concept

Ready to go…



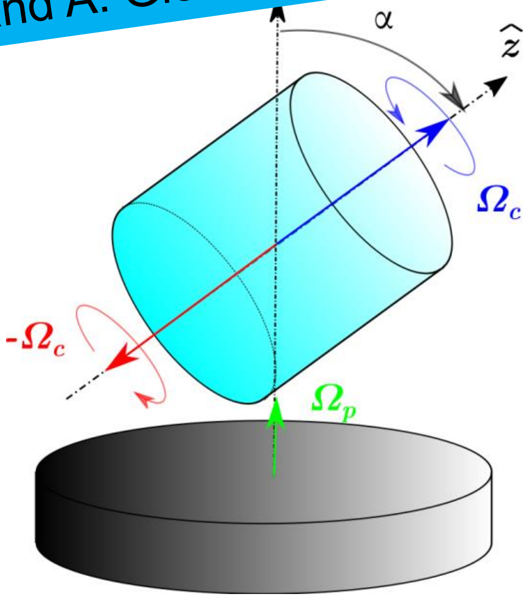
September 5, 2024: Rotation 1.7 Hz, Precession 0.08 Hz

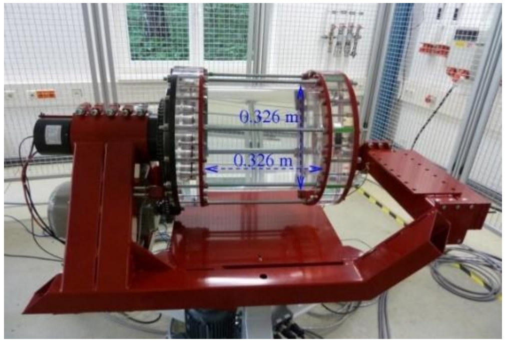


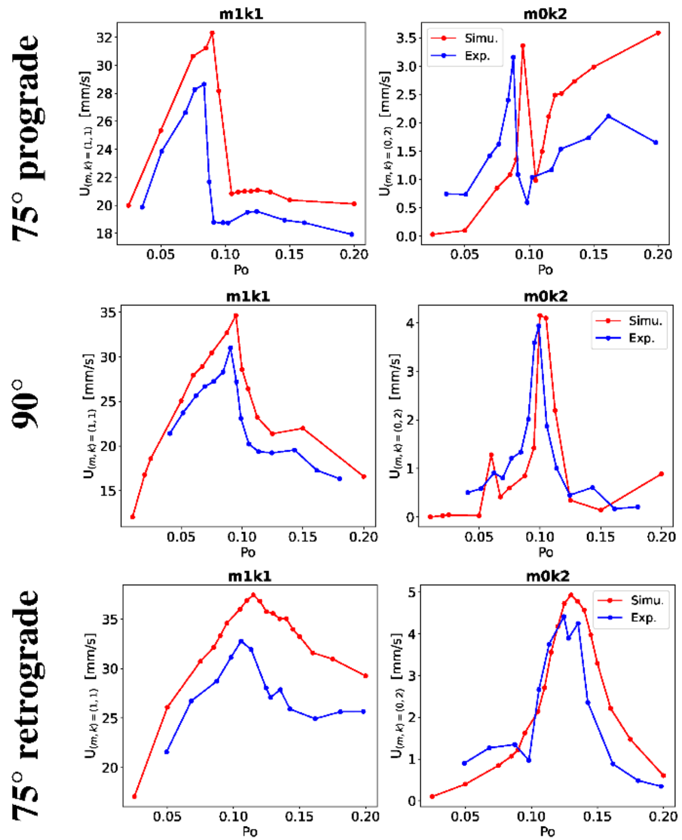
Precession driven dynamo: Prospects for self-excitation

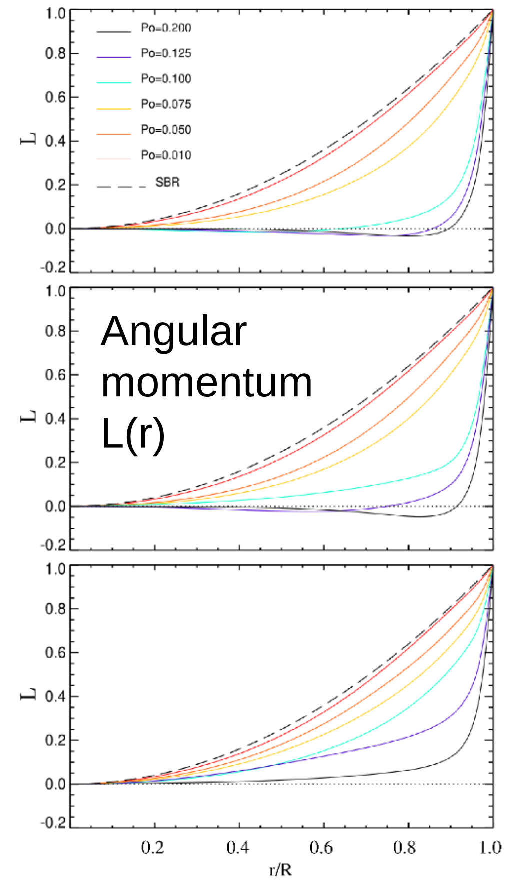
Good agreement of measured and simulated dynamo-relevant flow modes

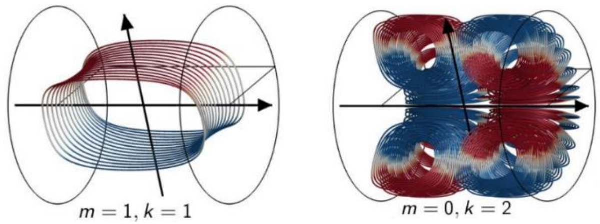
Talks by Th. Gundrum and A. Giesecke











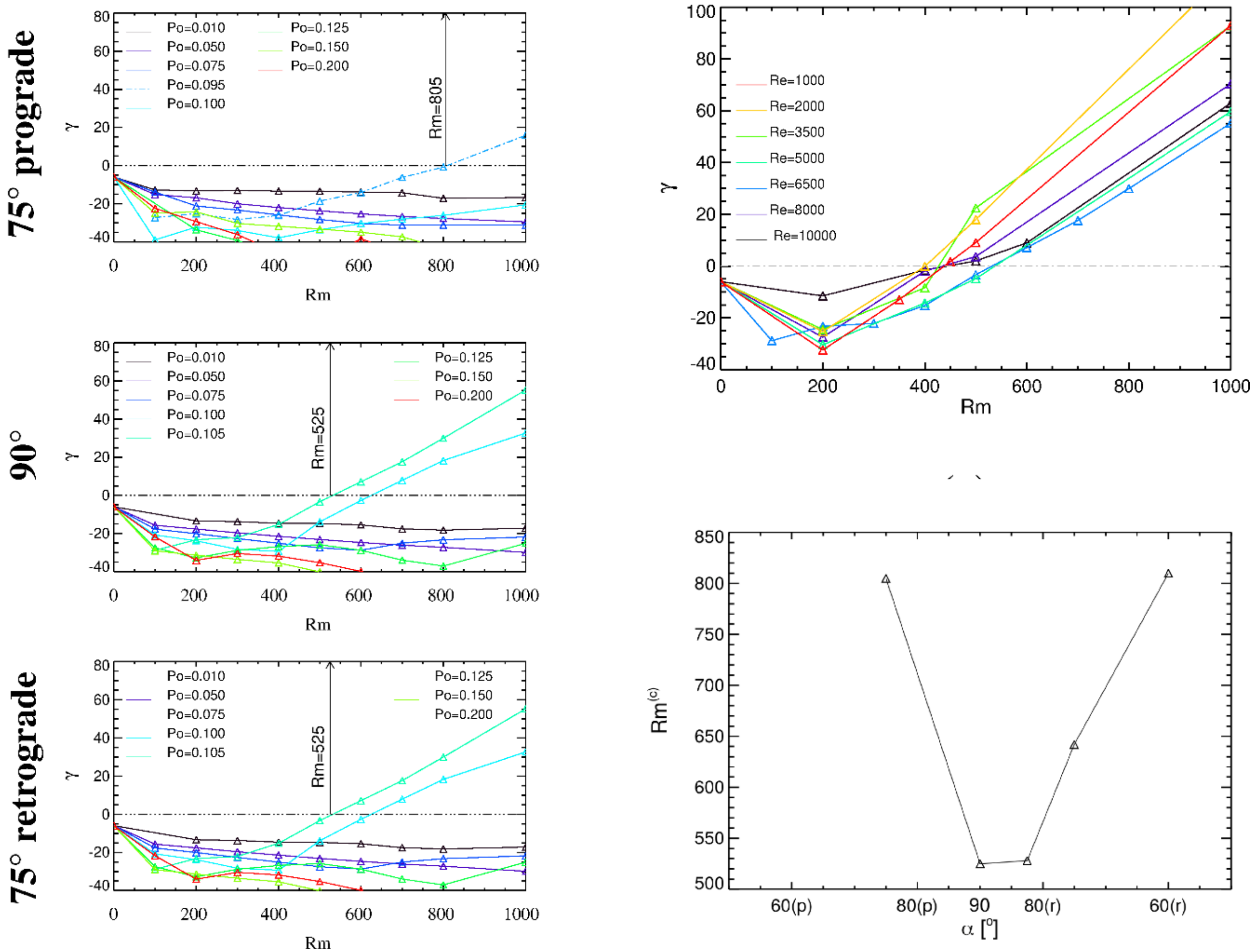
Kumar et al., Phys. Fluids 35 (2023), 014114;

Giesecke et al., JFM 998, (2024), A30

Precession driven dynamo: Prospects for self-excitation

Talk by A. Giesecke

In a narrow range of the precession ratio, **dynamo action is predicted for Rm~430** (Rm=700 is technically feasible)

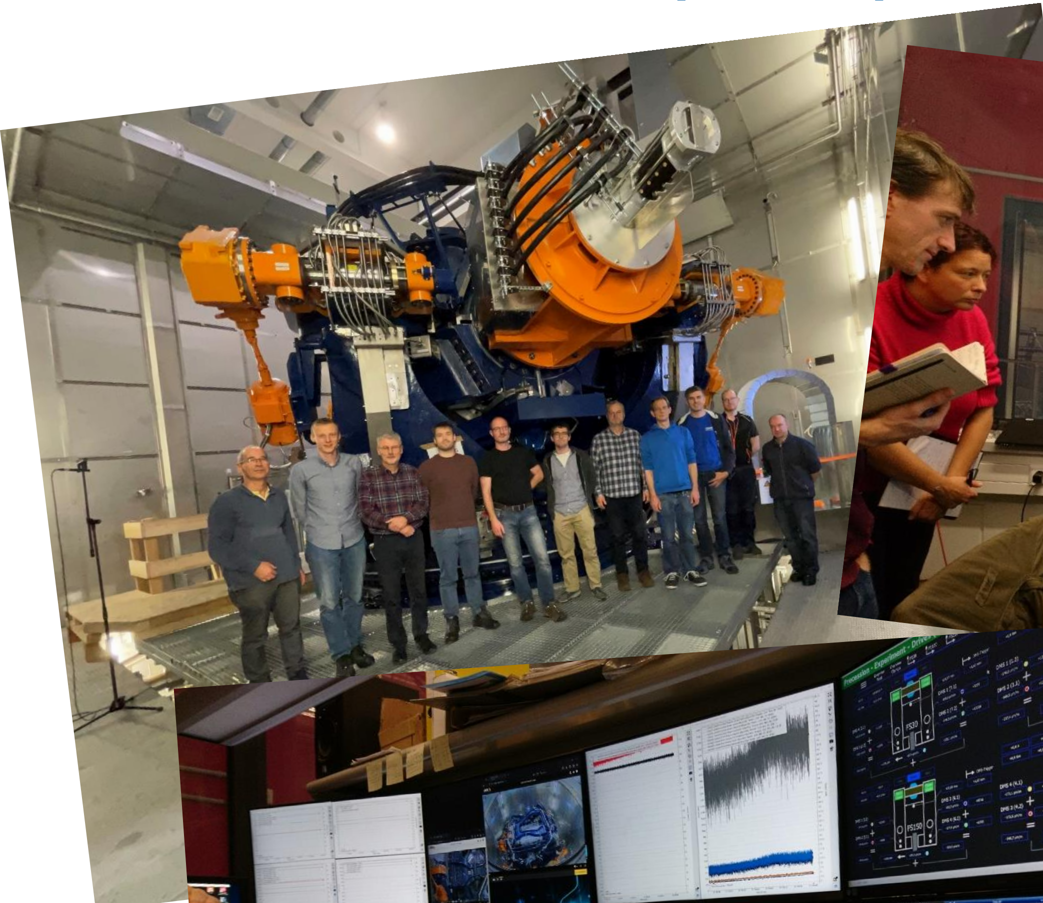


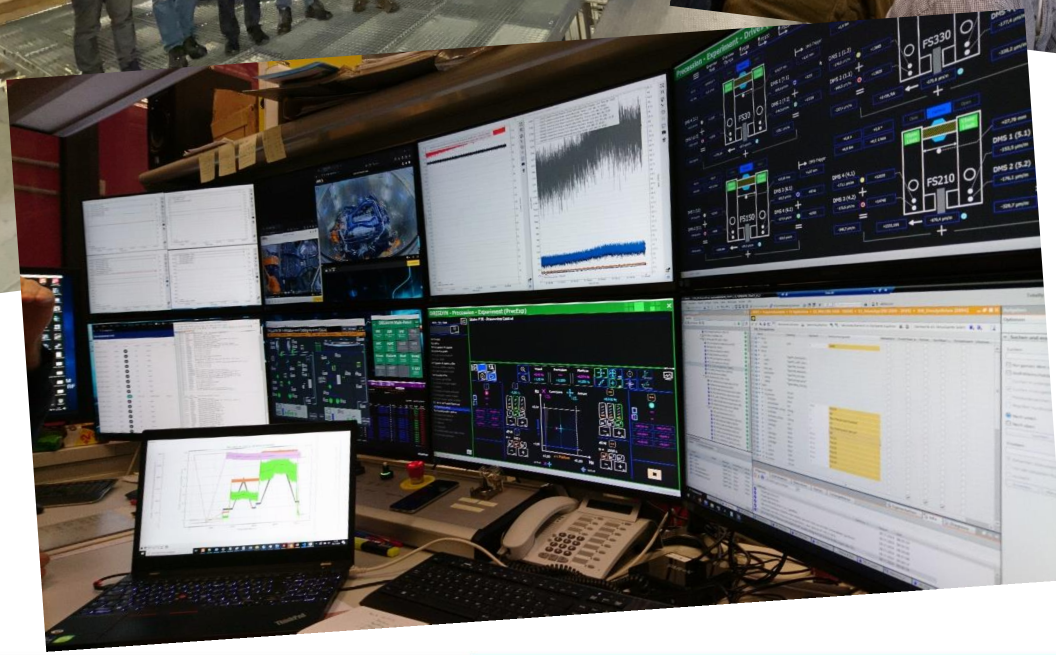
Giesecke et al., Phys. Rev. Lett. 120 (2018), 024502; Kumar et al., Phys. Fluids 35 (2023), 014114; Phys. Rev. E 109 (2024), 065101

DRESDEN concept

HZDR

First runs with water (at 1 Hz) on 28 November 2024





For first results, see talk by Th. Gundrum

Thank you for your attention!