4th Dynamo Thinkshop
Rome, November 25-26, 2019

Schwabe, Gleissberg, Suess-de Vries: A simple model for synchronizing solar cycles by planetary forces

Frank Stefani, André Giesecke, Martin Seilmayer, Rodion Stepanov, Tom Weier

European Research Council
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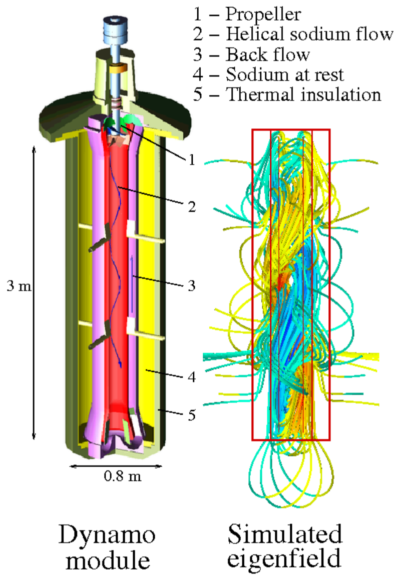
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

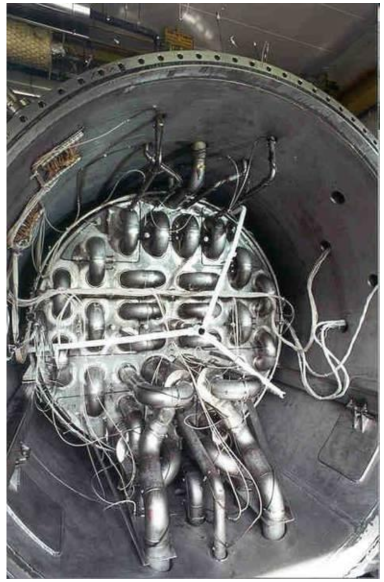
Outline

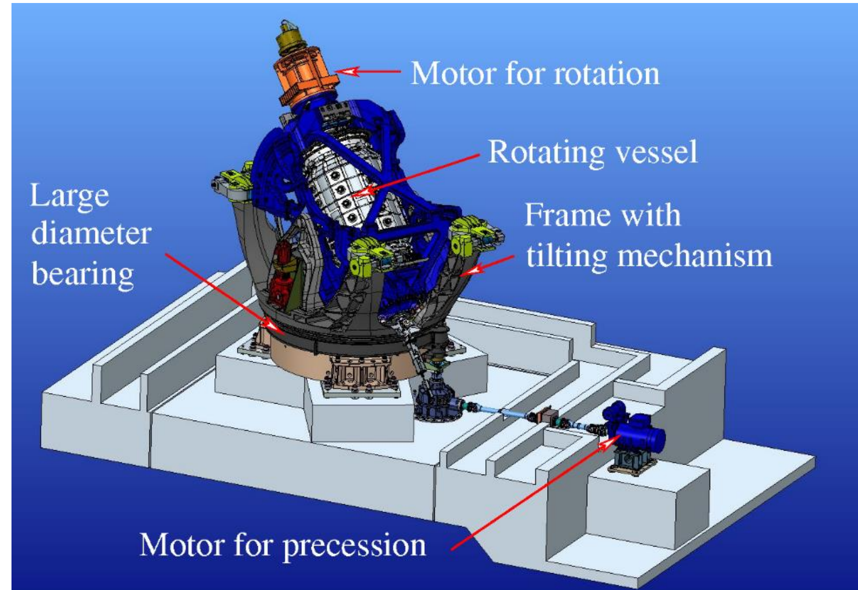
1. Things I won´t speak about
2. **Schwabe, Hale**
3. Suess-de Vries
4. Gleissberg (…and the Wilson gap)

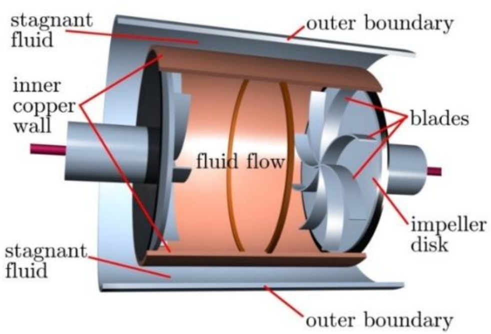
Things I won´t speak about

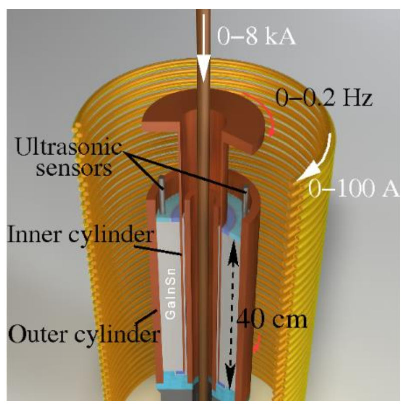
Liquid metal experiments: Riga, Karlsruhe, Cadarache, HZDR…

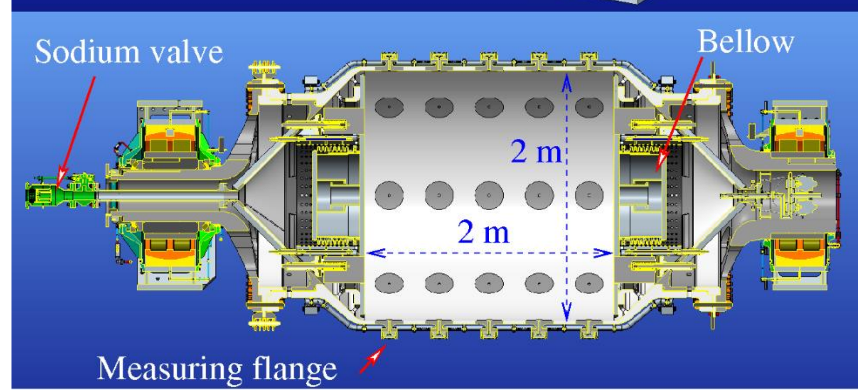








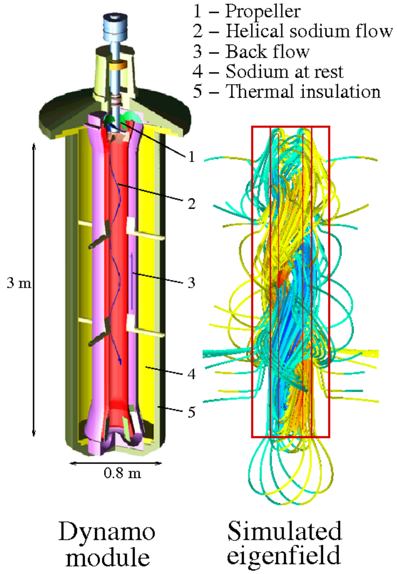


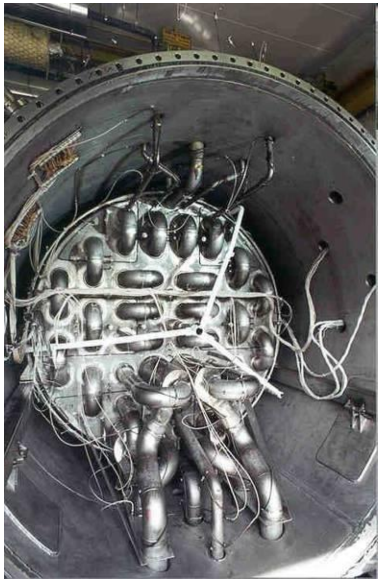


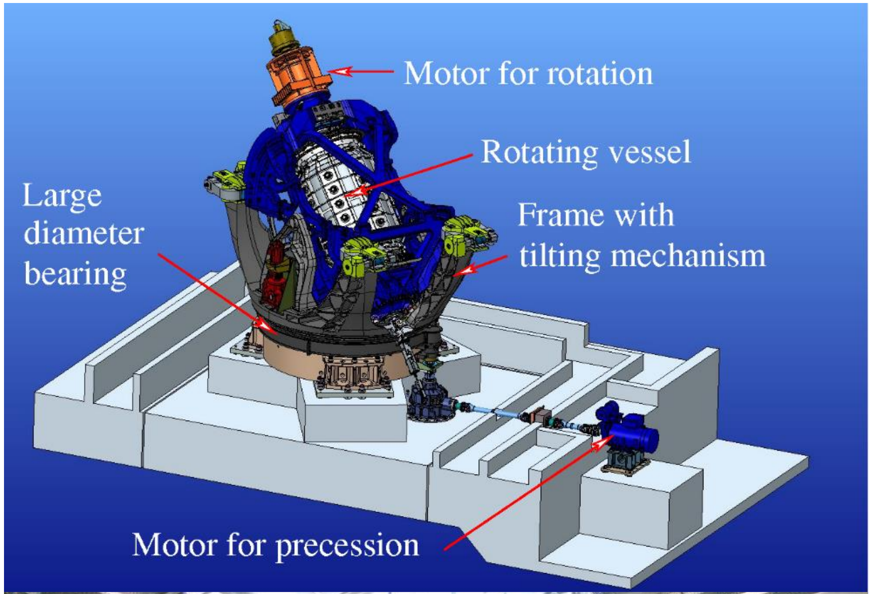
Gailitis et al., Rev. Mod. Phys. 74 (2002) 973; J. Plasma Phys. 84, 735840301 (2018); Stefani et al., Geophys. Astrophys. Fluid Dyn. 113 (2019), 51

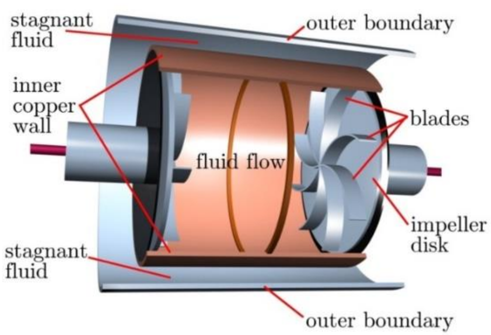
HZDR

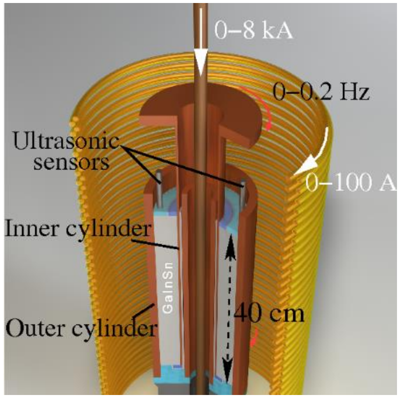
Liquid metal experiments: Riga, Karlsruhe, Cadarache, HZDR…

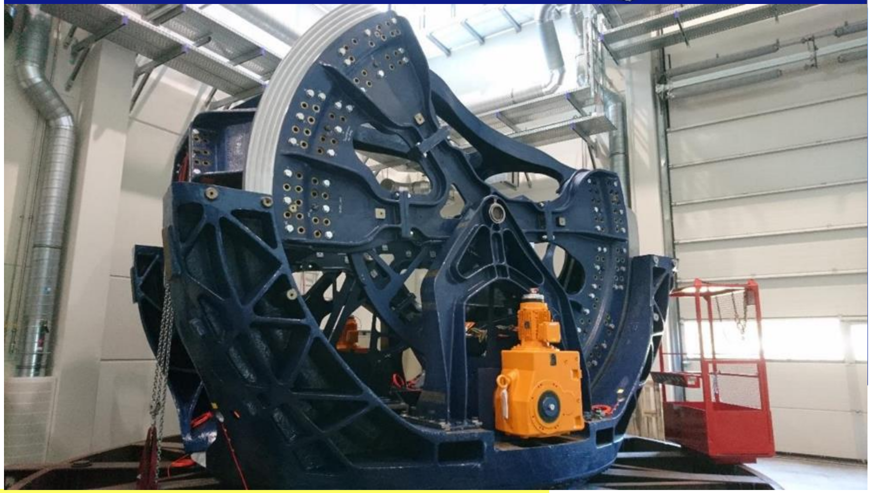










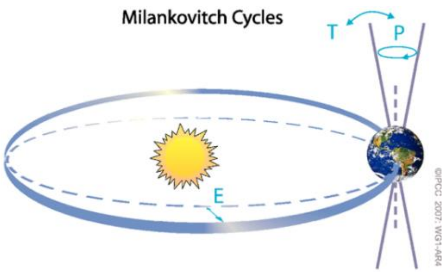


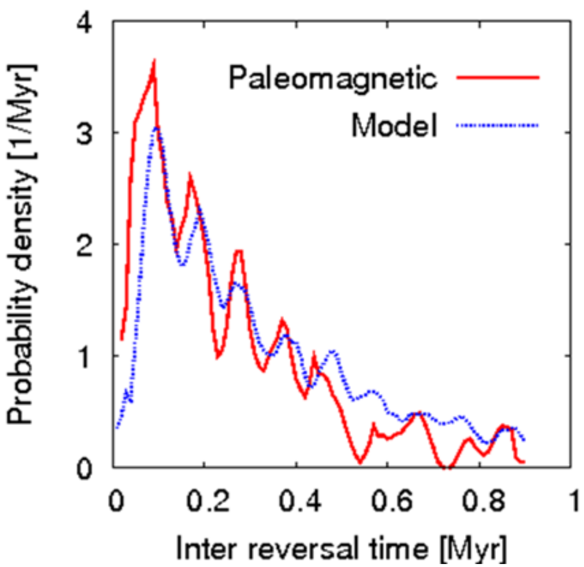
Gailitis et al., Rev. Mod. Phys. 74 (2002) 973; J. Plasma Phys. 84, 735840301 (2018); Stefani et al., Geophys. Astrophys. Fluid Dyn. 113 (2019), 51

HZDR

Geodynamo reversals and stochastic resonance

Strong indication for influence of variations of Earth´s orbit parameters (precession?, obliquity, excentricity) on the reversals of the geodynamo

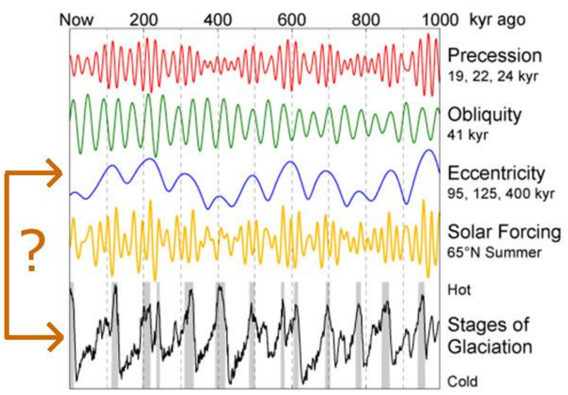




Probability density of inter-reversal times shows maxima at multiples of the Milankovic cycle of Earth's orbit eccentricity (95 ka)

connection with climate??

Doake, Nature 267 (1977), 415



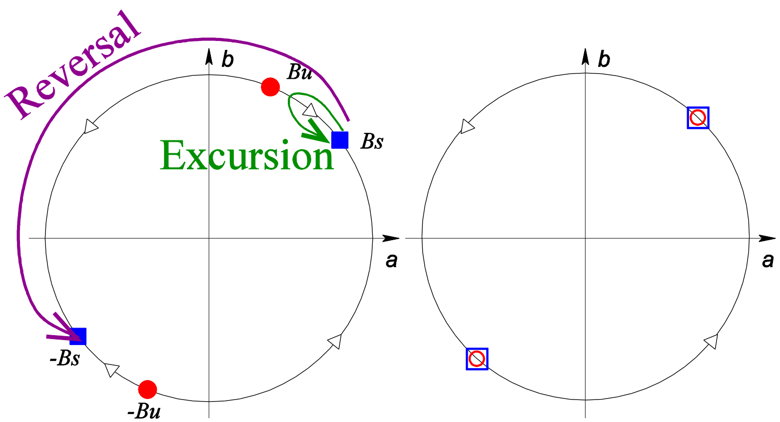
Benzi et al, J. Phys. A 14, L453

Consolini, De Michelis, Phys. Rev. Lett. 90 (2003), 058503

Fischer et al., Eur. Phys. J. B 65 (2008), 65; Inverse Problems 25 (2009), 065011

Interplay of coherence and stochastic resonance to explain various temporal features of reversals of the geodynamo

Two complementary pictures of field reversals



Saddle-node bifurcation (Petrelis et al. 2008)

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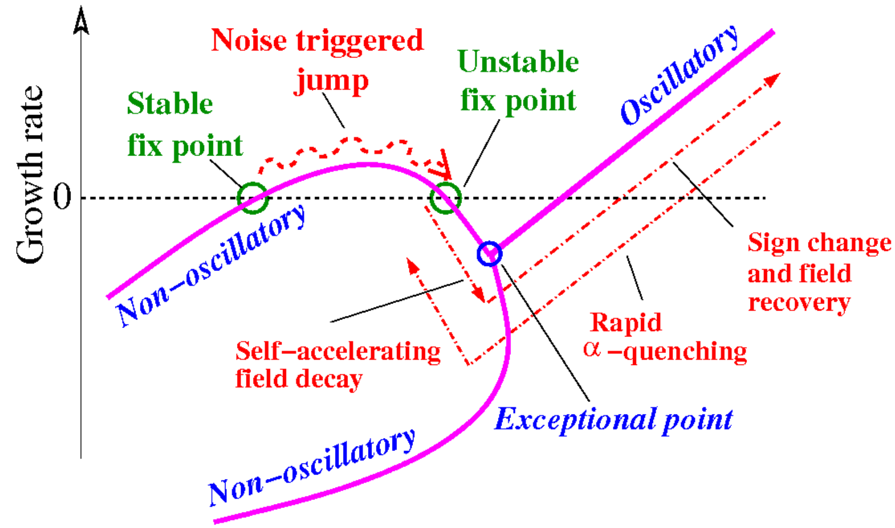


Dynamical systems picture:
Saddle-node bifurcation

$$\frac{d\Theta}{dt} = \alpha_0 + \alpha_1 \sin(2\Theta) + \text{noise}$$

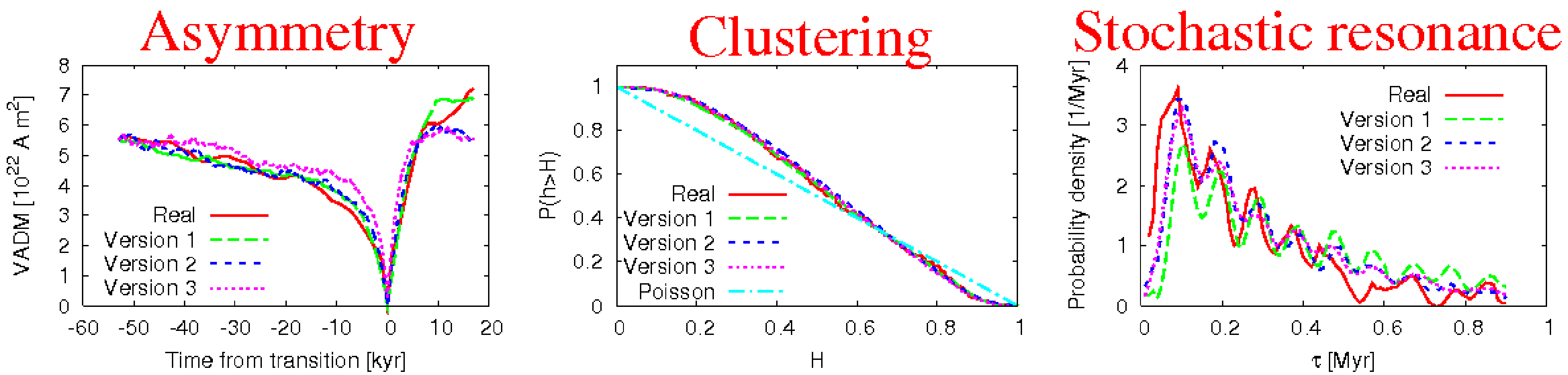
Petrelis et al., PRL 102 (2009), 144503

Spectral picture:
Noise triggered relaxation oscillations in the vicinity of spectral exceptional points of non-self-adjoint dynamo operator

Highly supercritical dynamos tend to self-tune into a reversal-prone state ("self-organized criticality" ???)

Stefani et al., Phys. Rev. Lett. 94 (2005) 184506; Earth Planet. Sci. Lett. 243 (2006), 828; GAFD 101 (2007)

Reversals of the geomagnetic field and stochastic resonance



Simple spherically symmetric α^2 dynamo model explains many features of reversals, and can constrain basic parameters of the geodynamo.

Best results for:

- Supercriticality of the dynamo: Factor 10
- Relative strength of periodic forcing: 10 per cent
- Diffusion time: 64 kyr, i.e reduction by a factor 3.5 compared to 225 kyr resulting from molecular conductivity. This is in rough agreement with measurements in Perm (Frick, PRL 2010), when Rm is scaled

Fischer et al., Inverse Probl. 25 (2008) 065011

Schwabe, Hale

Planetary tides and the solar cycle: an old idea of R. Wolf

the researches commenced in the seventh number. I shall accordingly show, by employing, on the one hand, my own observations in the year 1849 to 1858; and on the other, extracts from the observations of Schwabe in the years 1826 to 1848, that the formula

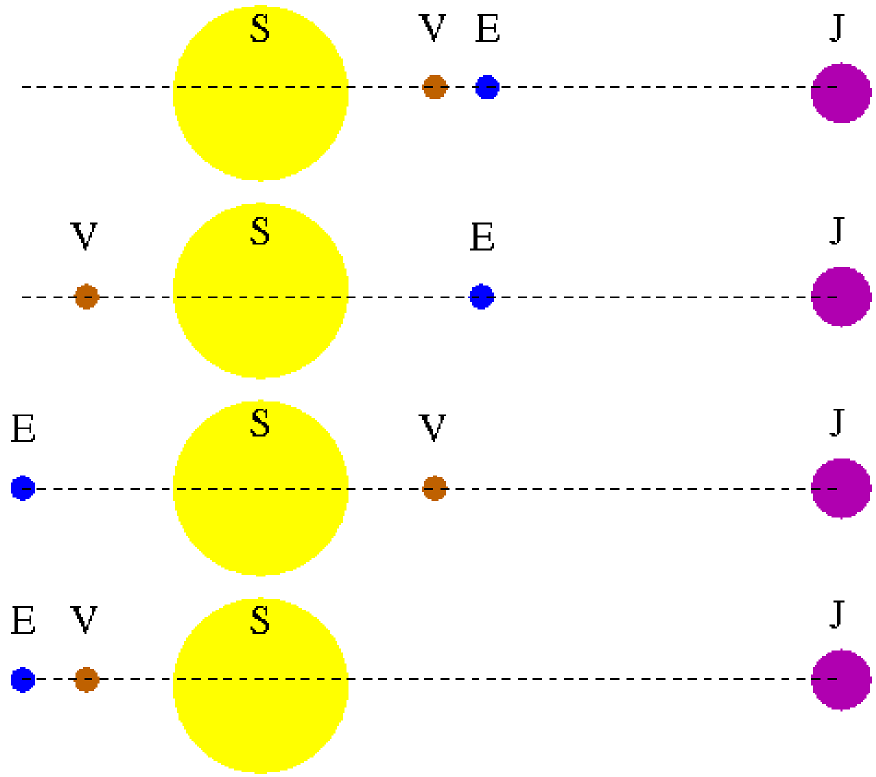
$$M = 50{\cdot}31 + 3{\cdot}73 \left\{ \begin{array}{l} 1{\cdot}68 \ \sin 585^{\circ}{\cdot}26\, t + 1{\cdot}00 \ \sin 360^{\circ}\, t + \\ 12{\cdot}53 \ \sin 30^{\circ}{\cdot}35\, t + 1{\cdot}12 \ \sin 12^{\circ}{\cdot}22\, t \end{array} \right\}$$

in which t denotes the number of years elapsed since a period of mean spot-frequency, gives a curve very similar to the sun-spot-curve; and therefore is very fit to be taken as the foundation of the more detailed research which I have now in hand. Now, as the coefficients of the four sines are the values which the fraction $\frac{m}{r^2}$ assumes, when for m and r are successively substituted the masses and mean distances of *Venus, Earth, Jupiter, and Saturn*; and the angles of the four sines are the values of $\frac{360^{\circ}}{t}$, when for t are substituted the periodic times of

Wolf, R., Mon. Not. R. Astron. Soc. 19 (1859), 85

Planetary tides and the solar cycle: Venus-Earth-Jupiter alignments

Amazing synchronization of solar cycle with the 11.07 years alignment cycle of the Venus-Earth-Jupiter system (despite tiny tidal forces!)



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

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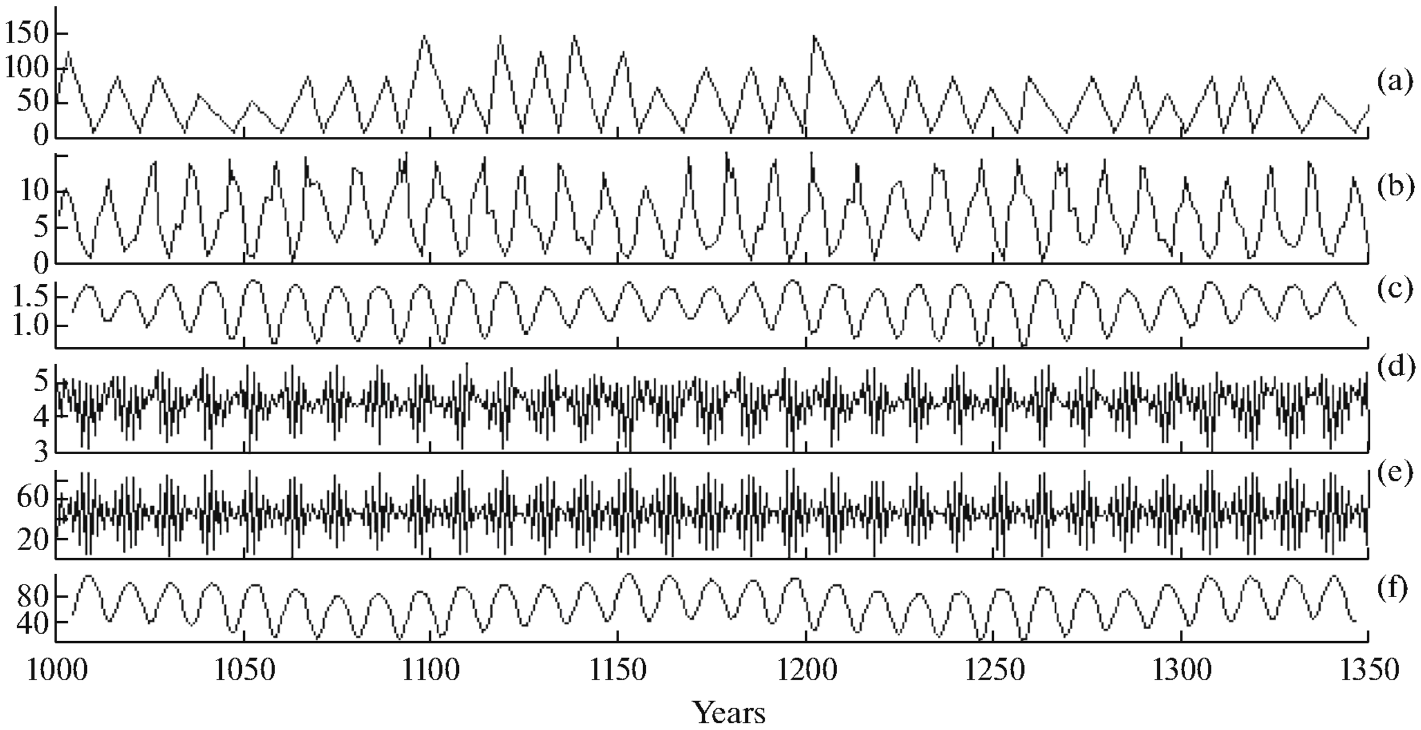
Sunspots

VEJ index



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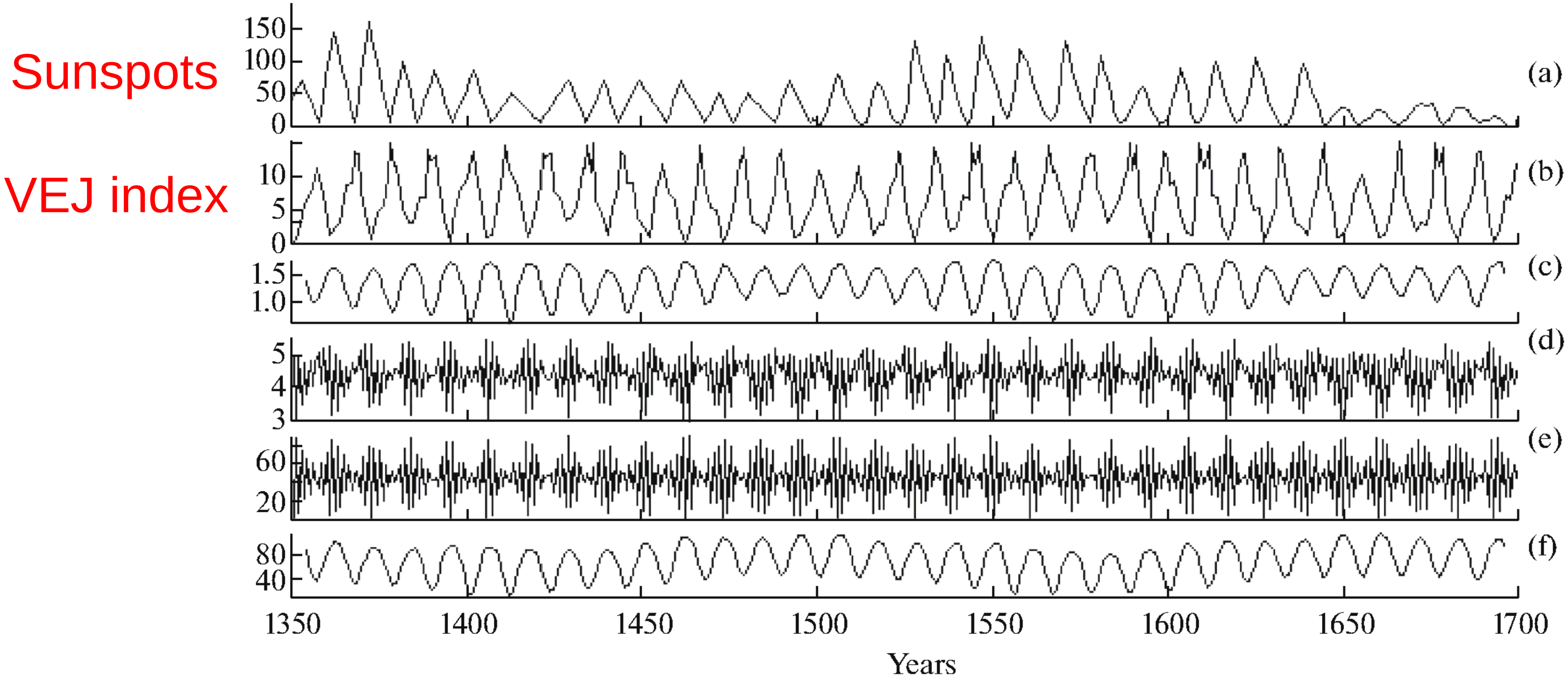

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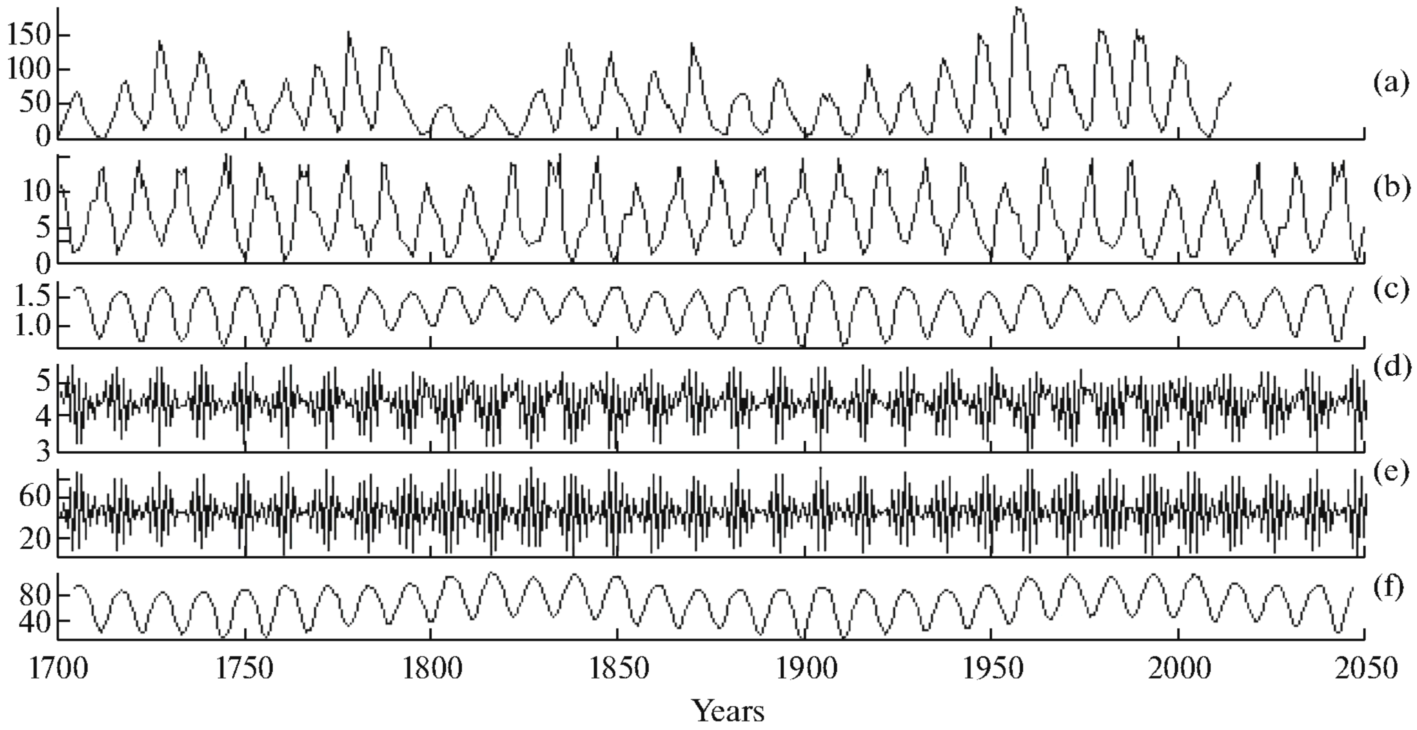

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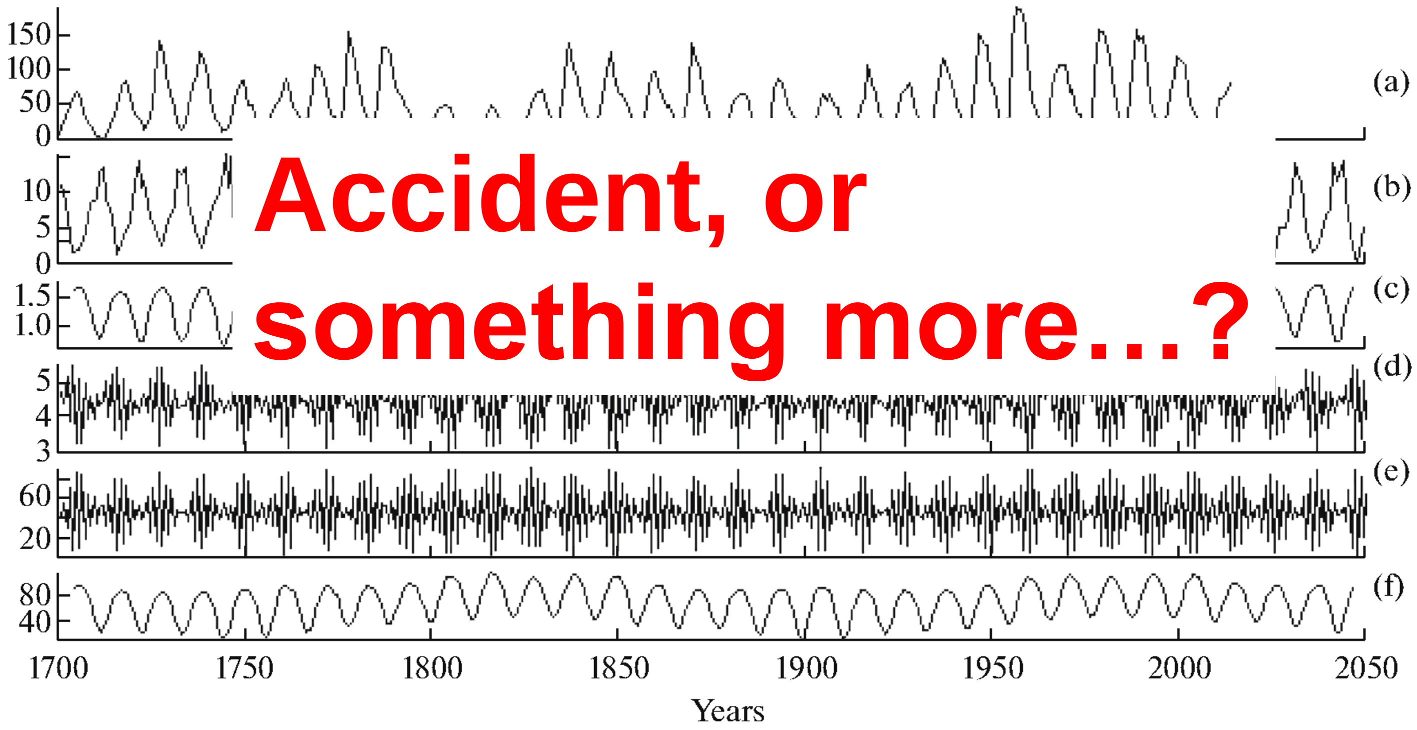

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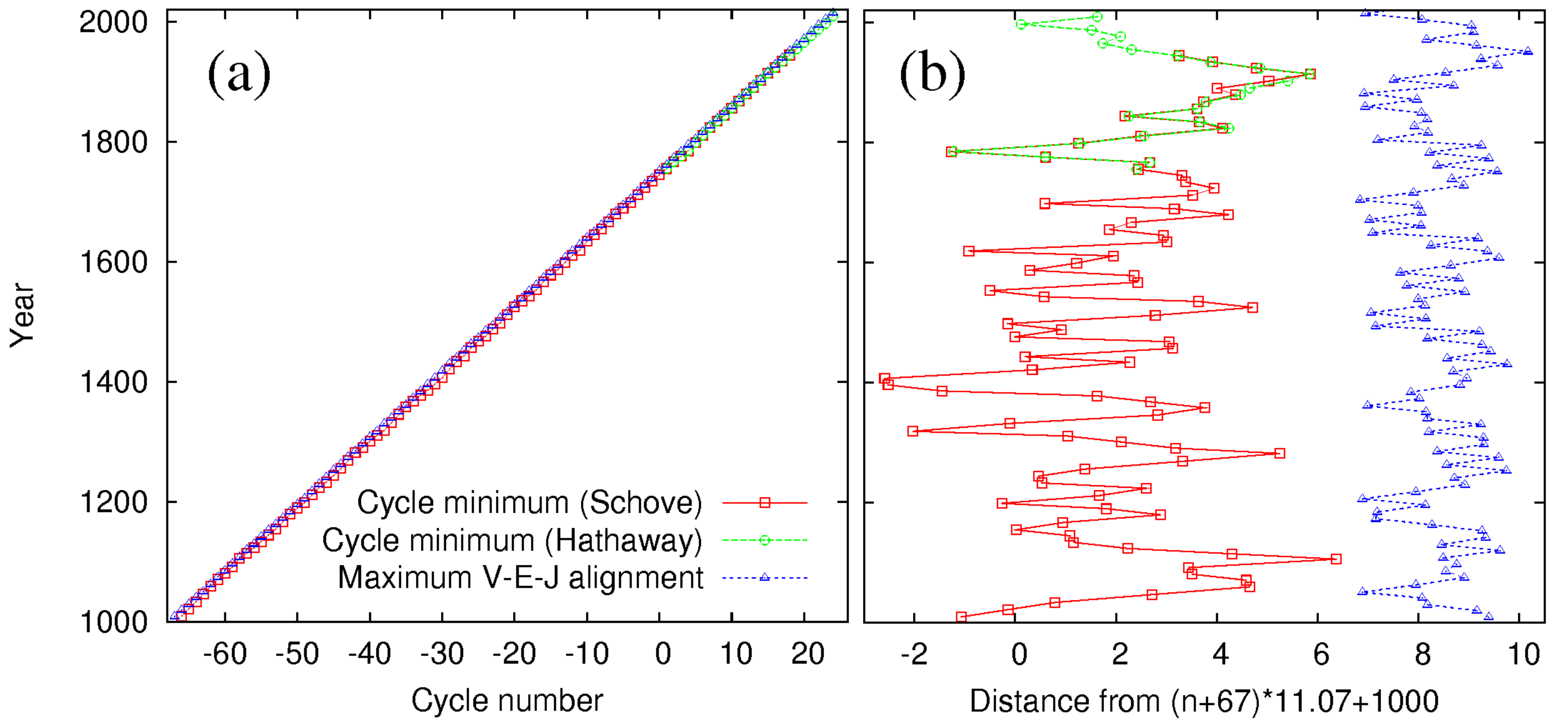
Planetary tides and the solar dynamo: The basic 22 years cycle

Amazing synchronization of solar cycle with the 11.07 years alignment cycle of the Venus-Earth-Jupiter system (despite tiny tidal forces!)



Schove, D.J.: J. Geophys. Res. 60 (1955), 127; Hathaway, D.H., Liv. Rev. Sol. Phys. 7 (2010), 1; Okhlopkov, Mosc. U. Bull. Phys. B. 71 (2016), 444

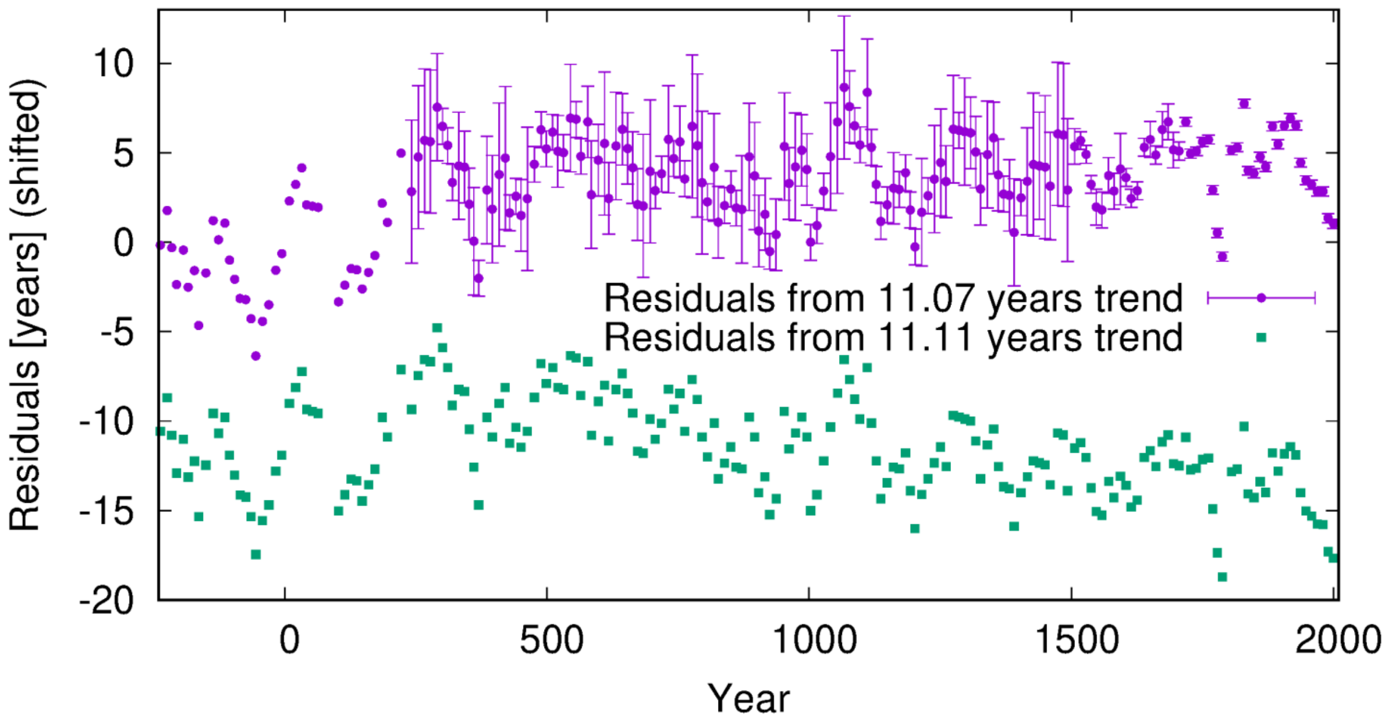
Stefani et al., Solar Physics 294 (2019), 60

DRESDEN concept

HZDR

Planetary tides and the solar dynamo: The basic 22 years cycle

Schove´s maxima data, with two different trends subtracted…



Schove, D.J.: Sunspot cycles, 1983; Hathaway, D.H., Liv. Rev. Sol. Phys. 7 (2010), 1

Stefani et al., arXiv:1910.10383

Planetary motion and the solar cycle: Dicke´s argument

Dicke (1978): „No support is found for the conventional view of the sunspot cycle, that there exists a large random walk in the phase of the cycle. Instead, both sunspots and the [D/H] solar/terrestrial weather indicator seem to be paced by an accurate clock inside the sun.“

Is there a chronometer hidden deep in the Sun?

R. H. Dicke
Joseph Henry Laboratories, Physics Department, Princeton University, Princeton, New Jersey 08540

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IT has long been believed that "the sunspot disturbances, like the eruptions of a geyser, are inherently only roughly periodic"[1]. Observations show a large variation in the ~11 yr

cycle as follows: "It was previously believed that the sunspot cycle resulted from the superposition of different periodic cycles. . . . Since then it has become clear that the rise and fall in the number of spots is due to a number of practically independent individual processes. Thus the idea of a true periodic phenomenon was dropped in favour of the so-called 'eruption hypothesis'. On this hypothesis, each cycle represents an independent eruption of the Sun which takes about 11 yr to die down". This conception of an irregular sunspot cycle, implying a random walk in the phase of the cycle, seems to agree with the Babcock theory and with subsequent modifications of the

Dicke, R.H., Nature 276 (1978), 676

DRESDEN concept

Dicke´s argument

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Distinction between random walk (RW) and clocked process (CP) for the instants y_n of sunspot maxima (Dicke) or minima (here):

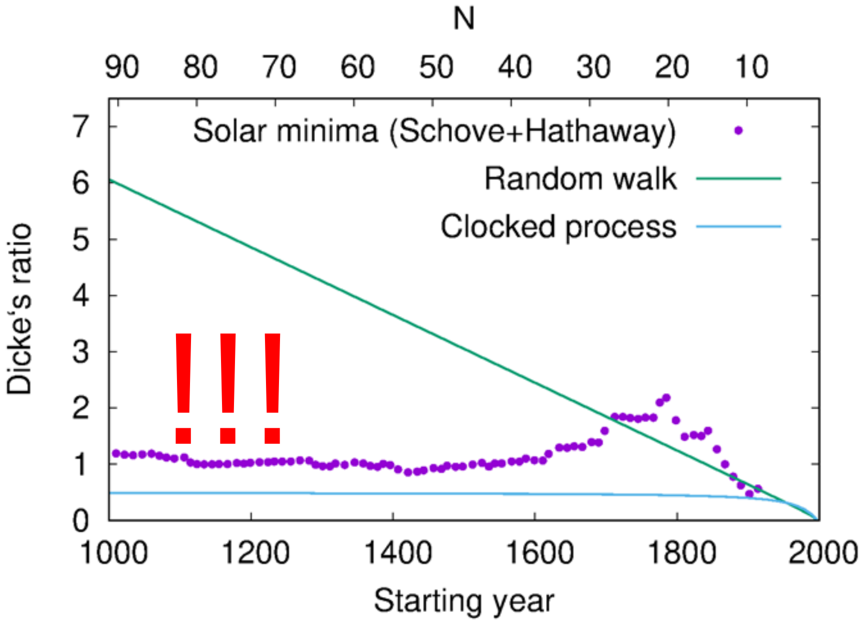
Residuals: $\delta y_n = y_n - y_0 - p(n-1)$, with p being the mean cycle period

A telling measure for discriminating between RW und CP is the RATIO between the mean square of δy_n and the mean square of $(\delta y_n - \delta y_{n-1})$

	RATIO	Limes N→ infinity
Random walk	$(N+1)(N^2-1)/3(5N^2+6N-3)$	N/15
Clocked process	$(N^2-1)/2(N^2+2N+3)$	1/2

DRESDEN concept HZDR

Dicke´s ratio in dependence on number of cycles



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DRESDEN concept HZDR

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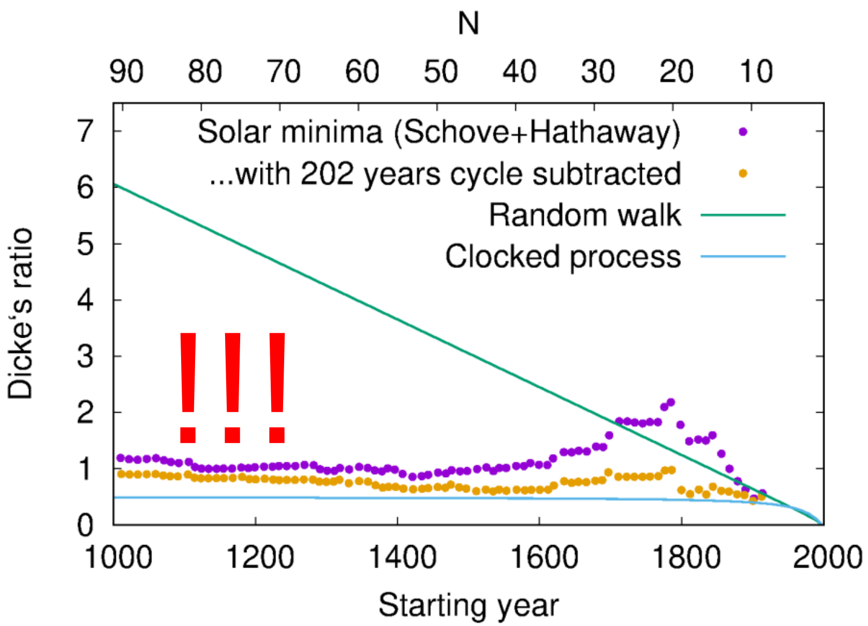

- After subtraction of Suess/de Vries cycle, Dicke's ratio fits nearly perfectly to a CP

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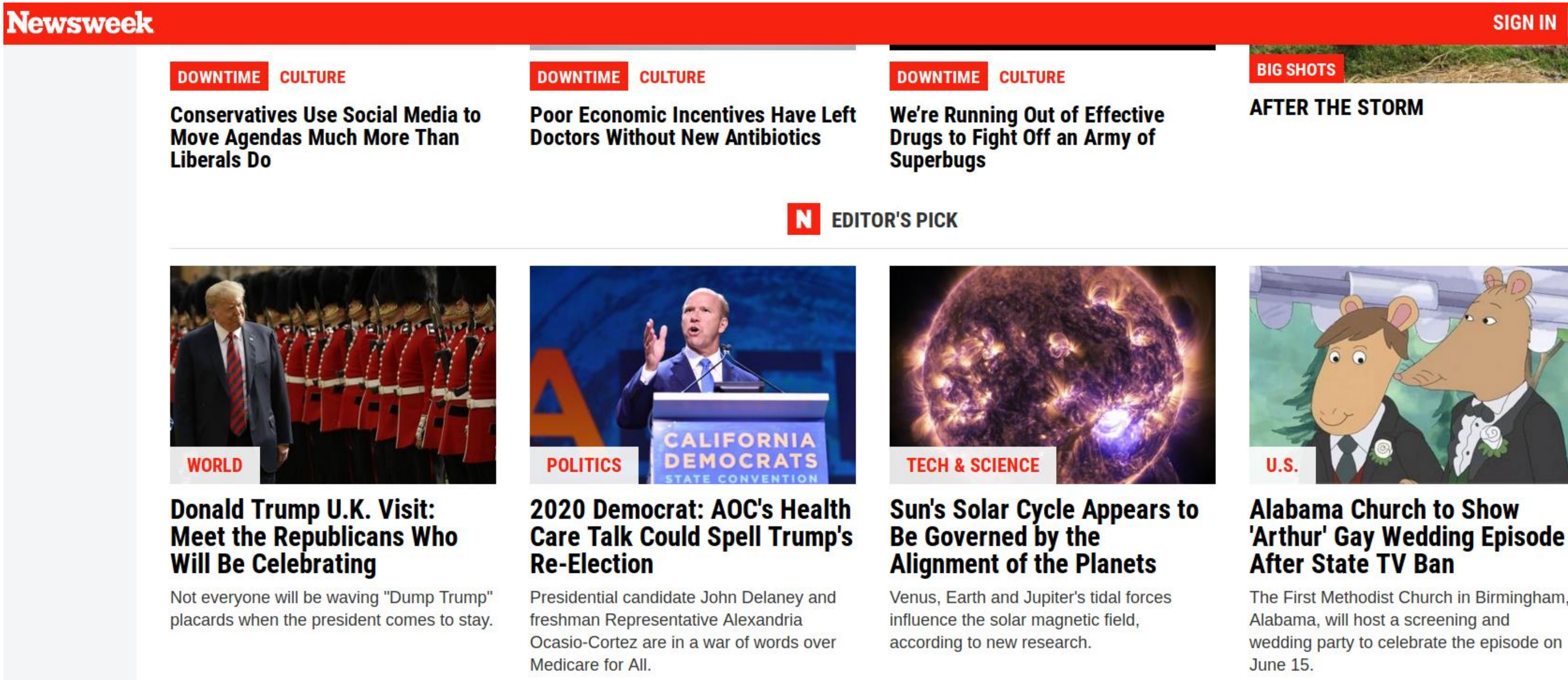
Stefani et al., Solar Physics 294 (2019), 60, arXiv:1803.08692

DRESDEN concept HZDR

Presse coverage: Newsweek of 4 June, 2019, Editor‘s pick



Newsweek SIGN IN

DOWNTIME CULTURE
Conservatives Use Social Media to Move Agendas Much More Than Liberals Do

DOWNTIME CULTURE
Poor Economic Incentives Have Left Doctors Without New Antibiotics

DOWNTIME CULTURE
We're Running Out of Effective Drugs to Fight Off an Army of Superbugs

BIG SHOTS
AFTER THE STORM

N EDITOR'S PICK

WORLD
Donald Trump U.K. Visit: Meet the Republicans Who Will Be Celebrating
Not everyone will be waving "Dump Trump" placards when the president comes to stay.

POLITICS
2020 Democrat: AOC's Health Care Talk Could Spell Trump's Re-Election
Presidential candidate John Delaney and freshman Representative Alexandria Ocasio-Cortez are in a war of words over Medicare for All.

TECH & SCIENCE
Sun's Solar Cycle Appears to Be Governed by the Alignment of the Planets
Venus, Earth and Jupiter's tidal forces influence the solar magnetic field, according to new research.

U.S.
Alabama Church to Show 'Arthur' Gay Wedding Episode After State TV Ban
The First Methodist Church in Birmingham, Alabama, will host a screening and wedding party to celebrate the episode on June 15.

Donald Trump

Alexandria Ocasio-Cortez

Solar Physics 294 (2019), 60

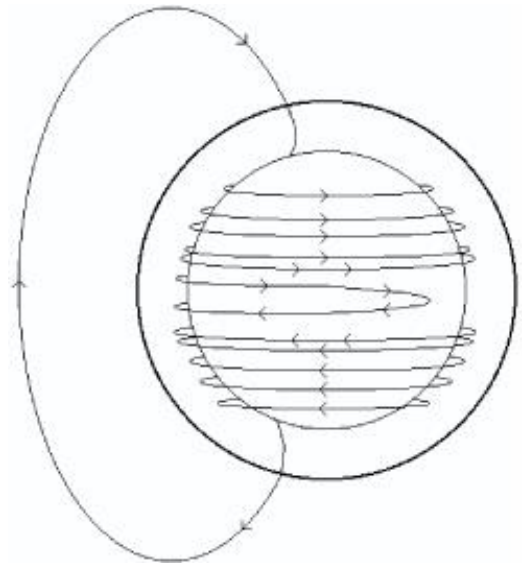
„Arthur“

DRESDEN concept HZDR

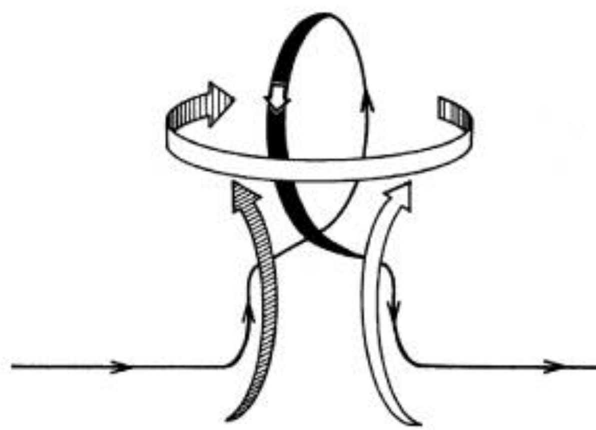
Solar dynamo models: Basics

Any solar dynamo needs:

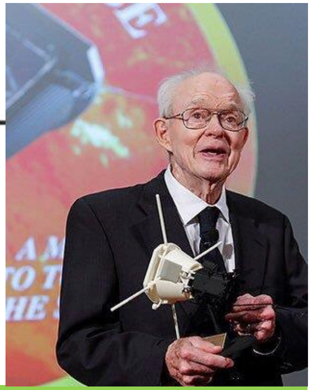
- some Ω effect to regenerate toroidal field from poloidal field
- some α effect to regenerate poloidal field from toroidal field



Ω effect



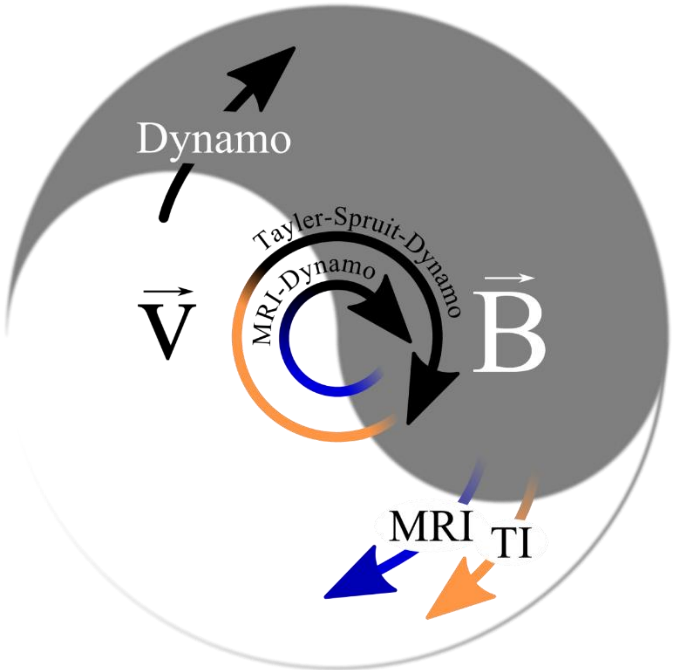
α effect



Parker, Astrophys J. 122, 293 (1955)

DRESDEN concept HZDR

Nonlinear dynamos



THE ASTROPHYSICAL JOURNAL, 446:741–754, 1995 June 20

DYNAMO-GENERATED TURBULENCE AND LARGE-SCALE MAGNETIC FIELDS IN A KEPLERIAN SHEAR FLOW

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Received 1994 October 27; accepted 1994 December 29

ABSTRACT

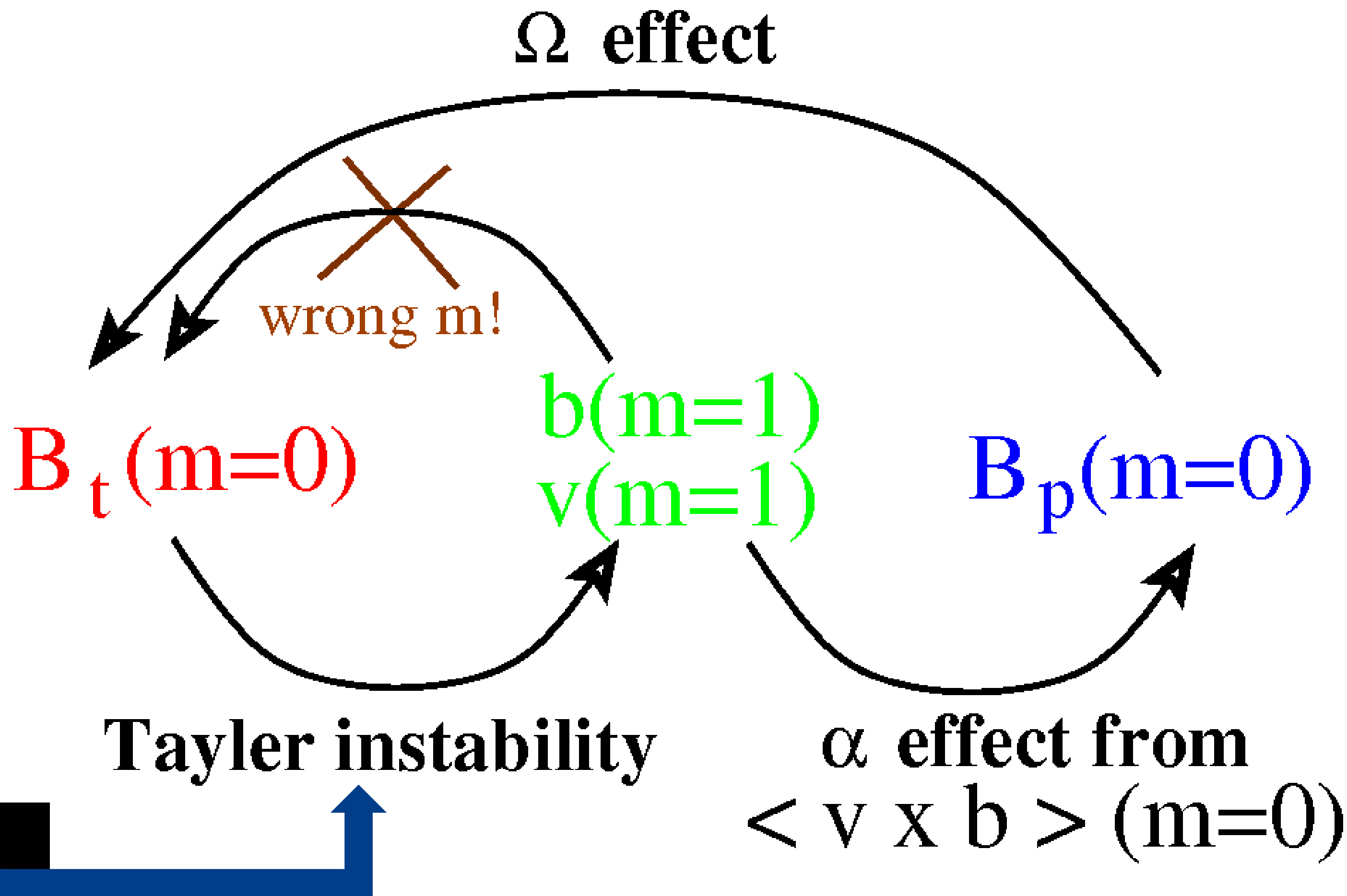
The nonlinear evolution of magnetized Keplerian shear flows is simulated in a local, three-dimensional model, including the effects of compressibility and stratification. Supersonic flows are initially generated by the Balbus-Hawley magnetic shear instability. The resulting flows regenerate a turbulent magnetic field which, in turn, reinforces the turbulence. Thus, the system acts like a dynamo that generates its own turbulence. However, unlike usual dynamos, the magnetic energy exceeds the kinetic energy of the turbulence by a factor of 3–10. By assuming the field to be vertical on the outer (upper and lower) surfaces we do not constrain the horizontal magnetic flux. Indeed, a large-scale toroidal magnetic field is generated, mostly in the form of toroidal flux tubes with lengths comparable to the toroidal extent of the box. This large-scale field is mainly of even (i.e., quadrupolar) parity with respect to the midplane and changes direction on a timescale of ~30 orbits, in a possibly cyclic manner. The effective Shakura-Sunyaev alpha viscosity parameter is between 0.001 and 0.005, and the contribution from the Maxwell stress is ~3–7 times larger than the contribution from the Reynolds stress.

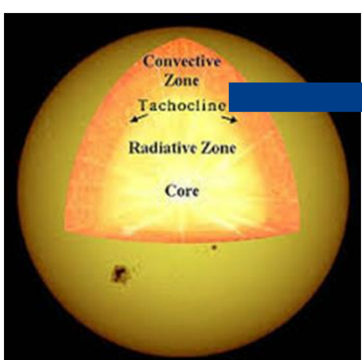
Subject headings: accretion: accretion disks — MHD — shock waves — turbulence

„The resulting flows regenerate a turbulent magnetic field which, in turn, reinforces the turbulence. Thus, the system acts like a dynamo that generates its own turbulence.“

Brandenburg, Nordlund, Stein, Torkelsson, ApJ 446 (1995), 741

Tayler-Spruit dynamo in the solar tachocline: The main problem





Ferriz Mas et al., Astron. Astrophys. 289 (1994), 949

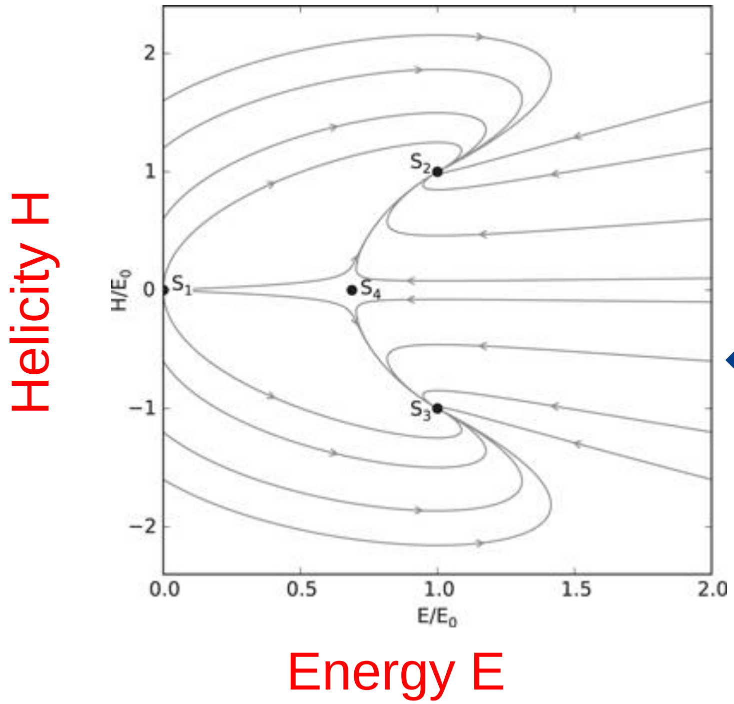
Spruit, Astron. Astrophys. 381 (2002), 923

Zahn et al., Astron. Astrophys. 474 (2007), 147

Bonanno, Brandenburg et al., Phys. Rev. E 86 (2012), 016313

Tayler-Spruit dynamo: Saturation of TI and helical symmetry breaking

Simple Lagrangian leads to spontaneous chiral symmetry breaking and mutual inhibition of the two helicities (like in biology)



$$\frac{dE}{dt} = 2\gamma E - 2(\mu + \mu_*)E^2 - 2(\mu - \mu_*)H^2$$

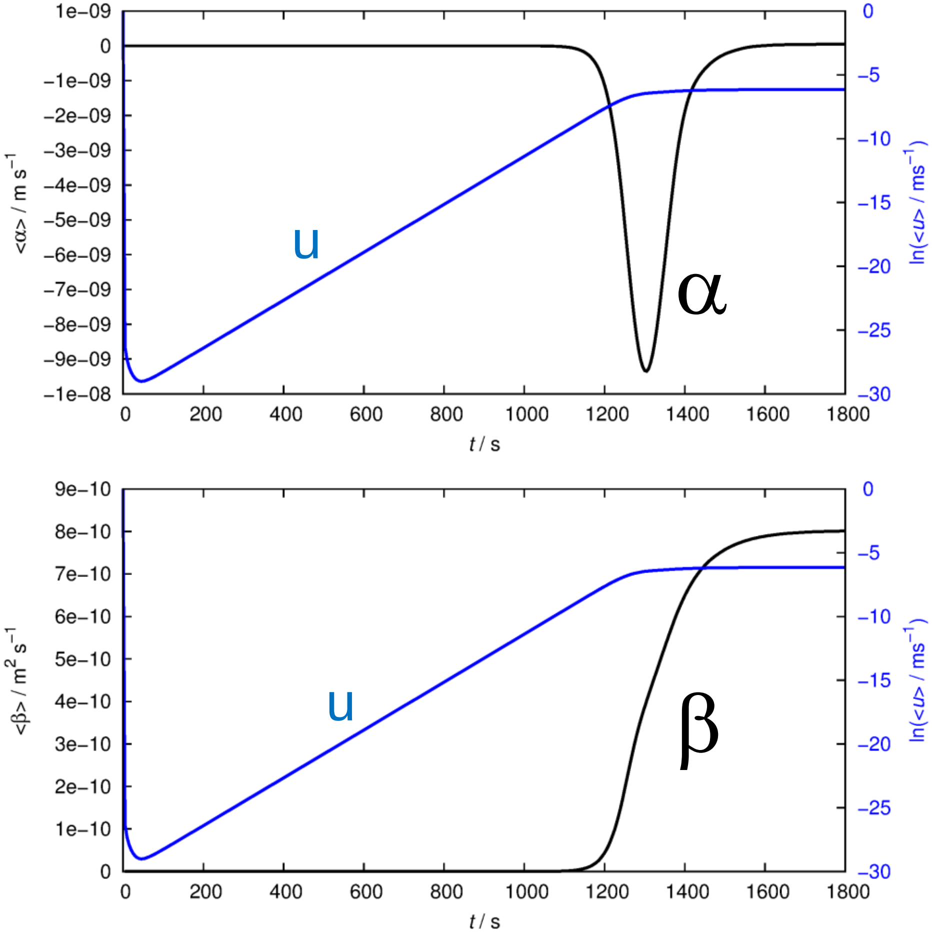
$$\frac{dH}{dt} = 2\gamma H - 4\mu E H$$

Bonanno, **Brandenburg** et al., Phys. Rev. E 86 (2012), 016313

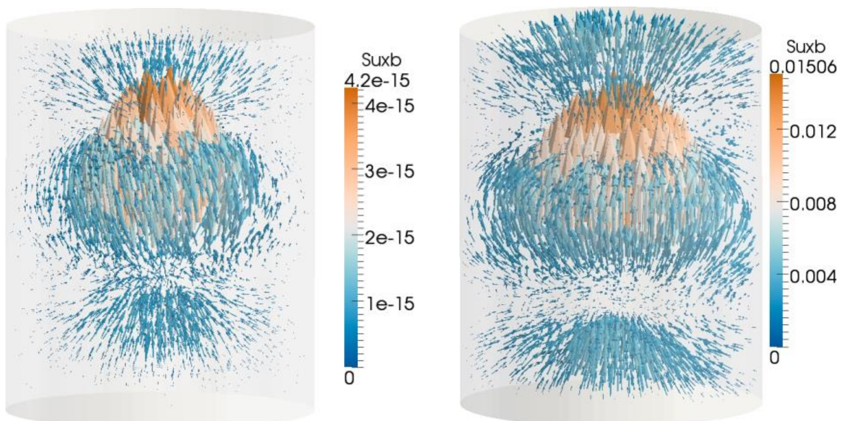
Weber et al., New J. Phys. 17 (2015), 113013

Any helical symmetry breaking at low Pm ?

At low Pm, neither the β effect nor the α effect are strong enough to change the magnetic base configuration. α effect appears only in the exponential growth phase and disappears in the saturation regime.



Induced current at…



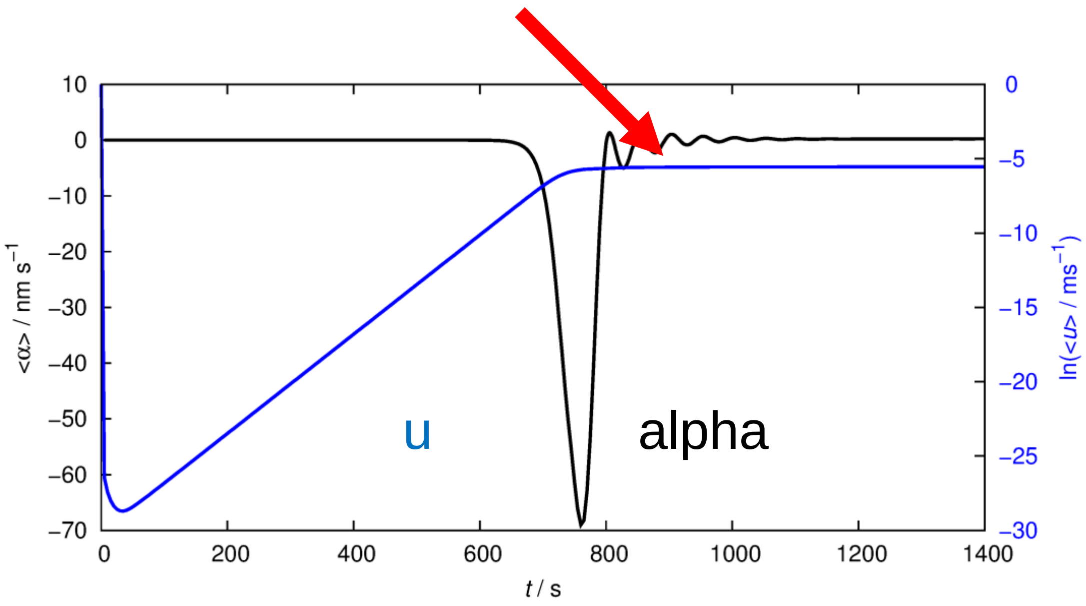
500 s 1800 s

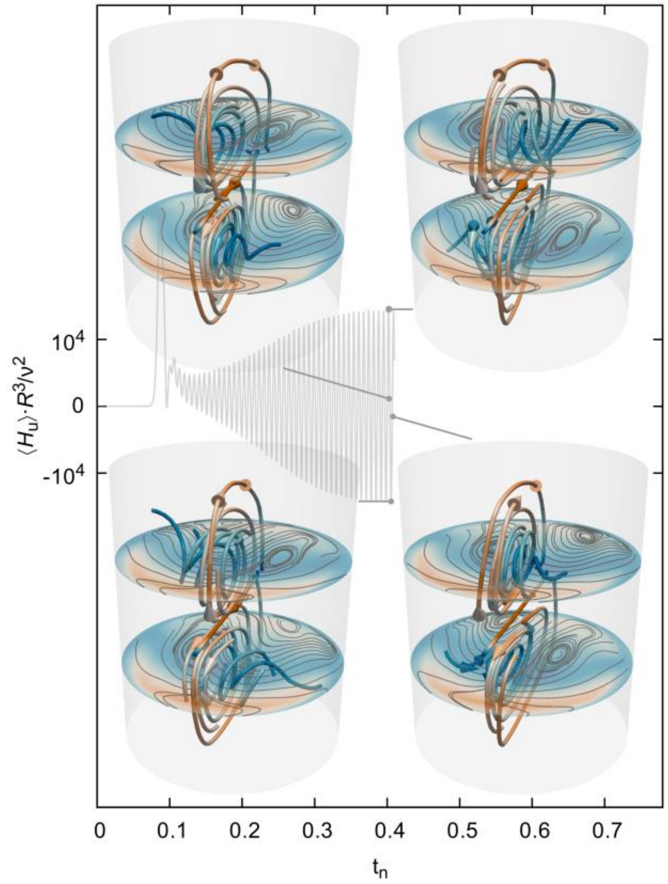
Example: h/d=1.25, Ha=55

Weber et al., New J. Phys. 17 (2015), 113013

Tayler instability: Saturation and helicity oscillations at $Pm=10^{-6}$

(Damped) helicity oscillations Ha =70

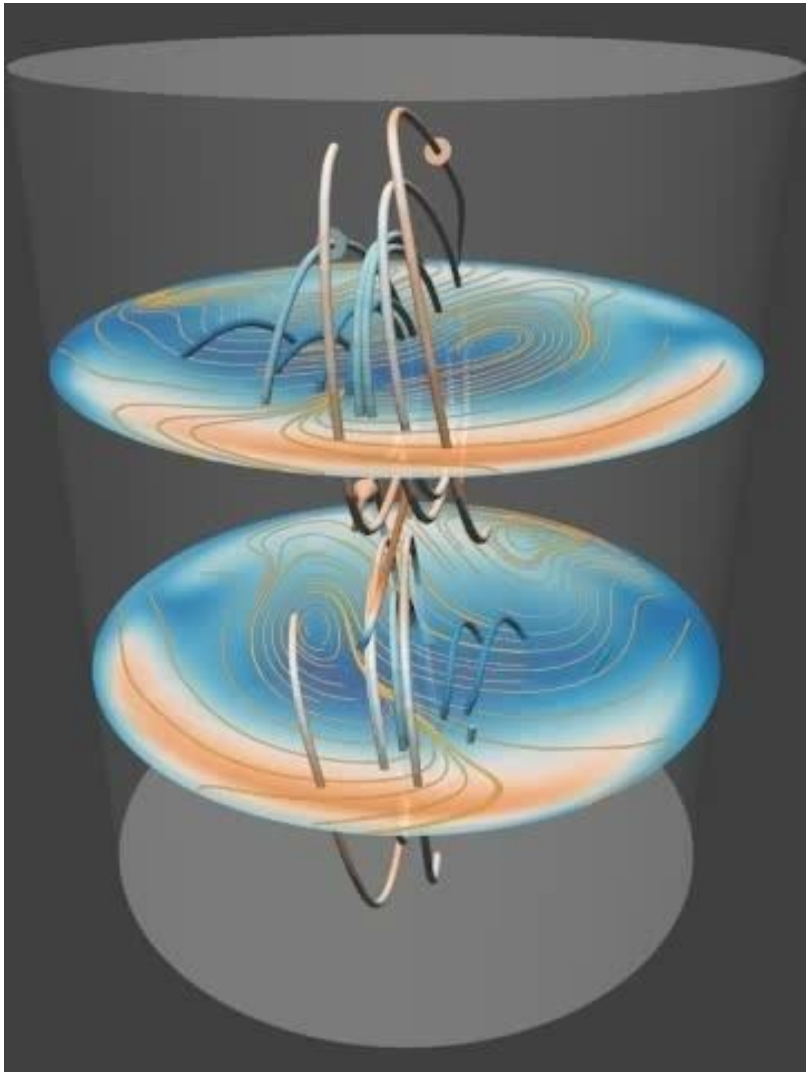




Ha =100

Weber et al., New J. Phys. 17 (2015), 113013

Character of the helicity oscillations



Ha =100
Pm=10^{-6}

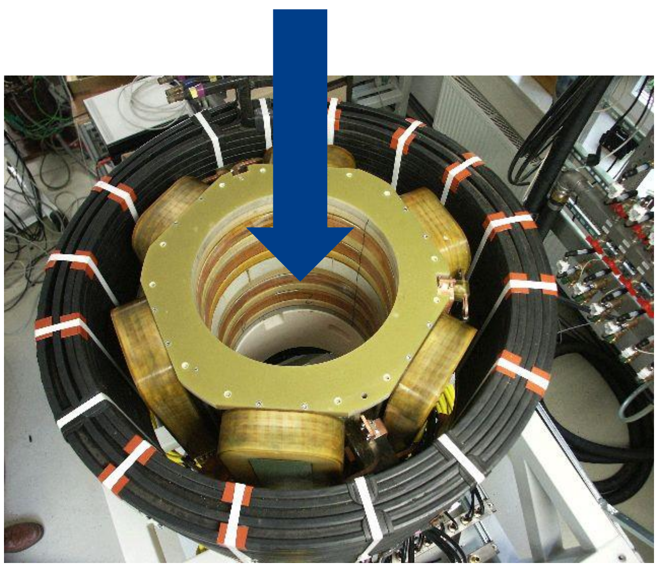
Weber et al., New J. Phys. 17 (2015), 113013

Rayleigh-Bénard experiment: helicity synchronization with m=2 forcing

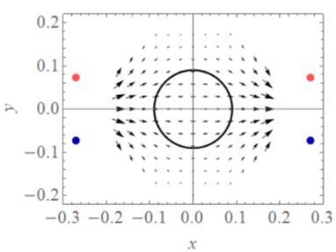
- Is this synchronization of helicity of an m=1 flow feature by m=2 (tidal) perturbations universal? What about (m=1) magnetic Rossby waves?

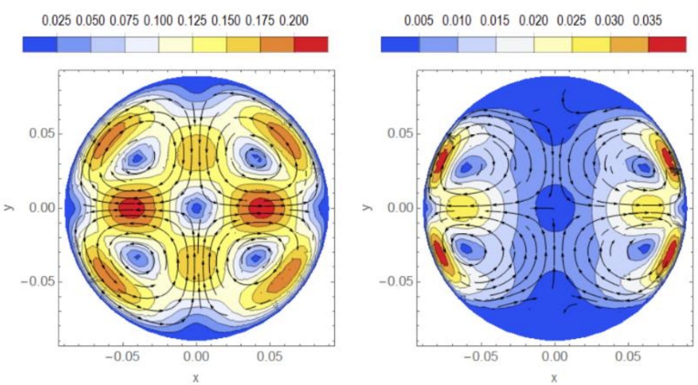
Dikpati et al., Sci. Rep. 7 (2017), 14750;
Zaqarashvili, ApJ. 856 (2018), 32

- Generic Rayleigh-Bénard experiment to show resonant excitation of helicity by an m=2 perturbation.
- How to realize this: Magnetic pressure by coils.



Magnetic field

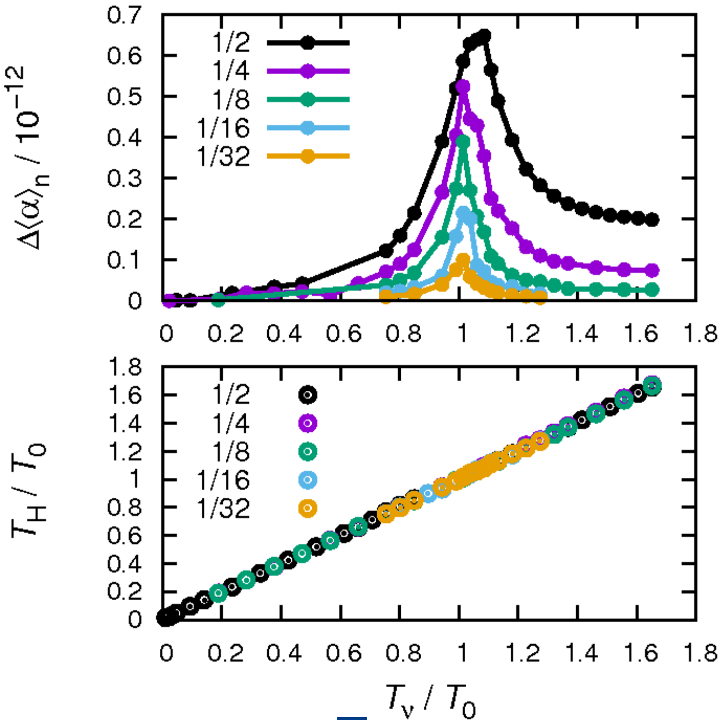


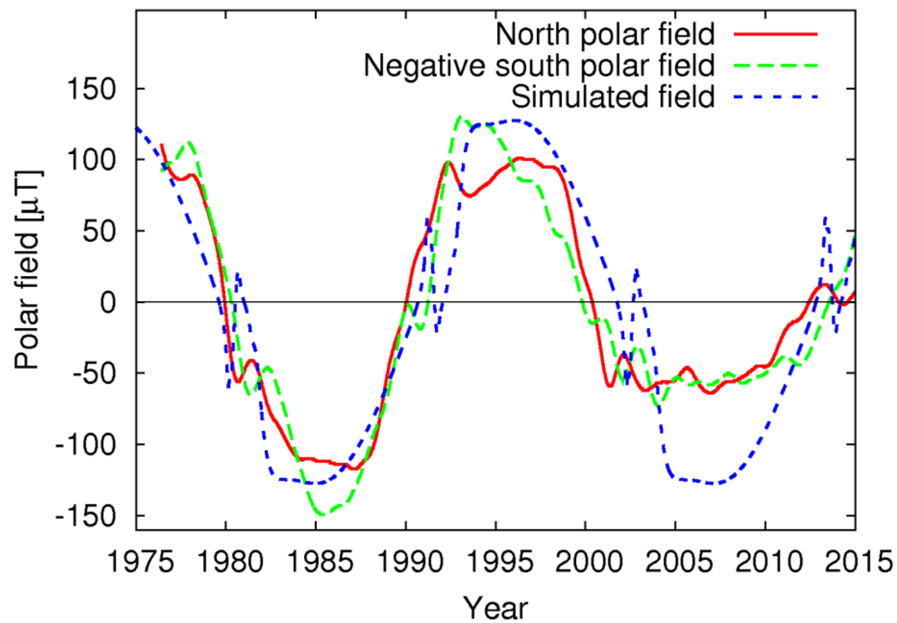


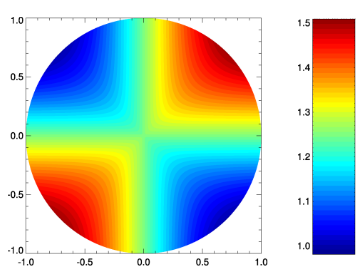
m=2 Velocity at
100 Hz 1600 Hz

Stepanov, Stefani: Magnetohydrodynamics 55 (2019) 207

Modelling the planetary synchronization of the solar dynamo







1:1 synchronization of the helicity of the Tayler instability with tidal (m=2) perturbation ...yields a 22.14 years cycle!

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

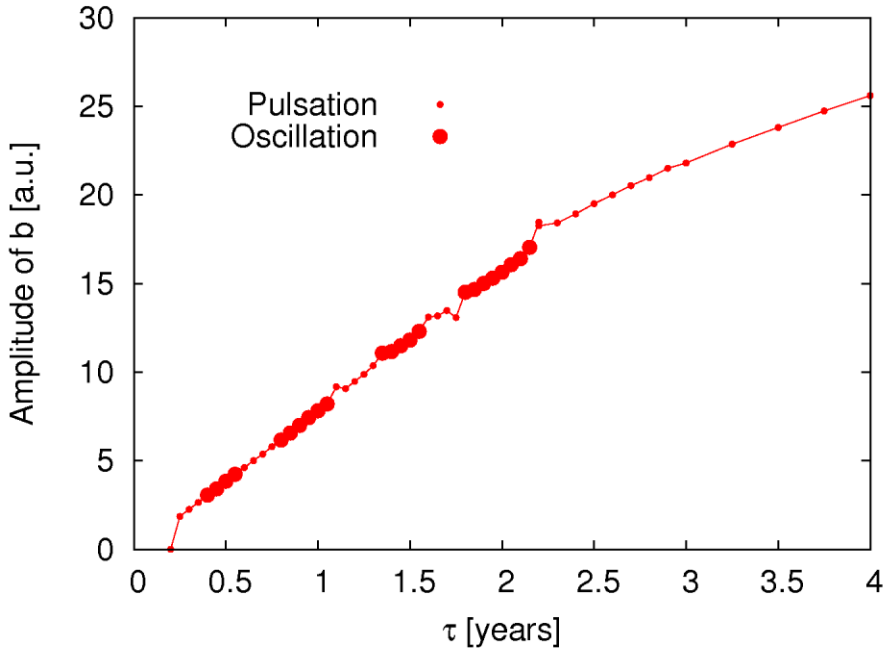
$$\dot{B}(t) = \omega A(t) - \tau^{-1} B(t)$$

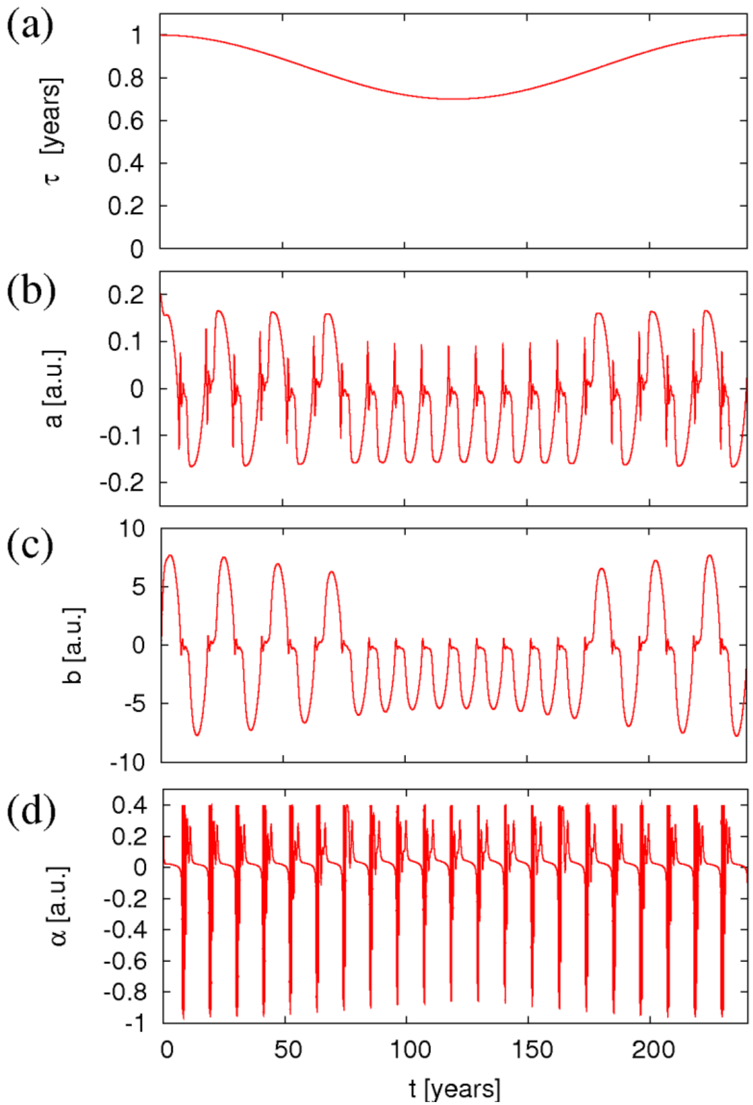
$$\alpha(t) = \frac{c}{1 + gB^2(t)} + \frac{pB^2(t)}{1 + hB^4(t)} \sin(2\pi t / T_\nu)$$

Stefani et al, Solar Phys. 291 (2016), 2197

Transitions between oscillations and pulsations → „Grand minima“ ?

Bands of oscillations and pulsations





„Grand minima“ with phase coherence?

Stefani et al., Solar Phys.293 (2018),12

1D-Model (after Parker, but with periodic, synchronized α term):

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

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

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

Stefani et al., Solar Physics 294 (2019), 60

1D-Model (after Parker, but with periodic, synchronized α term):

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

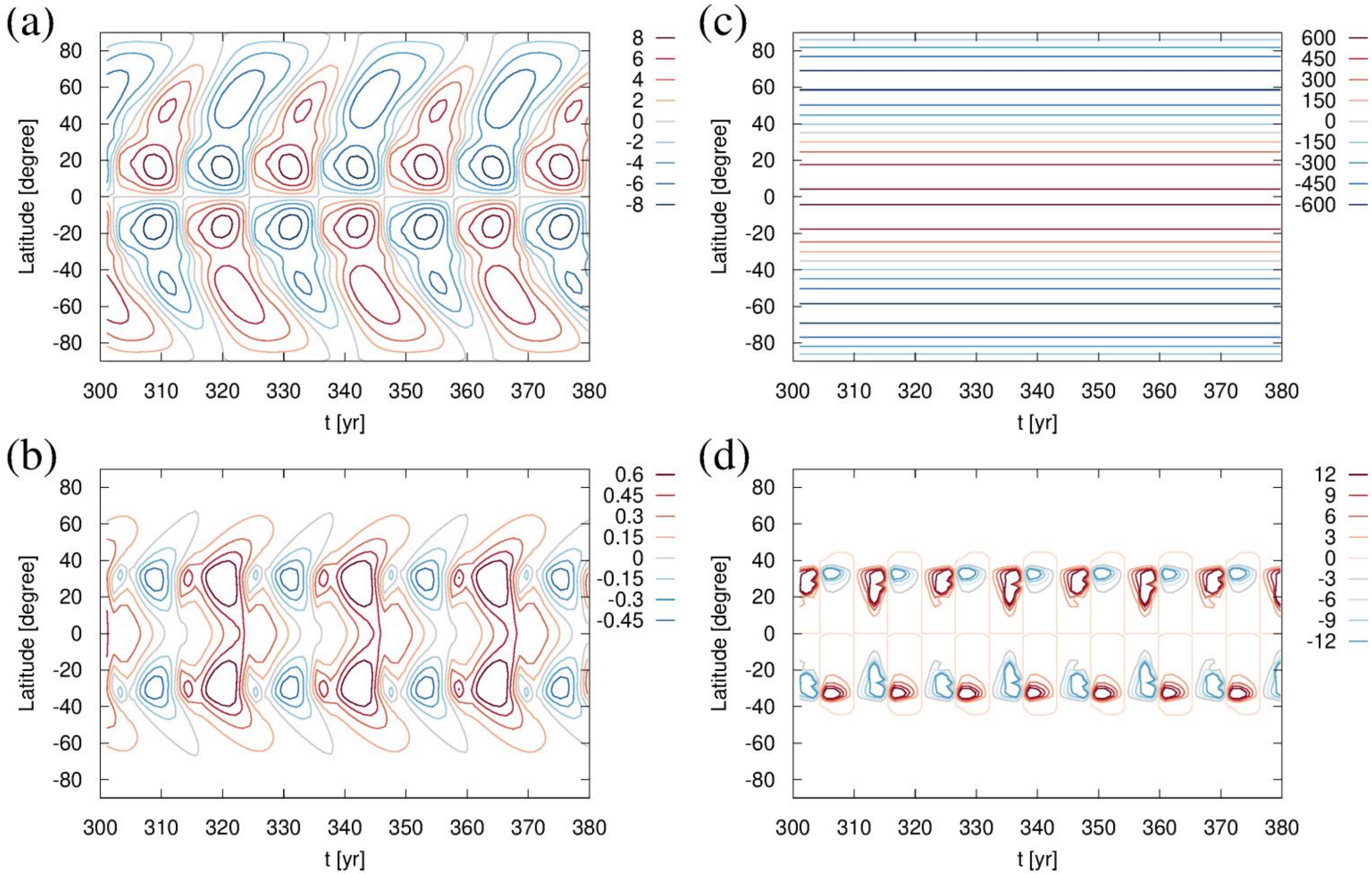
$$\frac{\partial A(\theta,t)}{\partial t} = \alpha(\theta,t) B(\theta,t) - \frac{\partial^2 A(\theta,t)}{\partial \theta^2},$$

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

$$\alpha^p(\theta,t) = \alpha^p_0 \sin(2\pi t/11.07)\mathrm{sgn}(90^\circ - \theta)\frac{B^2(\theta,t)}{(1 + q^p_\alpha B^4(\theta,t))} \text{ for } 55^\circ < \theta < 125^\circ$$

B(θ,t) ω(θ,t)

A(θ,t) α(θ,t)



ω_0=10000, κ=0.2, q_α^p=0.2, α_0^p=100

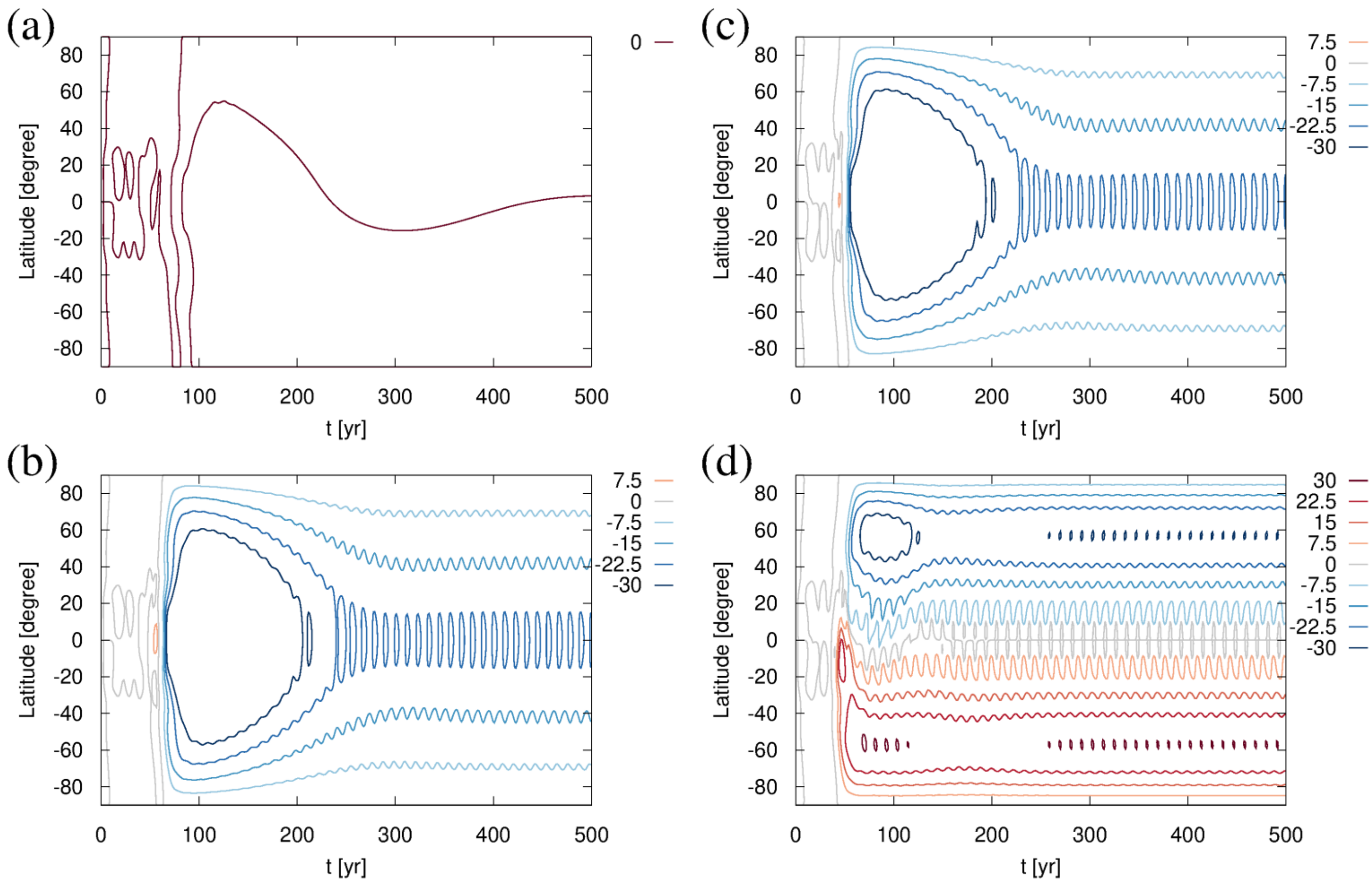
Stefani et al., Solar Physics 294 (2019), 60

A pure Tayler-Spruit dynamo with periodic α forcing

As a massively non-linear dynamo, it starts only at a certain threshold of the initial field strength

0.707 0.729

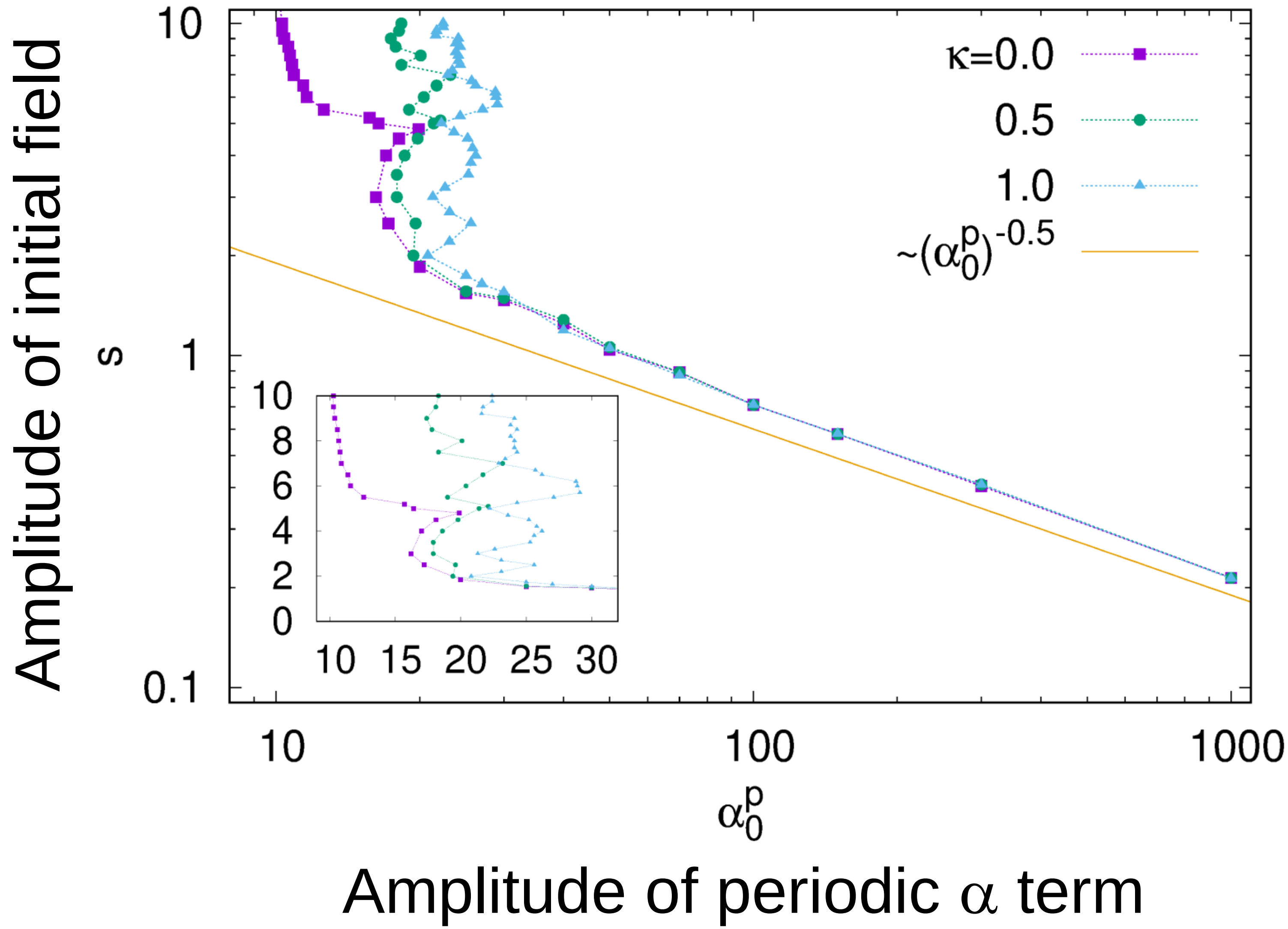
0.708 0.73



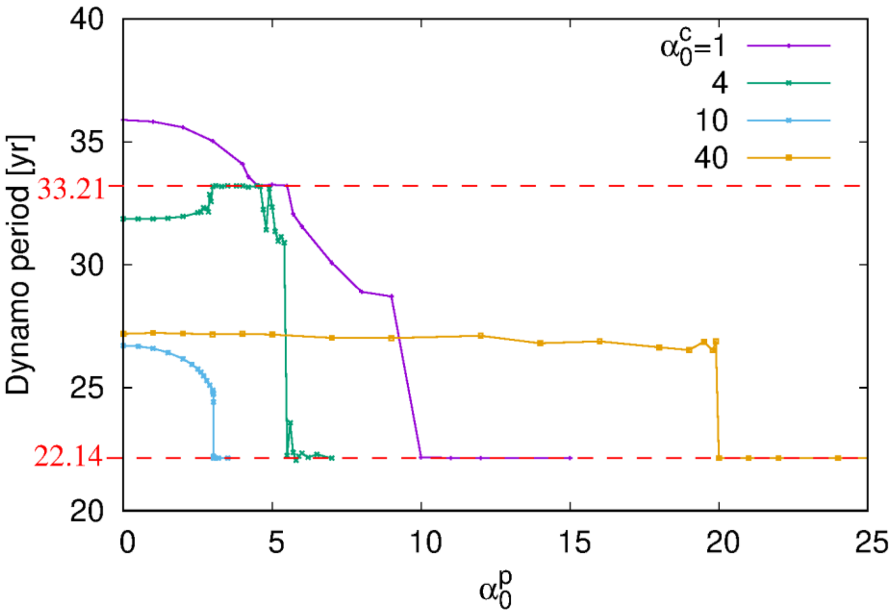
ω_0=10000, κ=0.0, $q_\alpha{}^p$=0.2, $\alpha_0{}^p$=100

DRESDEN concept HZDR

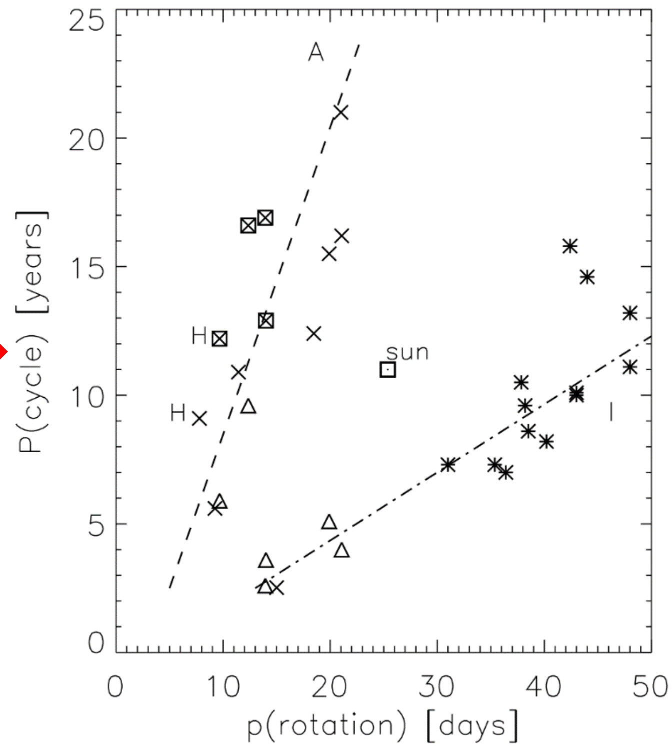
A pure Tayler-Spruit dynamo with periodic α forcing



Hybrid model: conventional α–Ω dynamo + periodic α term



?



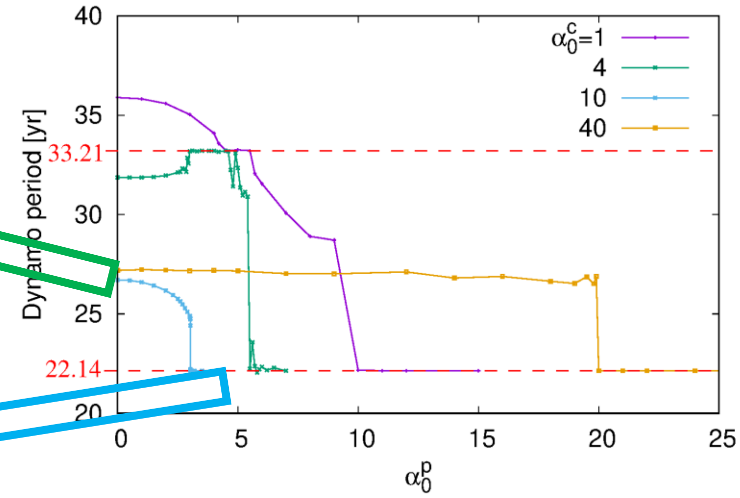
Conventional α–Ω dynamo can be synchronized (via parametric resonance) by the periodic α term (less than 1 m/s needed, which may be realistic)

Böhm-Vitense, ApJ 657 (2007), 486

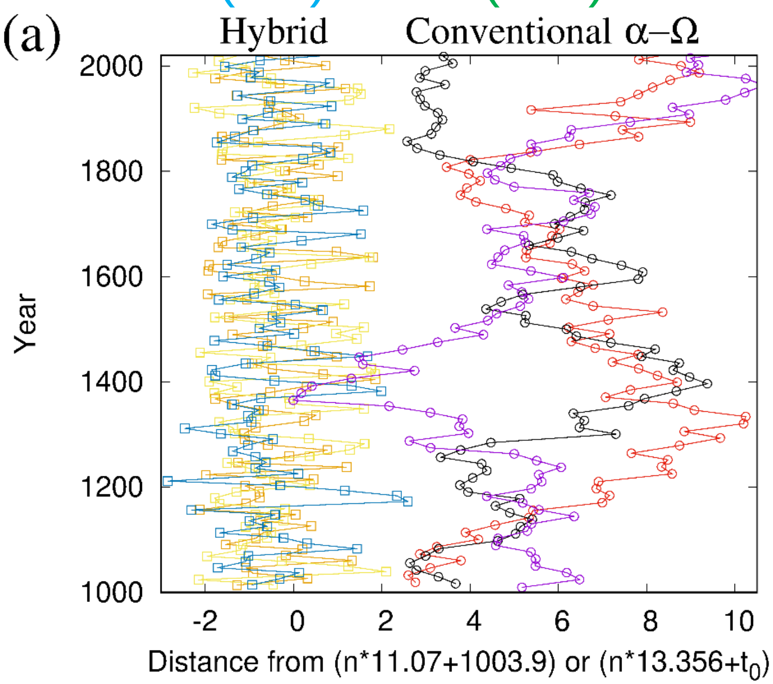
Hybrid model with noise

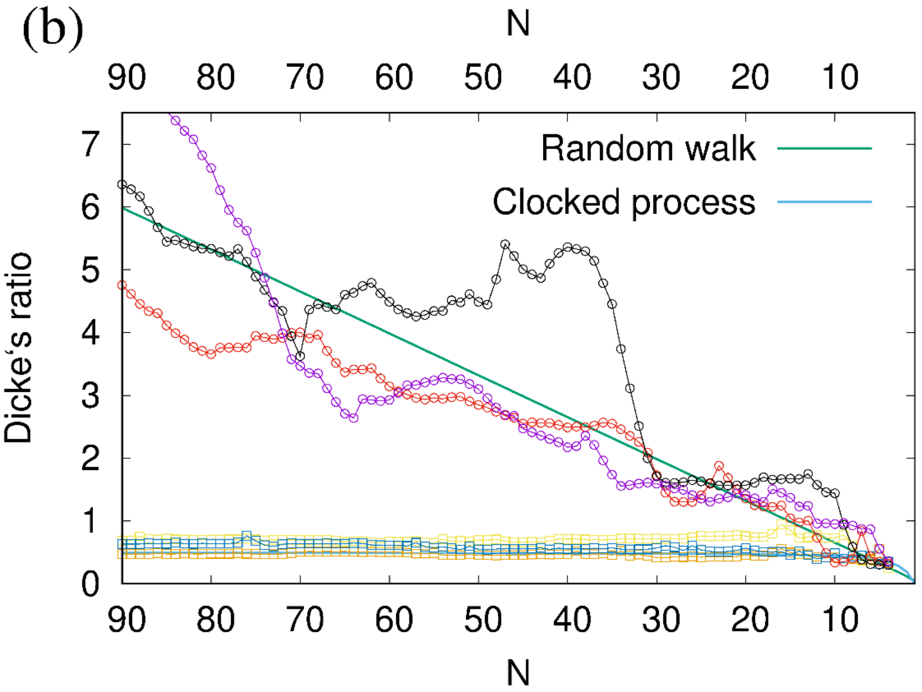
Conventional alpha-Omega dynamo yields random walk (RW)

Synchronized (hybrid) modell yields clocked process (CP)



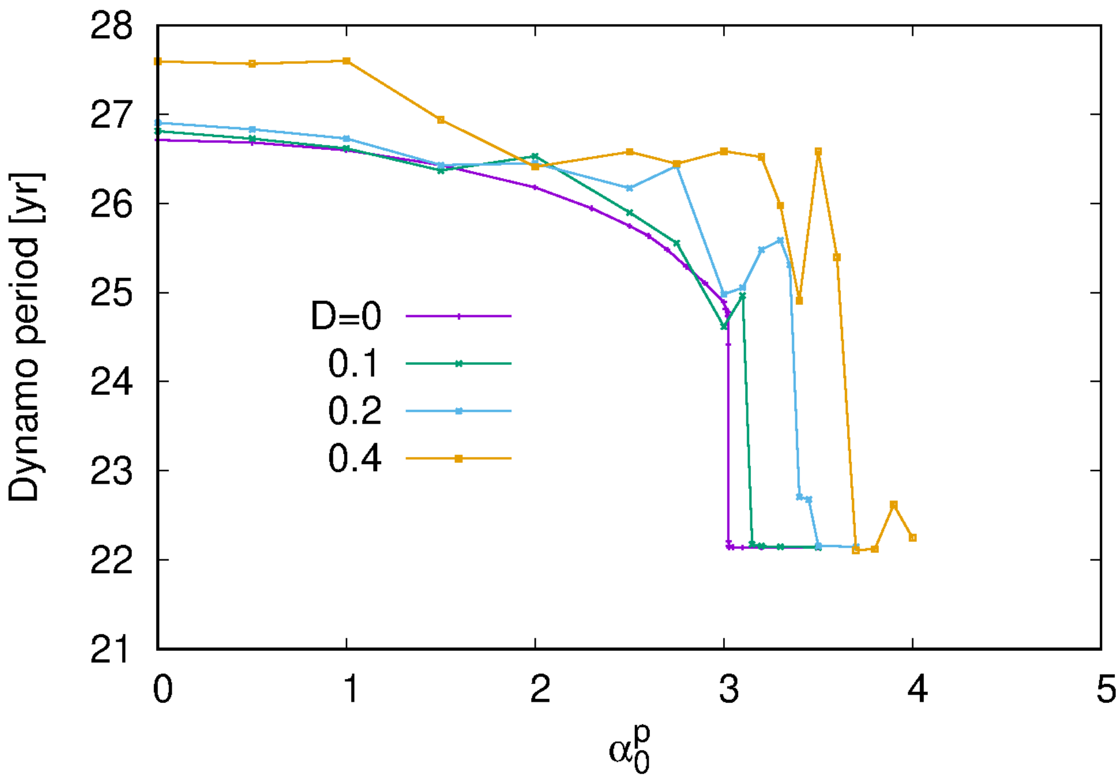
(CP) (RW)





Hybrid model with noise

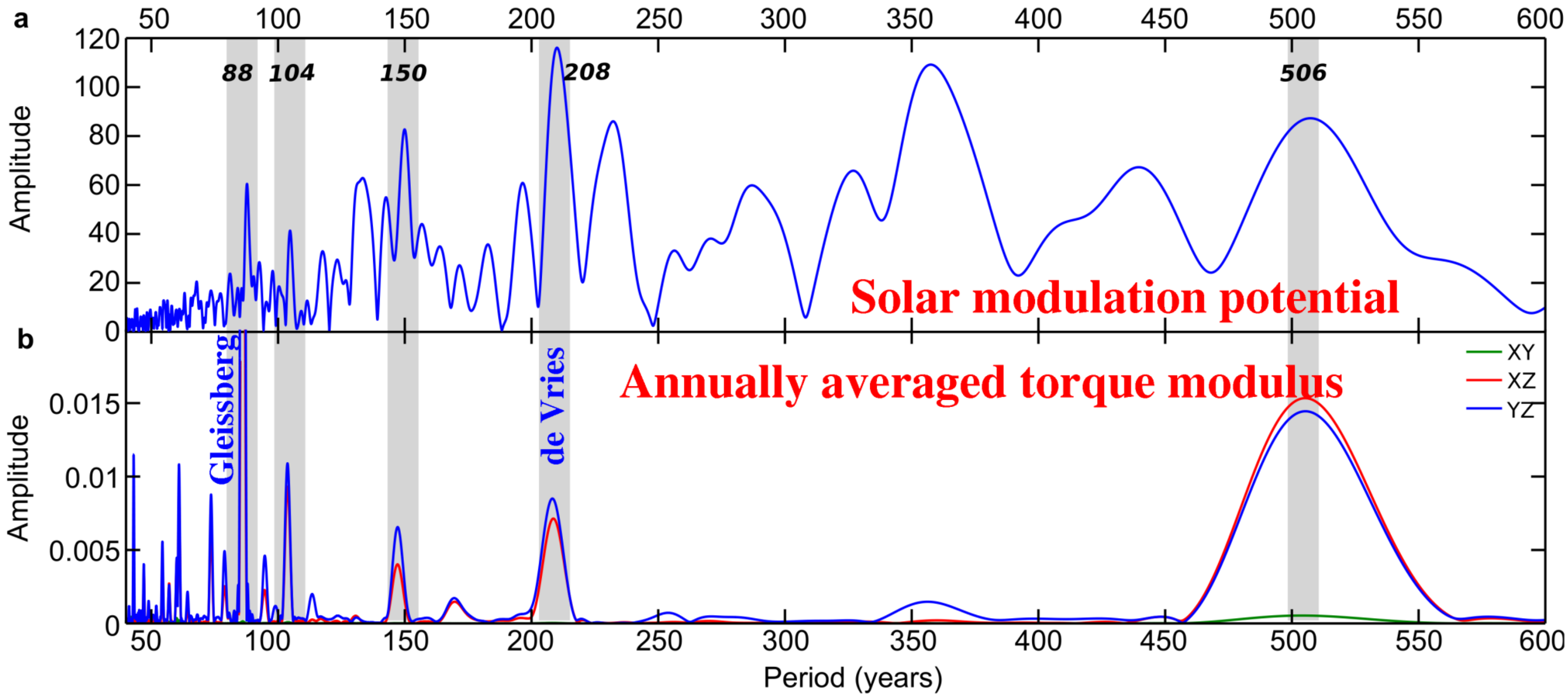
Can noise (D) foster the parametric resonance?



Apparantly not, it rather shifts it to higher values of periodic forcing.

Suess-de Vries

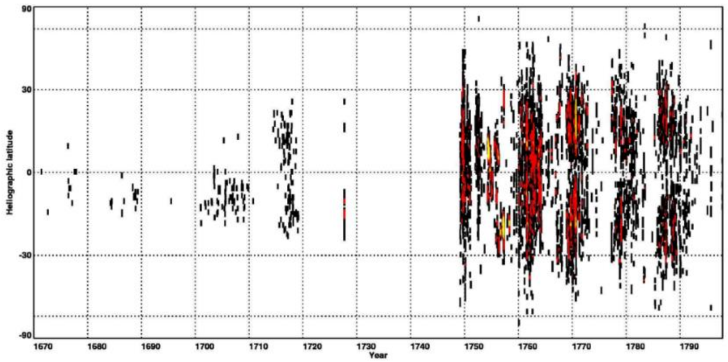
Planetary motion and long periods



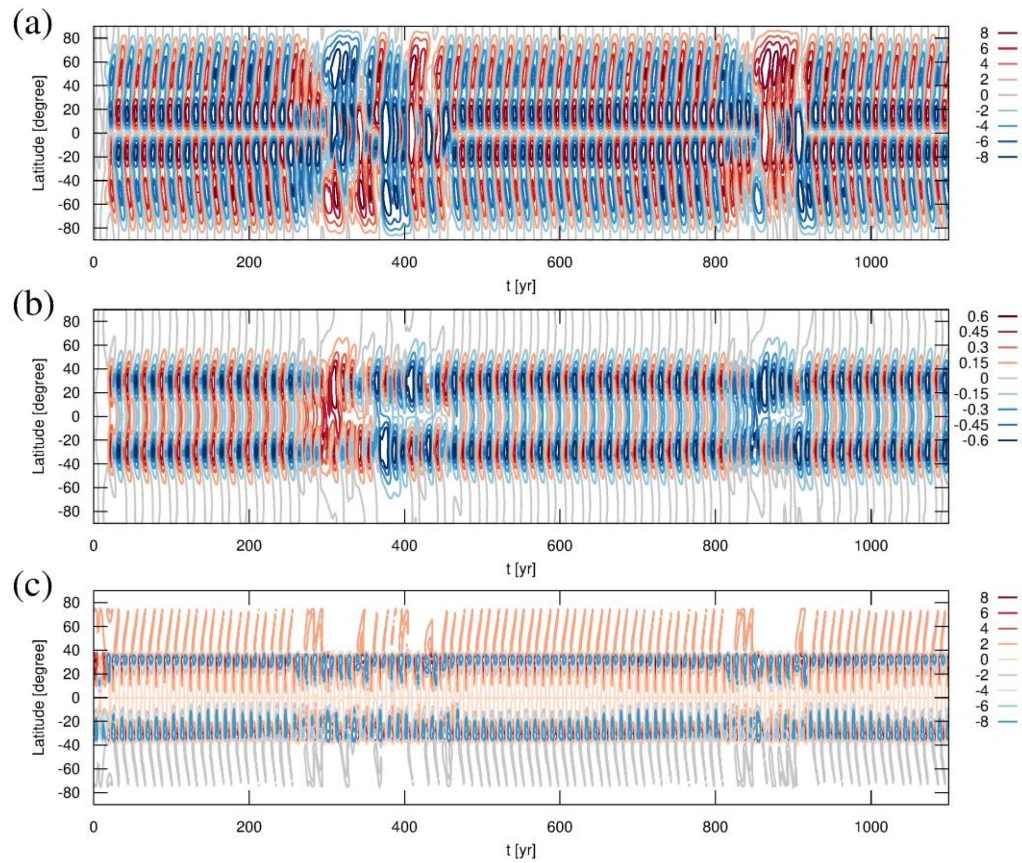
Abreu et al., Astron. & Astrophys. 548 (2012), A88

Long term periods from long term parameter variations

Shortly after grand minima, dipole fields are replaced by quadrupole fields. These transitions also appear in our model, with maintained phase coherence…



Arlt and Weiss, Space Sci. Rev. 186 (2014), 525

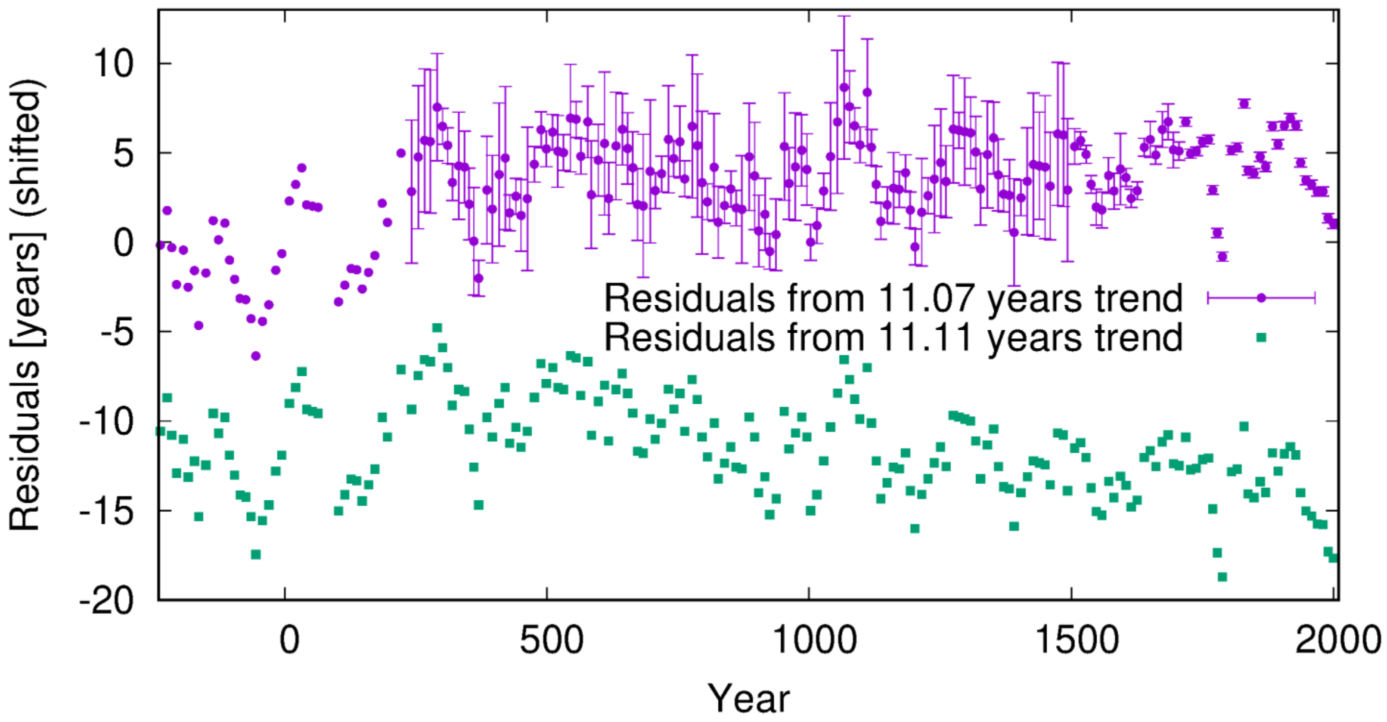


B(θ, t) (**a**), *A(θ, t)* (**b**), and *α(θ, t)* (**c**) showing transitions between dipole and quadrupole fields when varying κ according to $\kappa(t) = 1 - 0.6\sin^2(2\pi t/1100)$.

Stefani et al., Solar Physics 294 (2019), 60

Planetary motion and long periods

Schove´s maxima data, with two different trends subtracted…



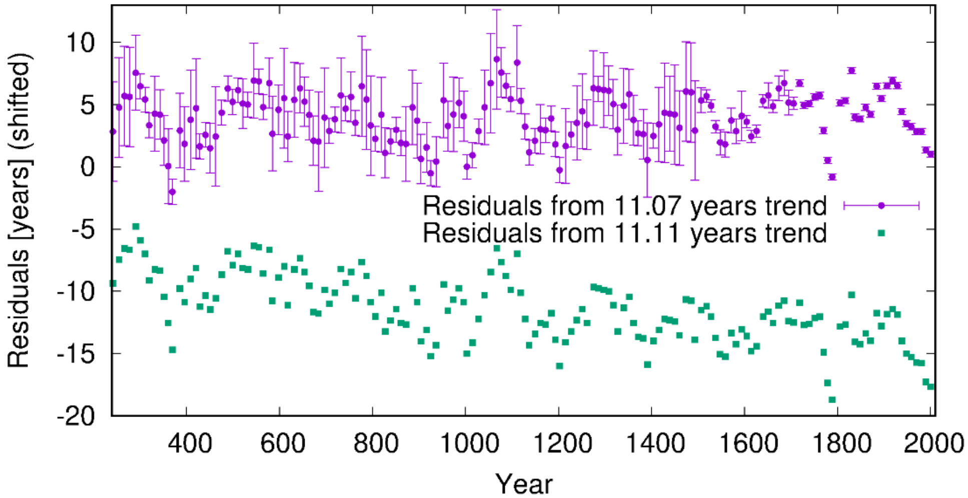
Schove, D.J.: Sunspot cycles, 1983; Hathaway, D.H., Liv. Rev. Sol. Phys. 7 (2010), 1

Stefani et al., arXiv:1910.10383

DRESDEN concept

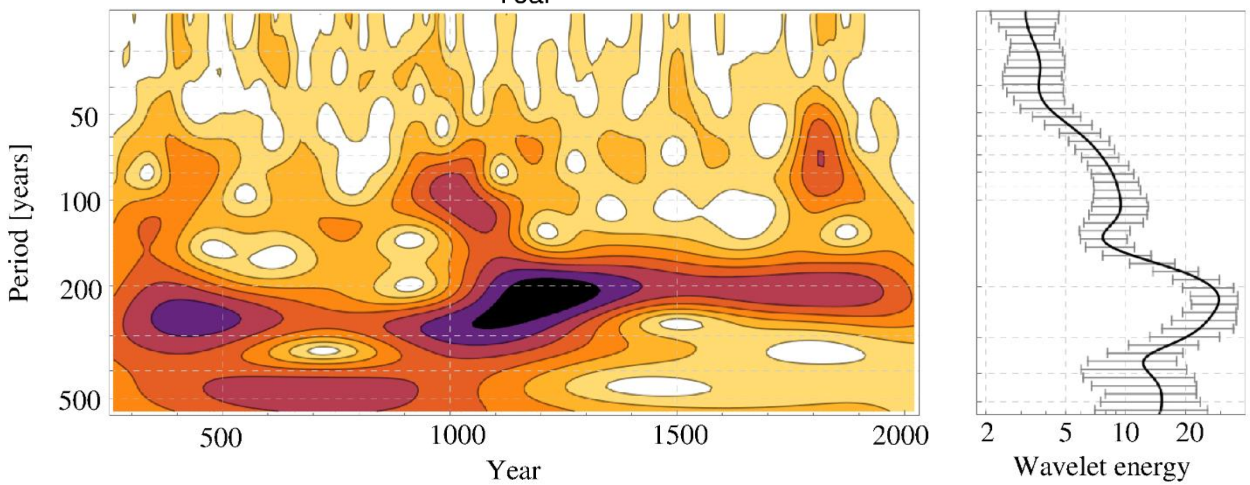
HZDR

Planetary motion and long periods



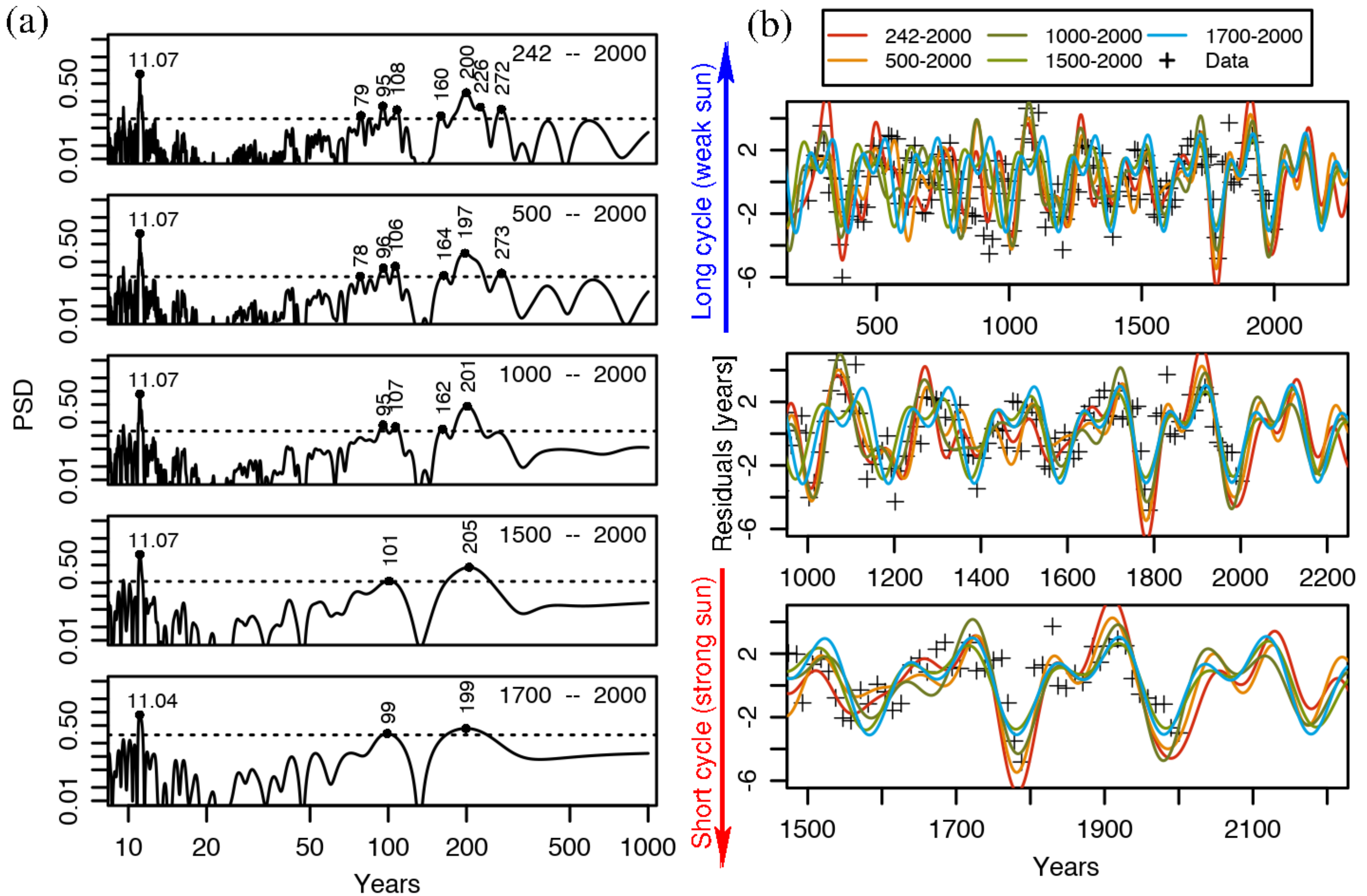
Schove´s maxima data, with two different trends subtracted…

…and wavelet analysis



Stefani et al., arXiv:1910.10383

Detailed analysis with different underlying time intervals



Lomb-Scargle periodograms based an different intervals

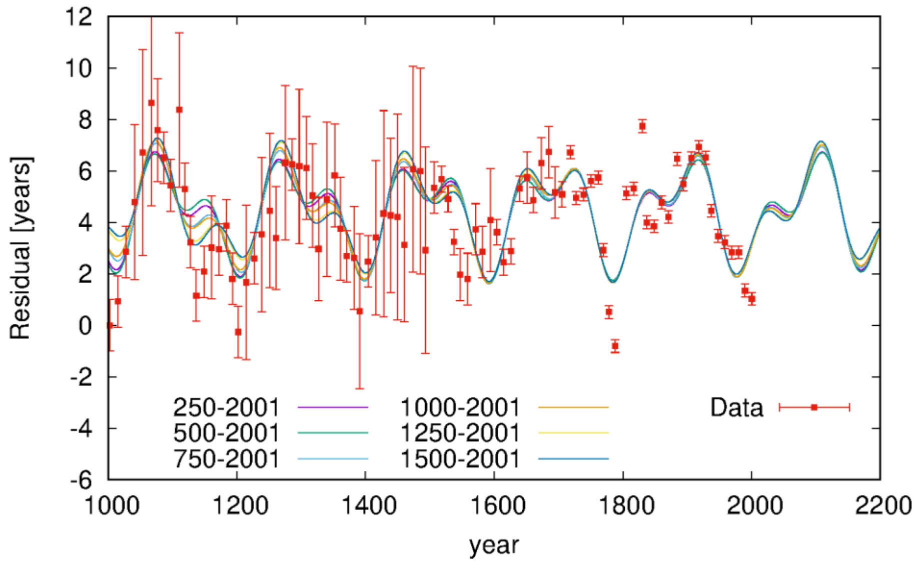
Fits with significant harmonics

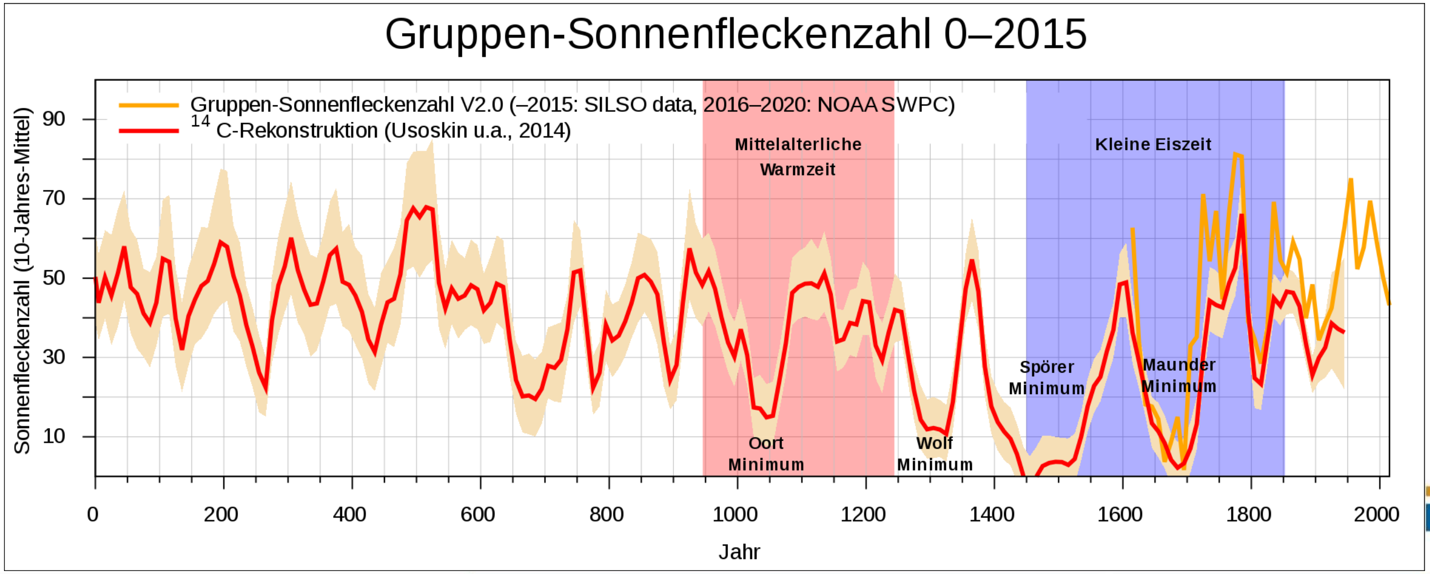
Extrapolation of Schove's data points to a new grand minimum

Slightly different fit with two dominant frequencies (Gleissberg and Suess-de Vries)

- Long cycle
- Weak dynamo
- Cold ???

- Short cycle
- Strong dynamo
- Warm ???





Extrapolation of Schove's data points to a new grand minimum

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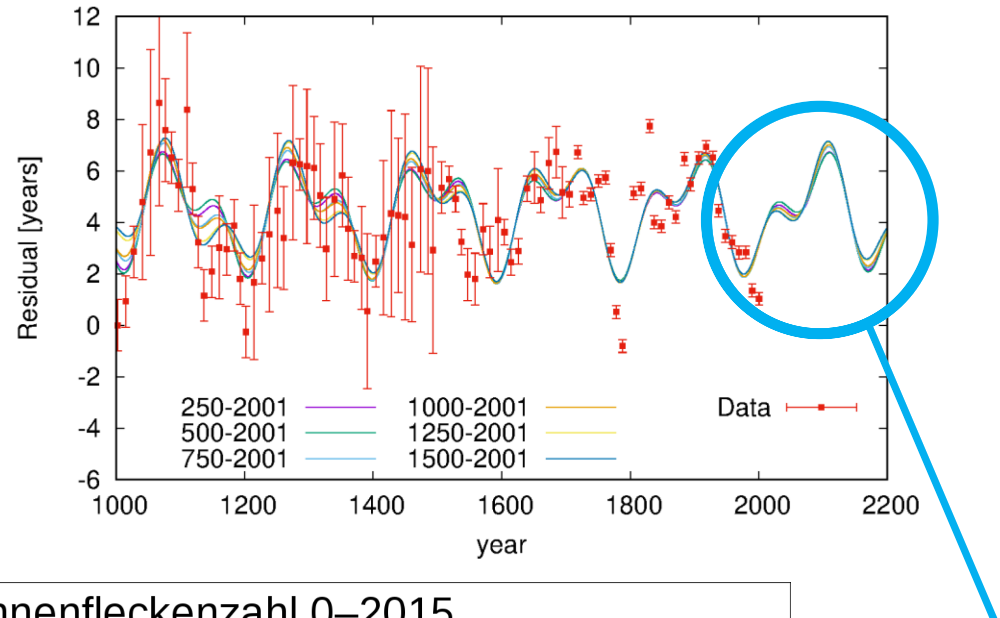
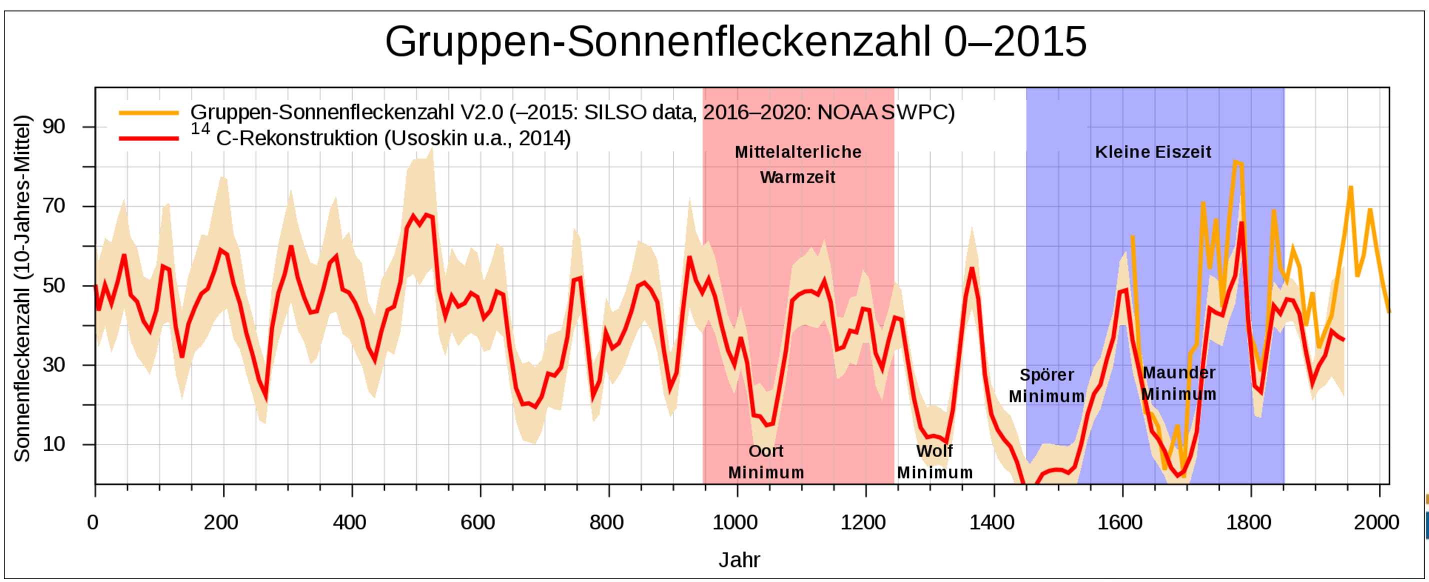
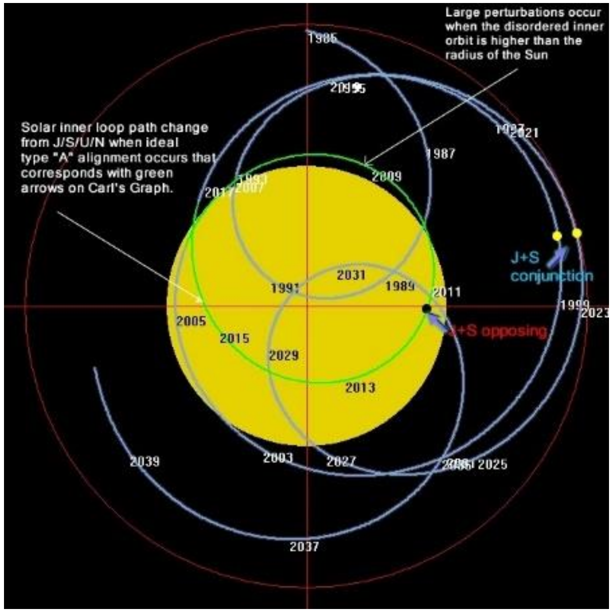


Forecast: New„Grand Minimum" ?



Is the Suess/de Vries cycle a beat period between 22.14 and 19.86 ?

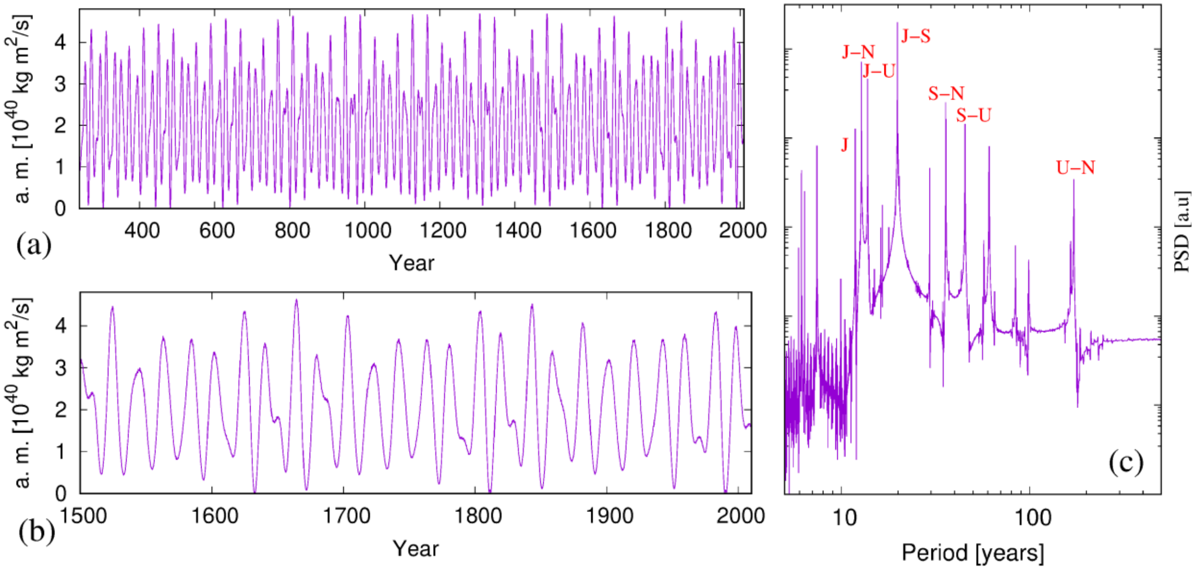


Sharp, Int J. Astron. Astrophys., vol. 3 (2013), 260

Wilson, Pattern Recogn. Phys. 1 (2013), 147; Solheim, Pattern. Recogn. Phys. 1 (2013), 159

Tidal forcing → 22.14 years
Sun around barycenter → 19.86 years
(with unclear physical effect on the dynamo)

Beat period: 193 years
19.86 x 22.14/(22.14-19.86)

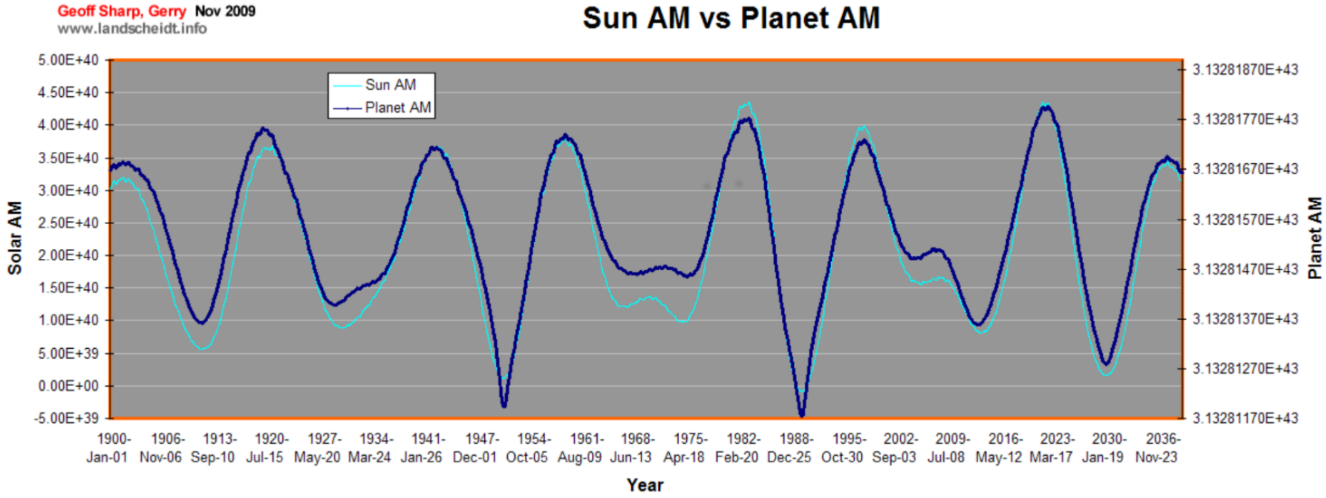


Warning: Spin-orbit coupling is not really understood…

…despite a huge body of work…

Fairbridge, Shirley, Solar Phys. 110 (1987), 191; Charvatova, Surv. Geophys. 18 (1997), 131; Palus et al, Int. J. Bifurc. Chaos Appl. Sci. Eng. 10 (2000), 2519; Jucket, Solar Phys. 191 (2000), 201; Shirley, Mon. Not. R. Astron. Soc. 368 (2006), 280; Wolff, Patrone, Solar Phys. 266 (2010), 227; Wilson, Pattern Recogn. Phys. 1 (2013), 147; Solheim, Pattern. Recogn. Phys. 1 (2013), 159, McCracken et al., Solar Phys. 289 (2014), 3207

Interesting…



Sharp, Int J. Astron. Astrophys., vol. 3 (2013), p. 260.

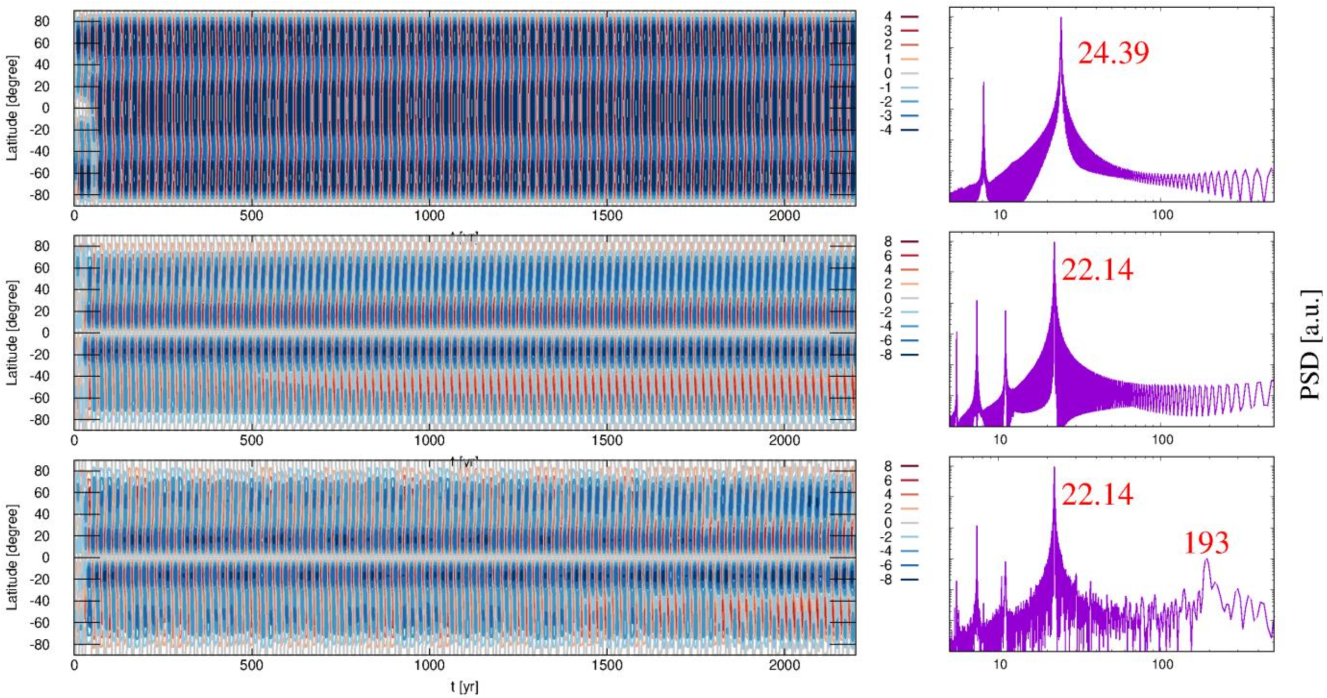
Is the Suess/de Vries cycle a beat period between 22.14 and 19.86 ?

Perhaps yes…

α–Ω-dynamo without synchronization

α–Ω-dynamo with tidal synchronization (11.07 years)

α–Ω-dynamo with tidal 11.07-years synchronization + ~19.86-year modulation



year

period

$$\kappa(t) = 0.5 + 0.5\, am(t)/am_{max}$$

Stefani et al., Magnetohydrodynamics (submitted),
arxiv.org/abs/1910.10383

DRESDEN concept HZDR

Gleissberg (…and the Wilson gap)

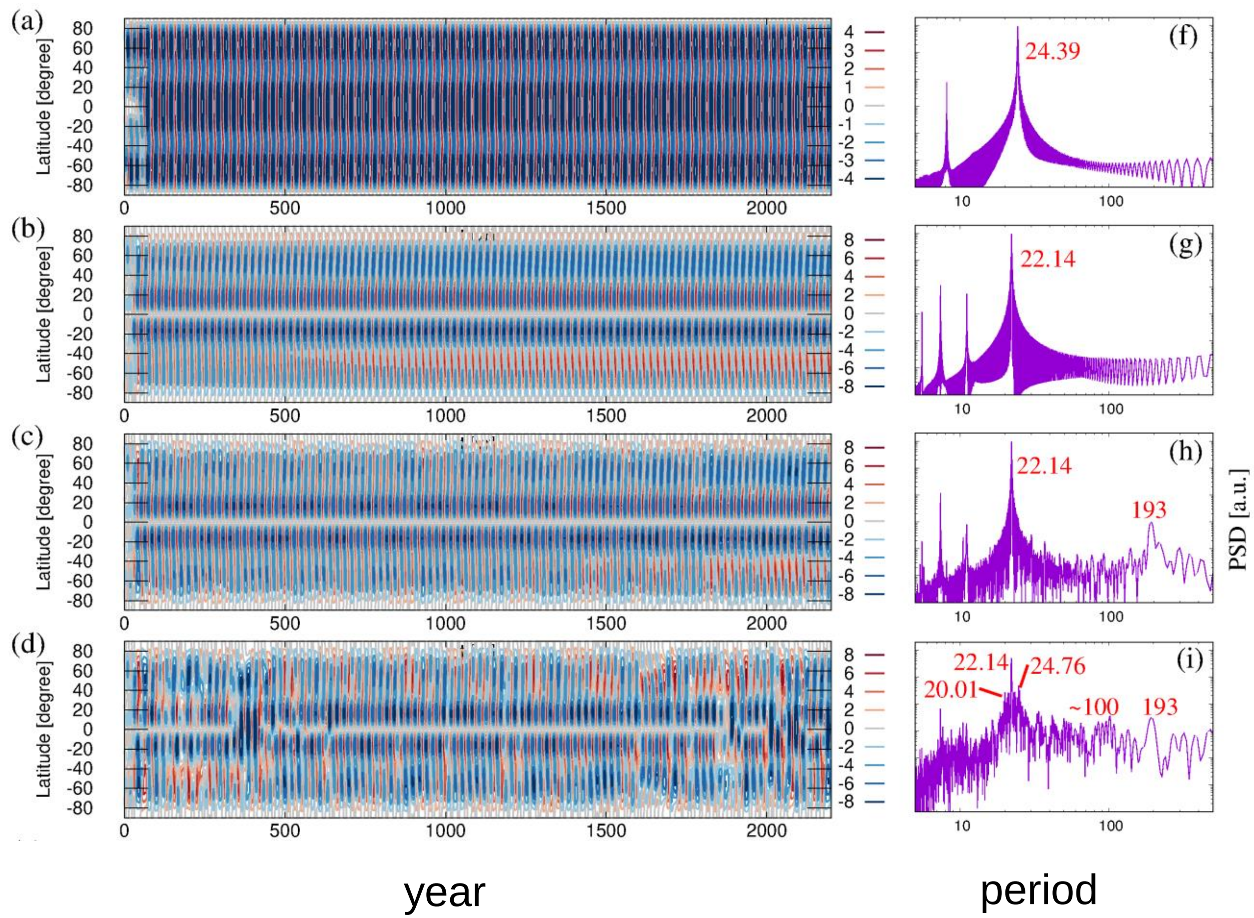
Consistent picture of Schwabe, Gleissberg, Suess/de Vries ?

α–Ω-dynamo without synchronization

α–Ω-dynamo with tidal synchronization (11.07 years)

α–Ω-dynamo with tidal 11.07-years synchronization + ~19.86-year modulation

α–Ω-dynamo with tidal 11.07-years-synchronization + stronger ~19.86-year modulation



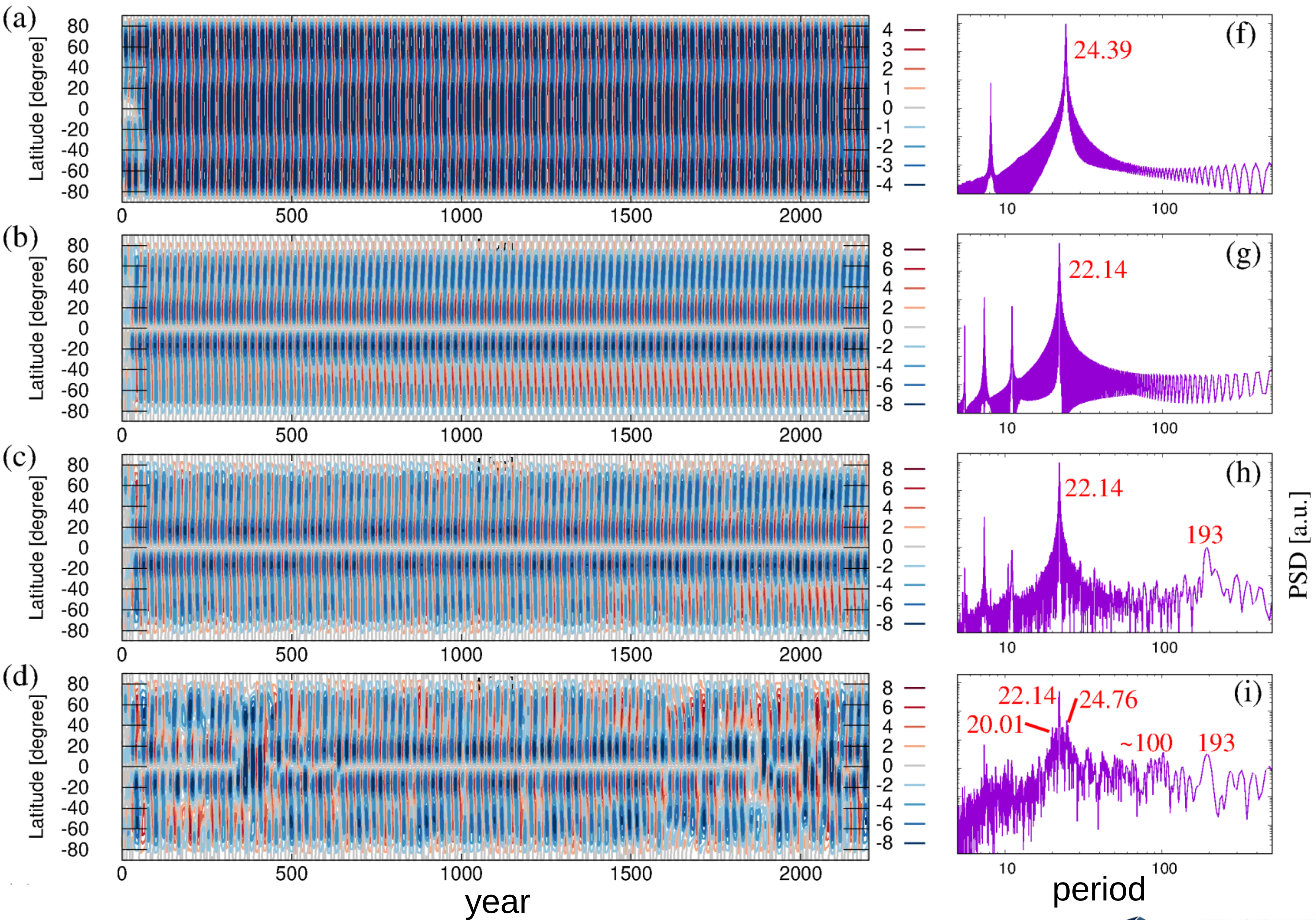
$$\kappa(t) = 0.18 + 1.0\ am(t)/am_{max}$$

Stefani et al., Magnetohydrodynamics (submitted), arxiv.org/abs/1910.10383

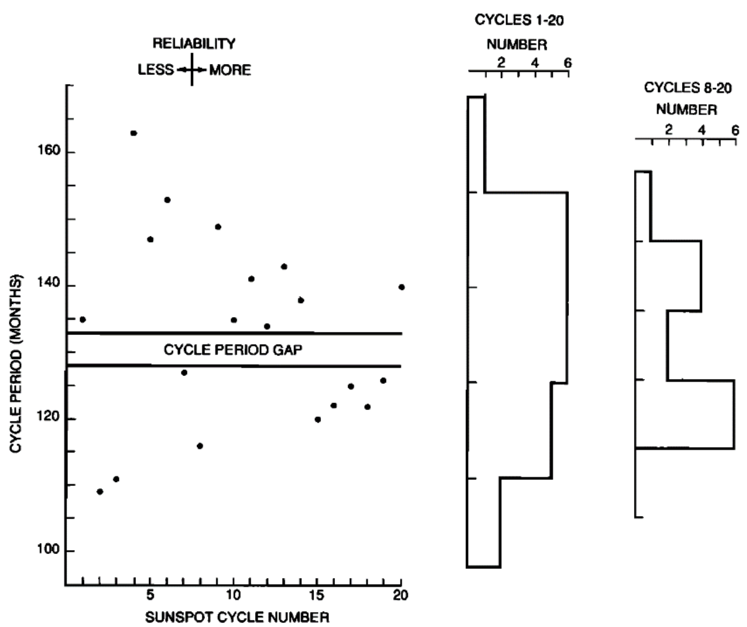
DRESDEN concept

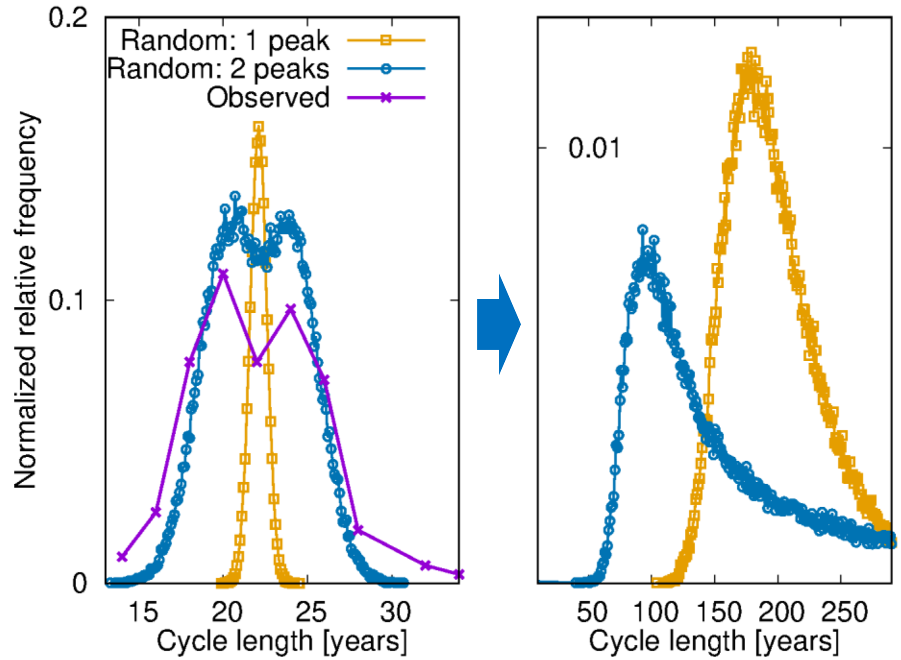
HZDR

Consistent picture of Schwabe, Gleissberg, Suess/de Vries ?



The Wilson gap: a consequence of synchronization+modulation?





Bimodality of cycle length fits data much better than assumption of normal distribution

Observed and 2 synthetic distributions of cycle lengths T_c

Resulting distributions of $19.86T_c/(19.86-T_c)$

Wilson, R.M.: J. Geophys. Res. 92 (1987), 10101

DRESDEN concept

HZDR

Role of Jupiter-Uranus/Neptun alignments → Not very important (?)

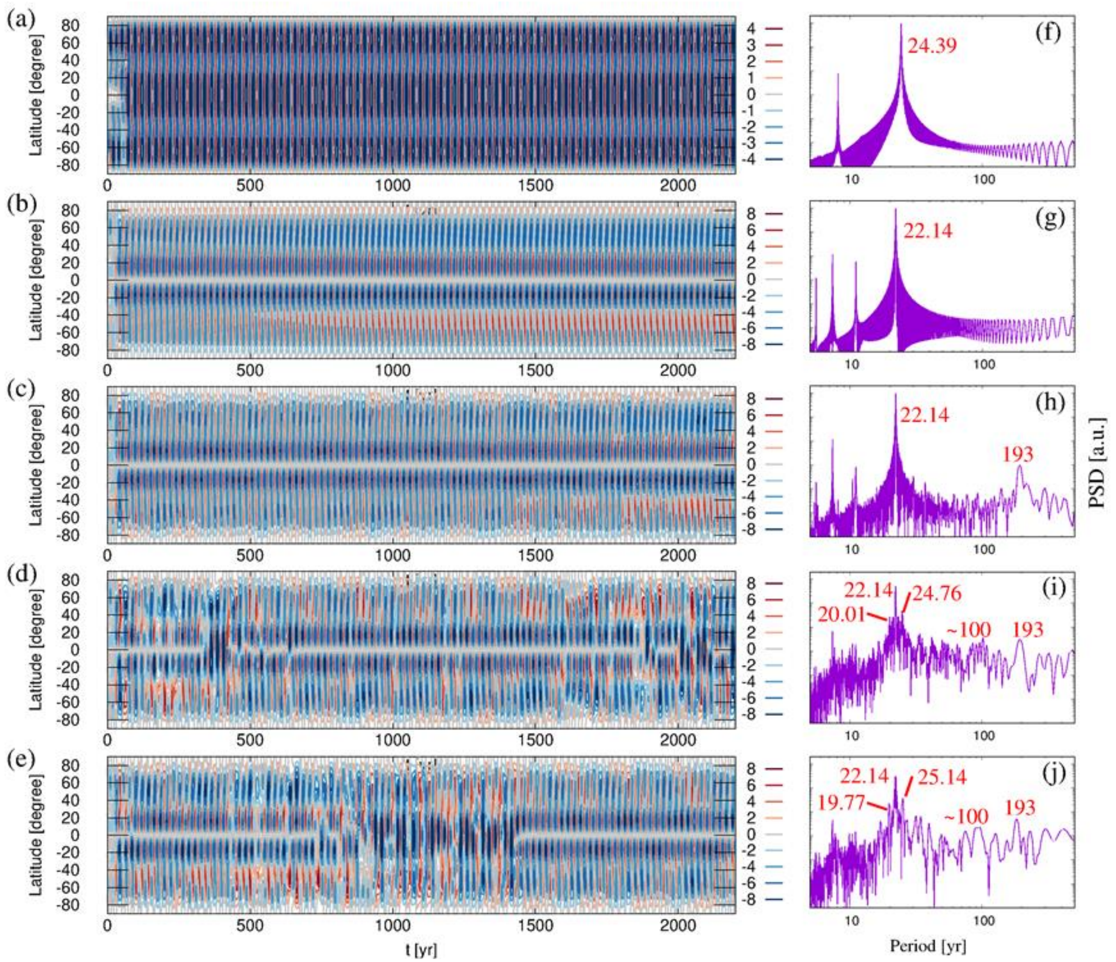
α–Ω-dynamo without synchronization

α–Ω-dynamo with tidal synchronization (11.07 years)

α–Ω-dynamo with tidal 11.07-years synchronization + ~19.86-year modulation

α–Ω-dynamo with tidal 11.07-years-synchronization + stronger ~19.86-year modulation

α–Ω-dynamo with tidal 11.07-years synchronisation + stronger and pure 19.86-year modulation



year

period

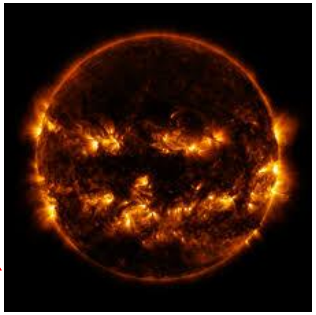
Summary of our model

11.07 years tidal forcing (m=2) synchronizes the oscillatory part of α related to some m=1 instability (Tayler instability, Rossby waves?)

Conventional α–Ω dynamo without synchronization

Hybrid α–Ω dynamo, synchronized to 22.14 years period

Wilson gap and second (more irregular) beat period around 100 years (Gleissberg?)



Some spin-orbit coupling (poorly understood!) with dominant 19.86 years period affects field storage capacity in the tachocline (κ-parameter)

Beat period 193 years (Suess-de Vries?)

With stronger κ-variation, emergence of side bands around ~19.86 and ~24.5 years (in order to compensate the “too short” cycles)

Thank you

European Research Council
Established by the European Commission

This project has received funding from the European Research Council (ERC) under the European Union´s Horizon 2020 research and innovation programme (grant agreement No 787544).

DRESDEN concept

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