

AstroMHD, 3rd December 2019

**Schwabe, Gleissberg, Suess-de Vries:
Towards a self-consistent model for synchronizing
short and long-term solar cycles
by planetary forces**

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

HZDR

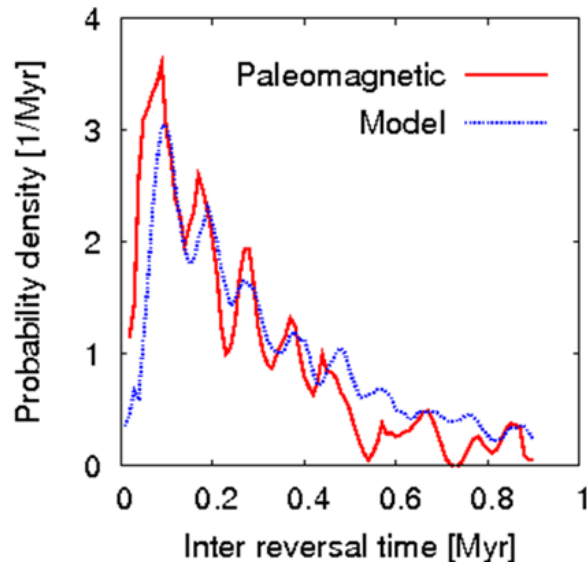
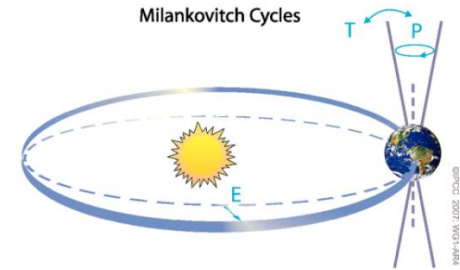
 **HELMHOLTZ**
| ZENTRUM DRESDEN
| ROSSENDORF

1. Consolini, Doake
2. Schwabe, Hale
3. Suess, de Vries
4. Gleissberg (...and the Wilson gap)

Consolini, Doake

Geodynamo reversals and stochastic resonance

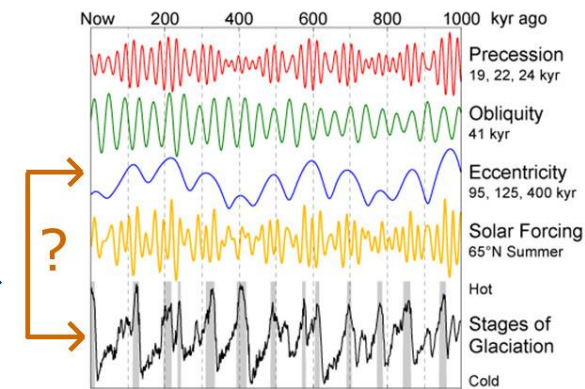
Strong indication for influence of variations of Earth's orbit parameters (precession?, obliquity, excentricity) on the reversals of the geodynamo



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



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

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

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

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

Chris Doake

Topographische Karte (Satellitenbildkarte)
Topographic Map (Satellite Image Map)

FILCHNER-RONNE-SCHELFEIS

Chris Doake

Doake ice rumples

Topographische Karte (Satellitenbildkarte)
Topographic Map (Satellite Image Map)

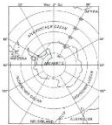
1 : 2 000 000

2. Ausgabe / 2nd Edition

FILCHNER-RONNE-SCHELFEIS

ANTARKTIS

Lageplan / Location diagram



Meeres- und Eisforschung, Hamburg 20. März, Unter Leitung:
Antarktis-Expedition, Bremerhaven, Germany
British Antarctic Survey, Cambridge, United Kingdom
Institut für Angewandte Geodäsie, Frankfurt am Main und Leipzig, Germany

Topographische Karte (Satellitenbildkarte) von Filchner-Ronne-Schelfeis

Topographic map (Satellite image map) of Filchner-Ronne Shelves

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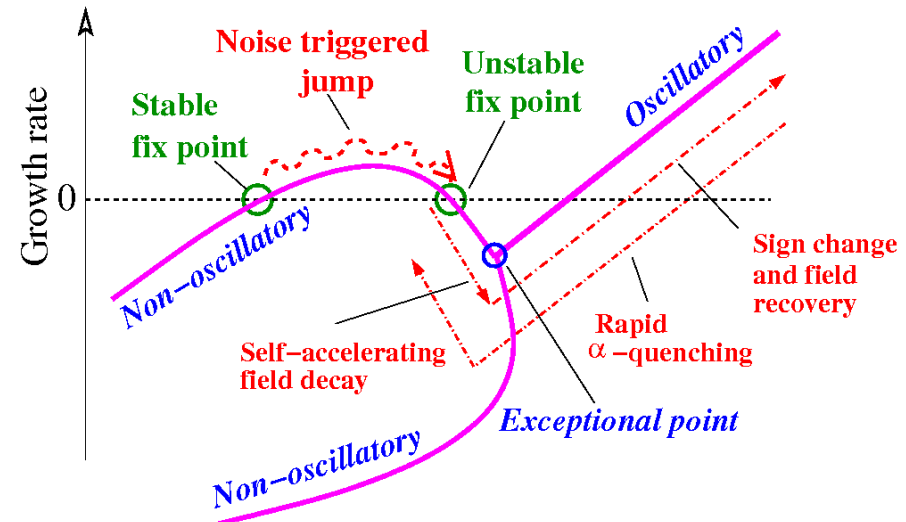
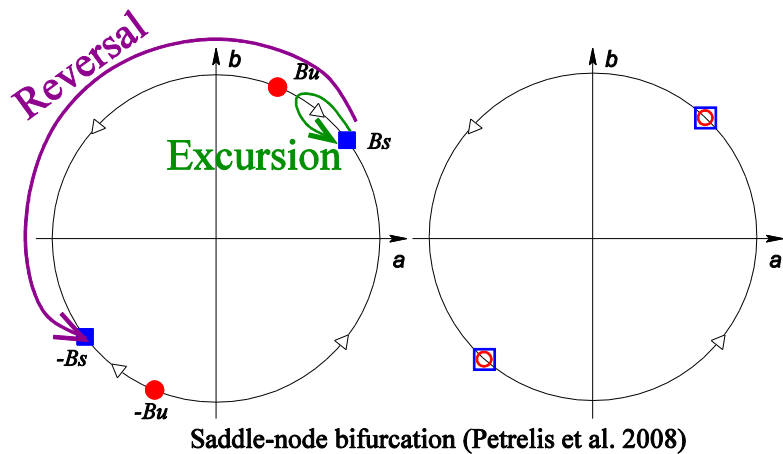
Three types of causality connecting Milankovich, climate, reversals

DOAKE: Ice-albedo feedback → build-up/break-up of ice caps → changing moment of inertia → changed Earth rotation → reversals

SVENSMARK (very likely neither politically nor scientifically correct): direct trigger of reversals by spin-orbit coupling → changing geomagnetic field → changing climate via Svensmark effect

INDEPENDENT: Ice-albedo feedback and *independent* spin-orbit coupling for geodynamo

Two complementary pictures of field reversals



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

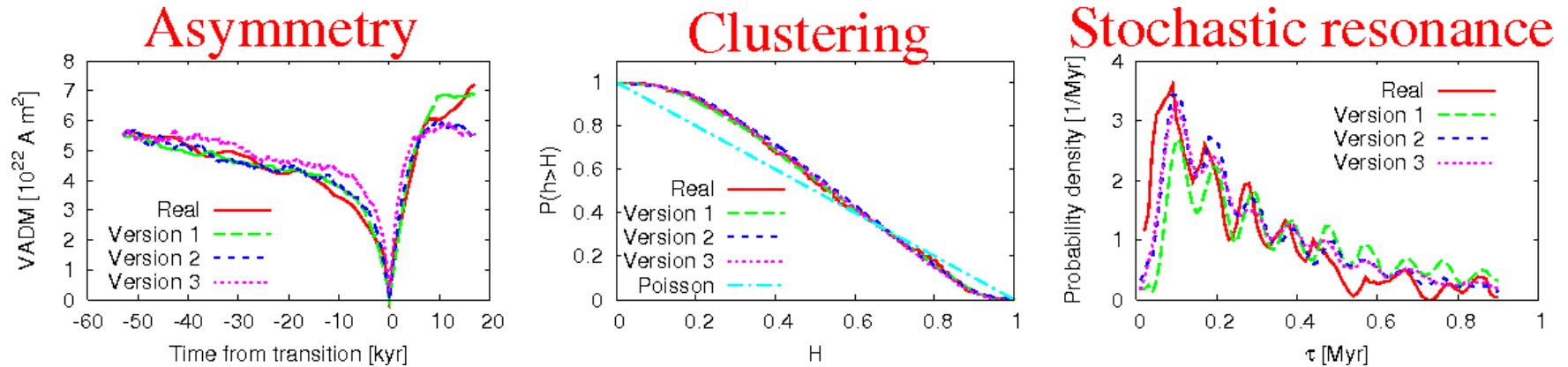
Spectral picture:

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 R_m 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

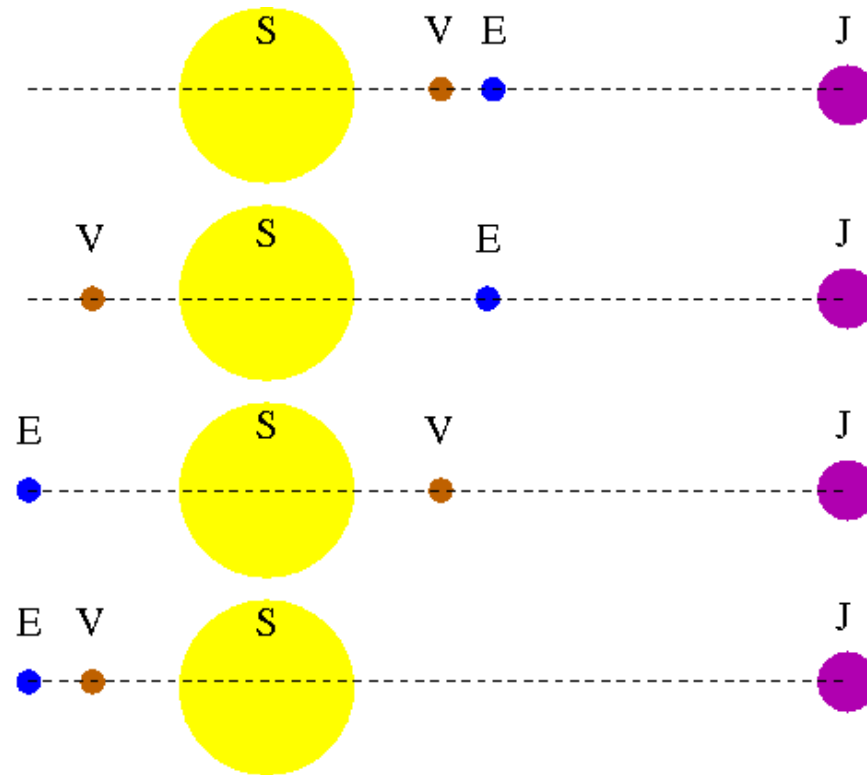
$$M = 50.31 + 3.73 \left\{ \begin{array}{l} 1.68 \sin 585^{\circ}.26 t + 1.00 \sin 360^{\circ} t + \\ 12.53 \sin 30^{\circ}.35 t + 1.12 \sin 12^{\circ}.22 t \end{array} \right\}$$

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

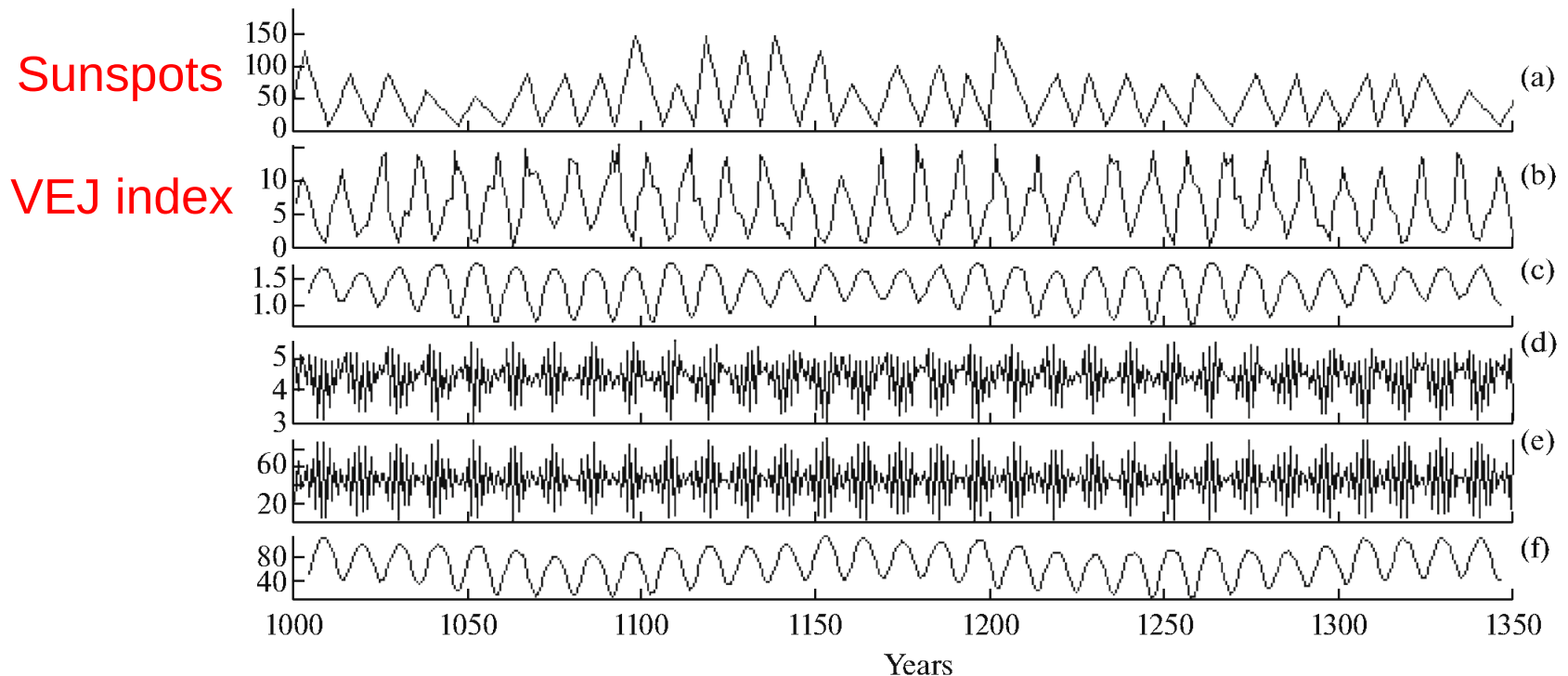
Amazing synchronization of solar cycle with the 11.07 years alignment cycle of the **V**enus-**E**arth-**J**upiter system (despite tiny tidal forces!)



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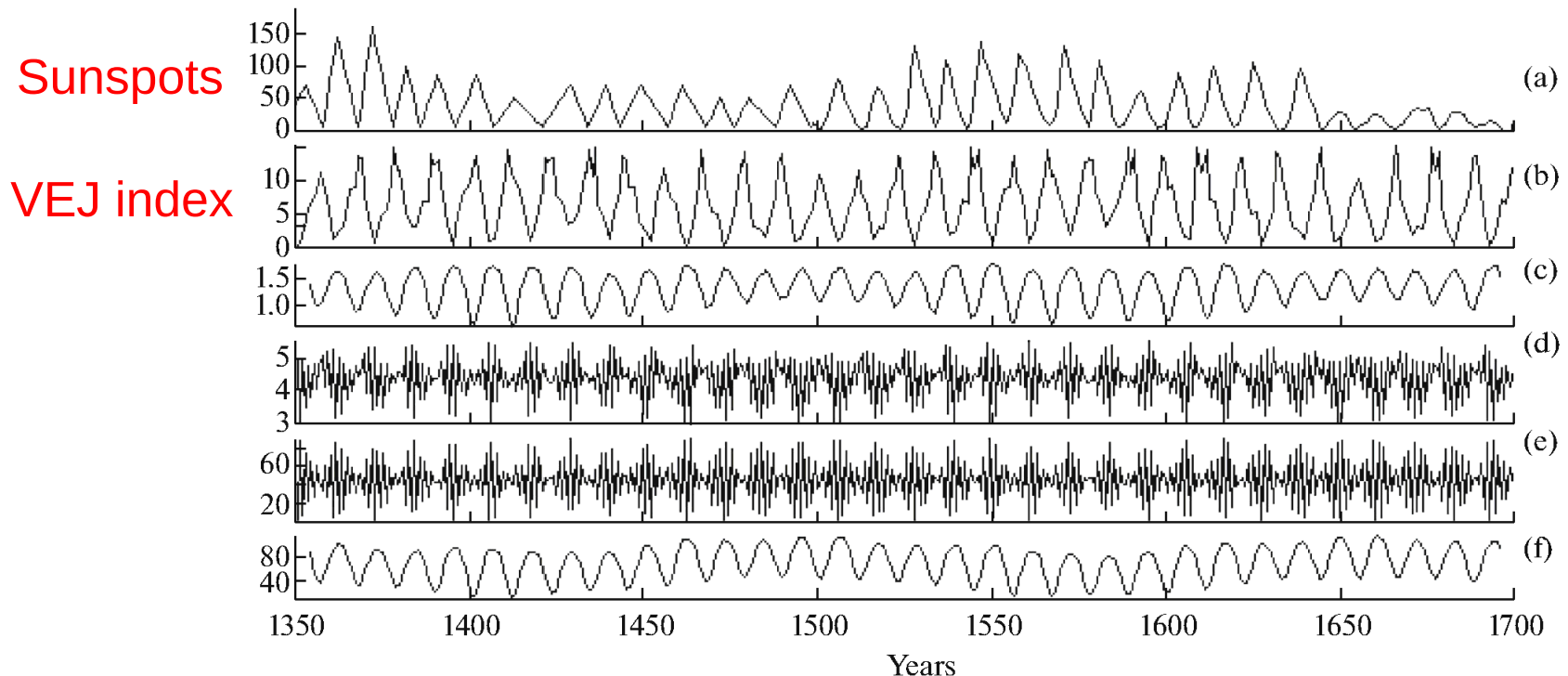
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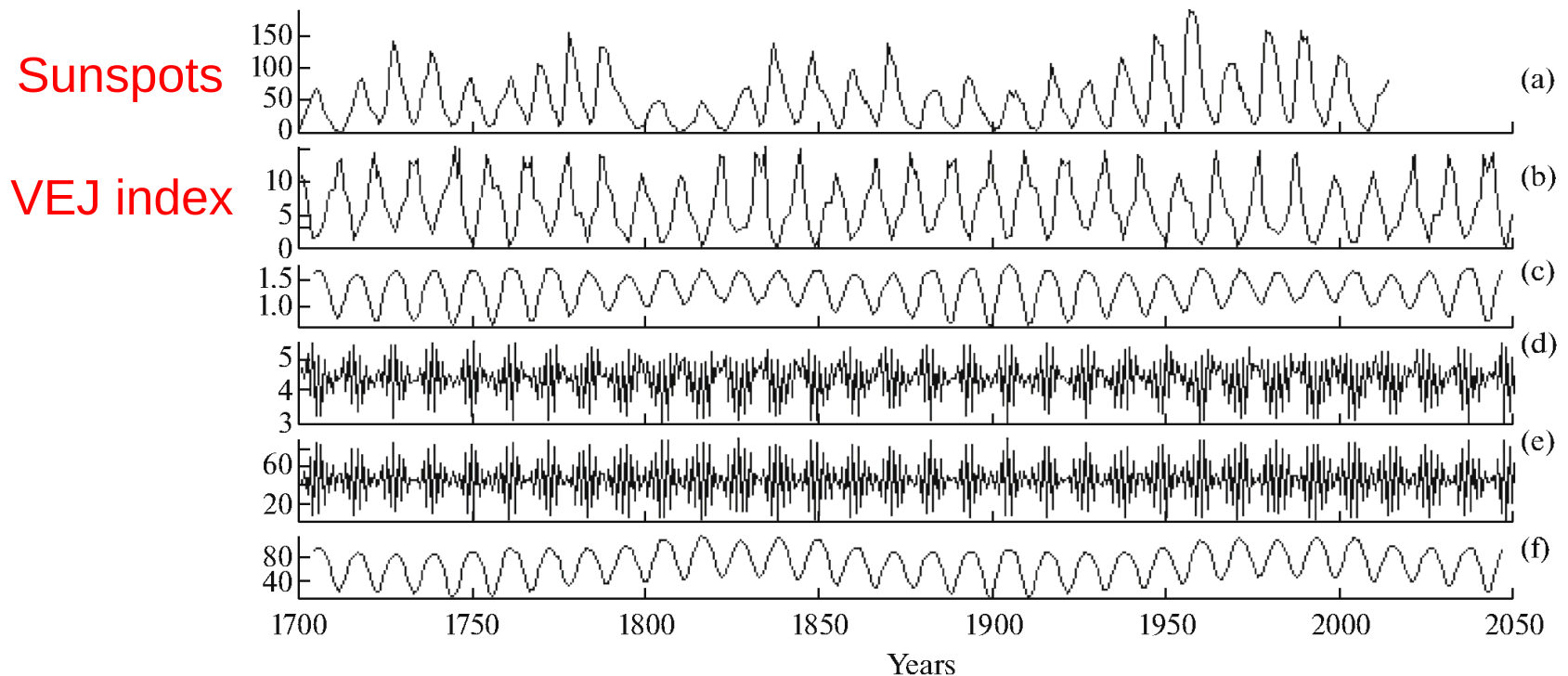
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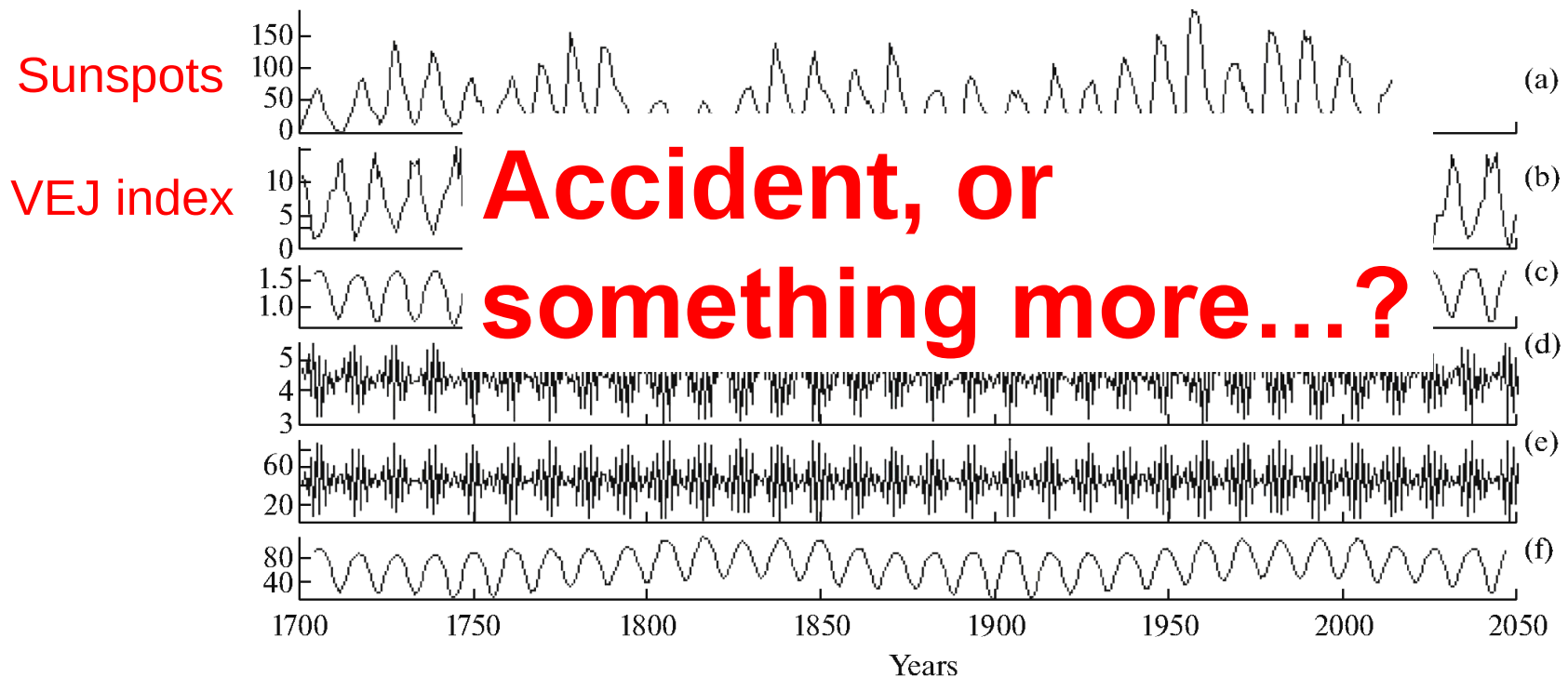
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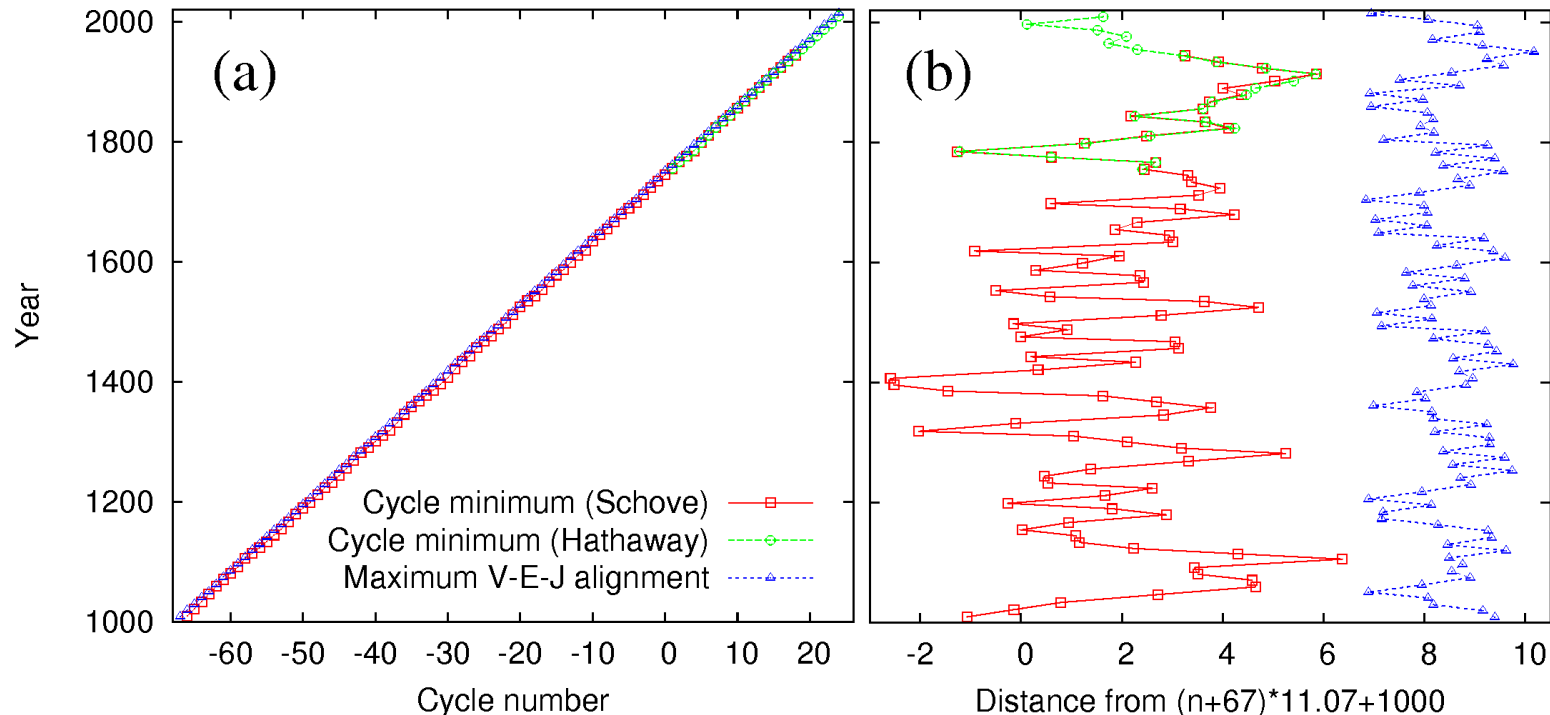
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Planetary tides and the solar dynamo: The basic 22 years cycle

Amazing synchronization of solar cycle with the 11.07 years alignment cycle of the **V**enus-**E**arth-**J**upiter system (despite tiny tidal forces!)

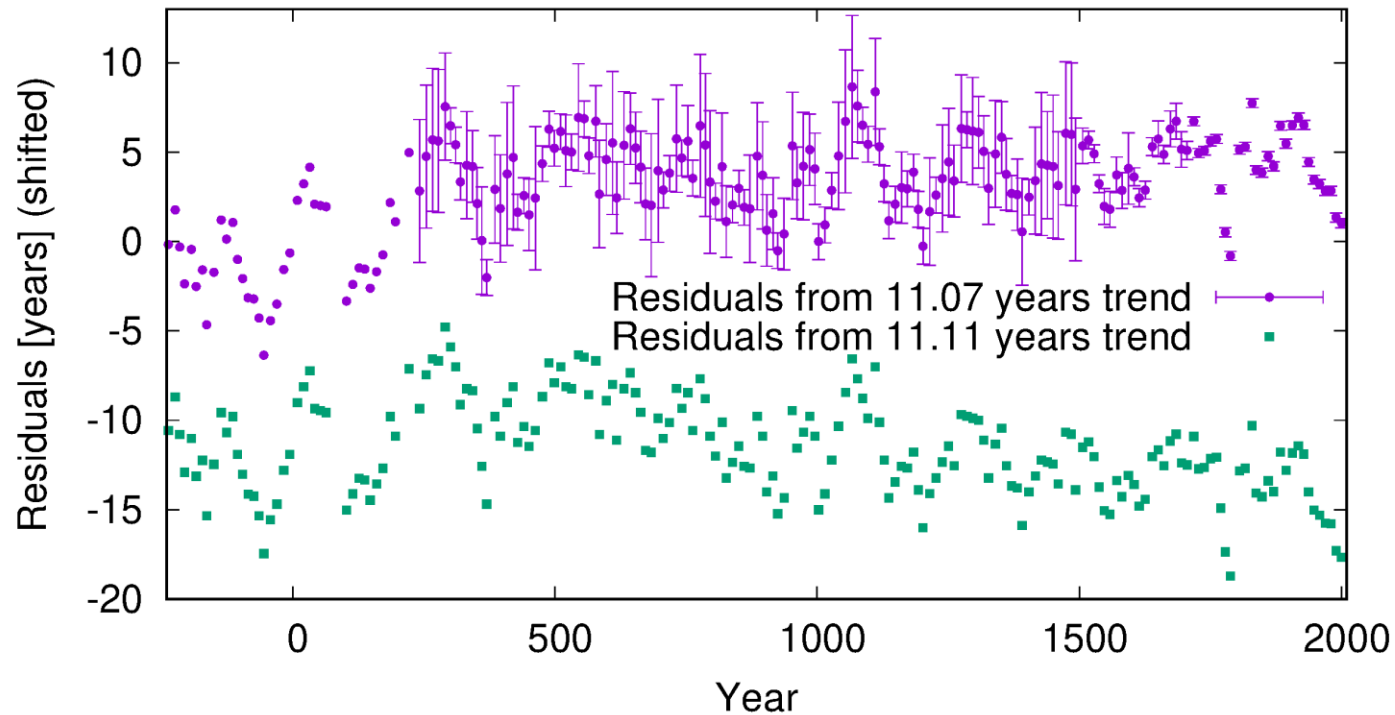


Schöve, D.J.: J. Geophys. Res. 60 (1955), 127; Hathaway, D.H., Liv. Rev. Sol. Phys. 7 (2010), 1; Okhlopov, Mosc. U. Bull. Phys. B. 71 (2016), 444

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

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

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.

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

Dicke's argument

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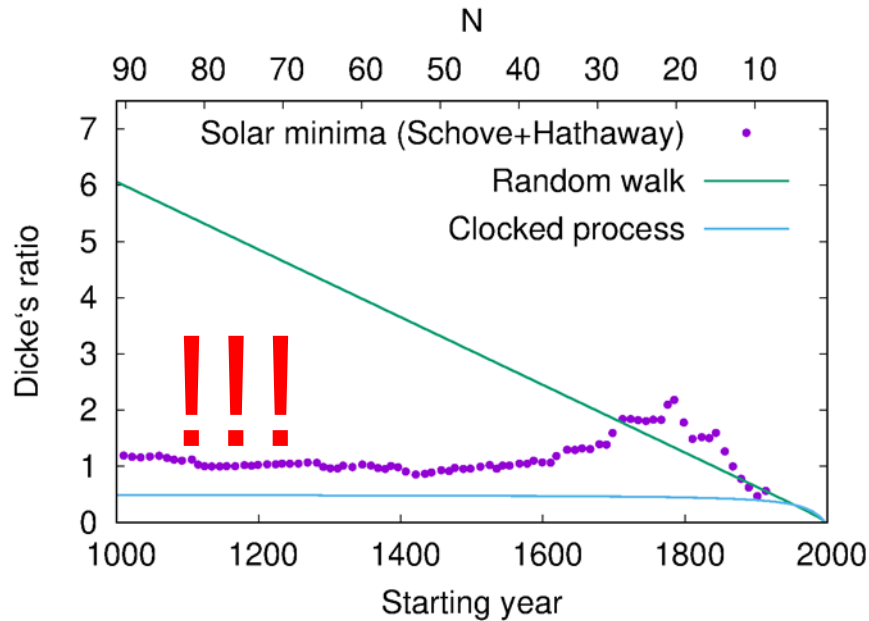
Distinction between **random walk (RW)** and **clocked process (CP)** for the instants y_n of sunspot maxima (Dicke) or minima (here):

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 $N \rightarrow \text{infinity}$
Random walk	$(N+1)(N^2-1)/3(5N^2+6N-3)$	$N/15$
Clocked process	$(N^2-1)/2(N^2+2N+3)$	$1/2$

Dicke's ratio in dependence on number of cycles



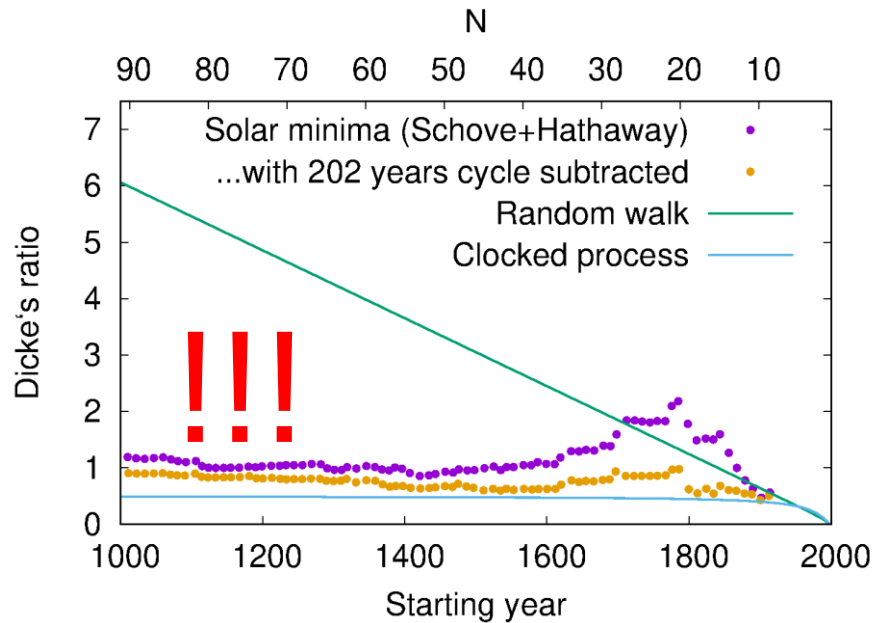
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- After subtraction of Suess/de Vries cycle, **Dicke's ratio** fits nearly perfectly to a **CP**

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

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

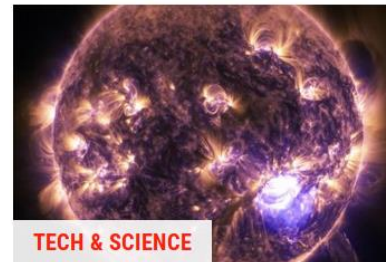
Not everyone will be waving "Dump Trump" placards when the president comes to stay.



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

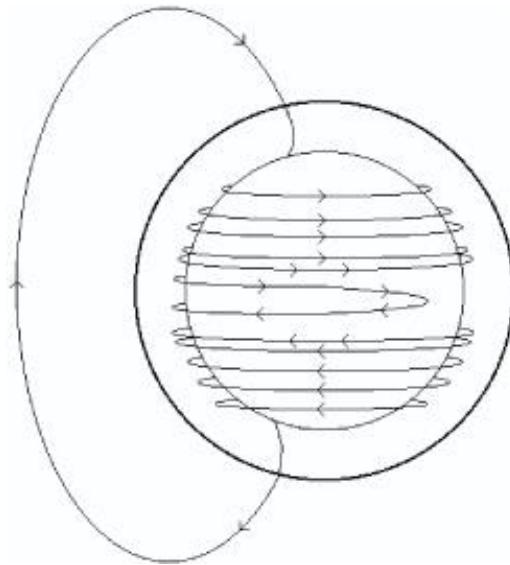
Solar Physics
294 (2019), 60

„Arthur“

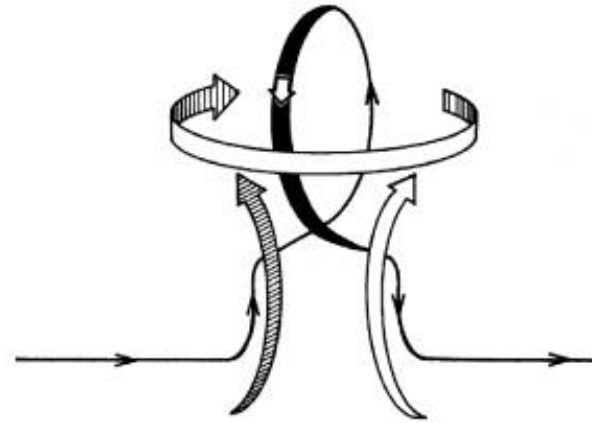
Solar dynamo models: Basics

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

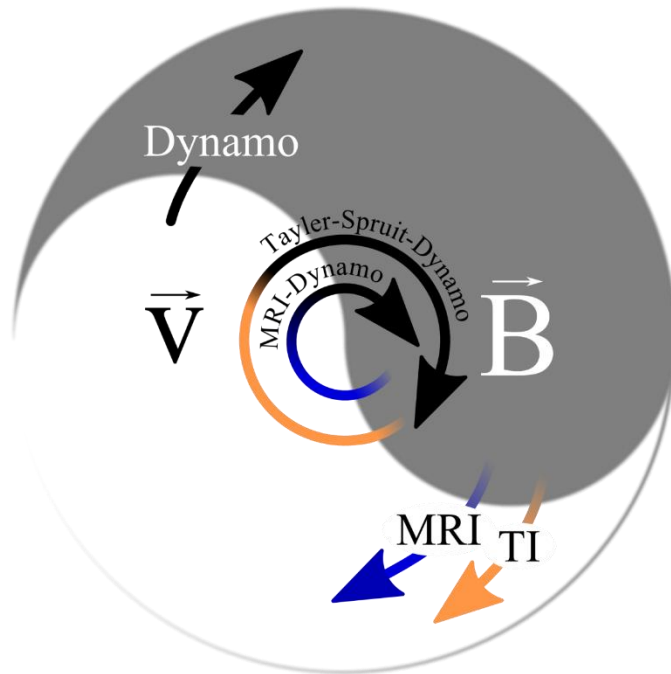


α effect



Parker, Astrophys J. 122, 293 (1955)

Nonlinear dynamos



THE ASTROPHYSICAL JOURNAL, 446:741–754, 1995 June 20
© 1995. The American Astronomical Society. All rights reserved. Printed in U.S.A.

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

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AND

ULF TORKELSSON

Lund Observatory, Box 43, S-221 00 Lund, Sweden; and Sterrenkundig Instituut, Utrecht

Received 1994 October 27; accepted 1994 December 29

ABSTRACT

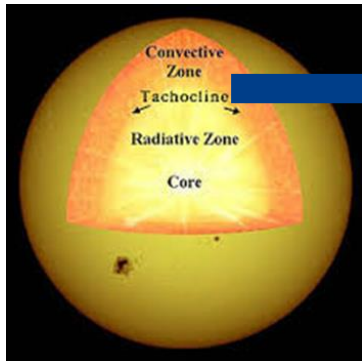
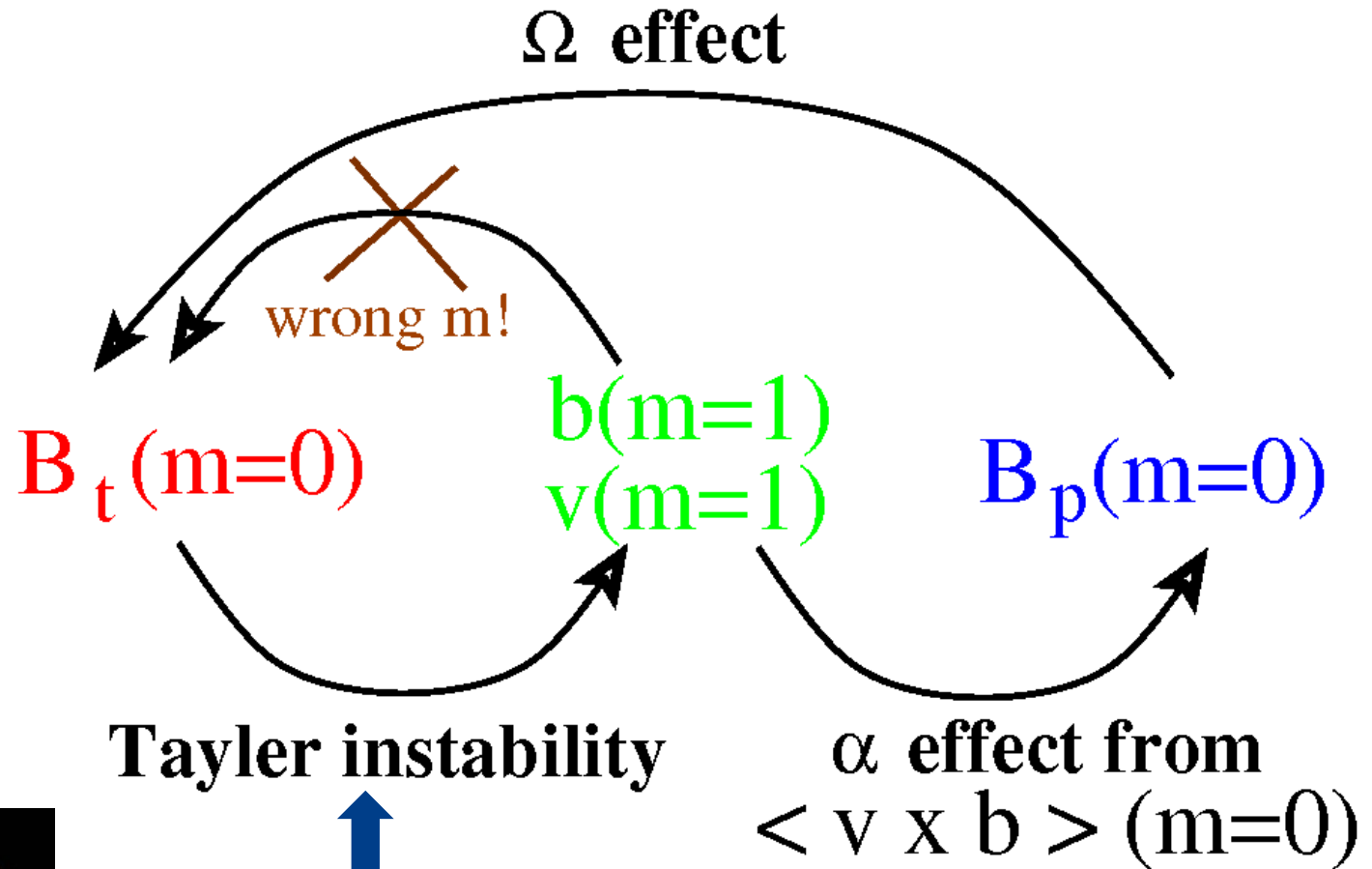
The nonlinear evolution of magnetized Keplerian shear flows is studied in a local, three-dimensional model, including the effects of compressibility and stratification. Supersonic flows are initially generated by the Péclet-Hawley magnetic shear instability. The resulting flows regenerate a turbulent 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 chaotic 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

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



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

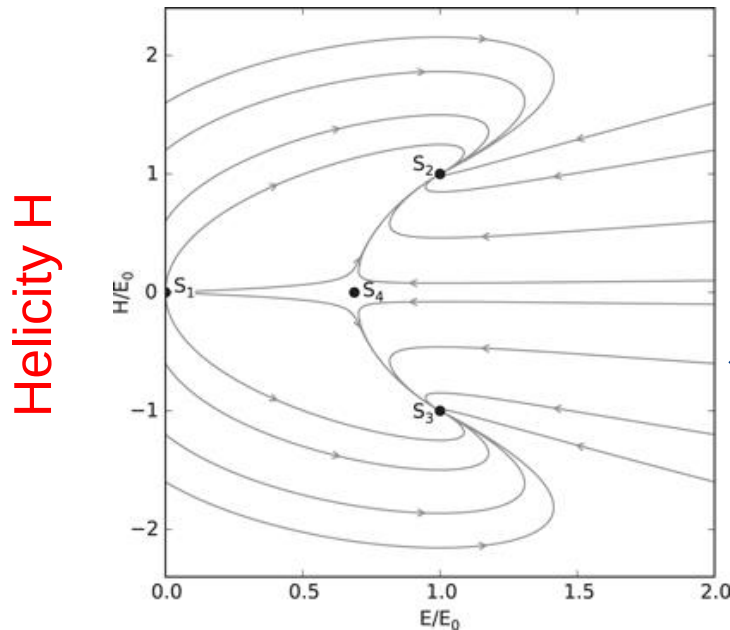
Spruit, Astron. Astrophys. 381 (2002), 923

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)



$$\begin{aligned}\frac{dE}{dt} &= 2\gamma E - 2(\mu + \mu_*)E^2 - 2(\mu - \mu_*)H^2 \\ \frac{dH}{dt} &= 2\gamma H - 4\mu EH\end{aligned}$$

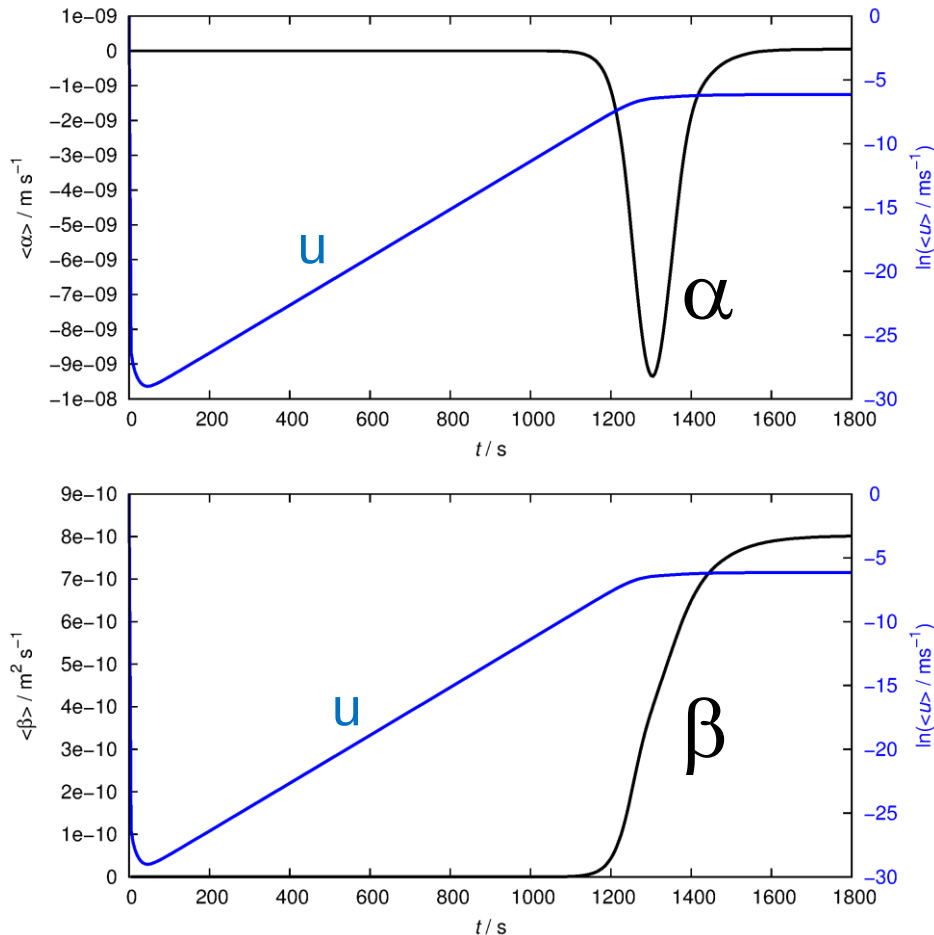
Energy E

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

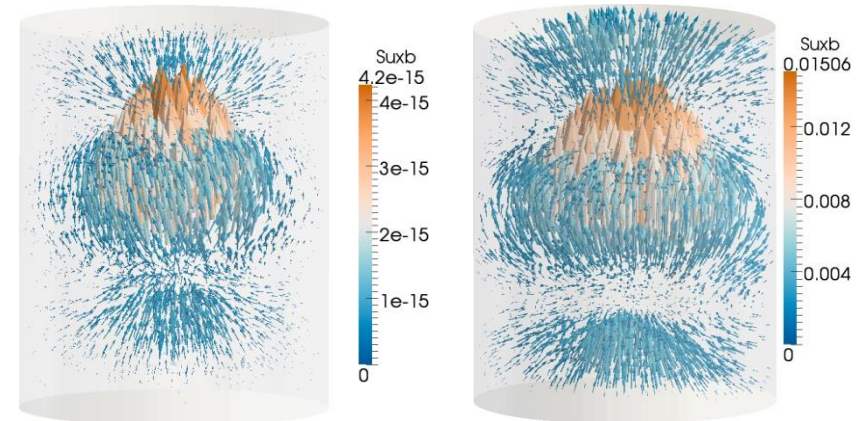
Weber et al., New J. Phys. 17 (2015), 113013

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

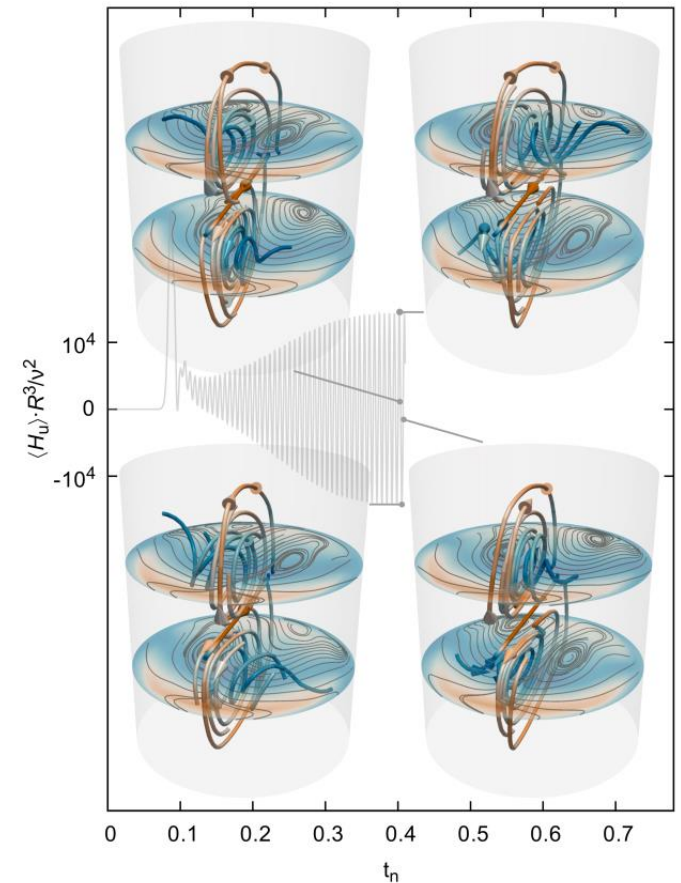
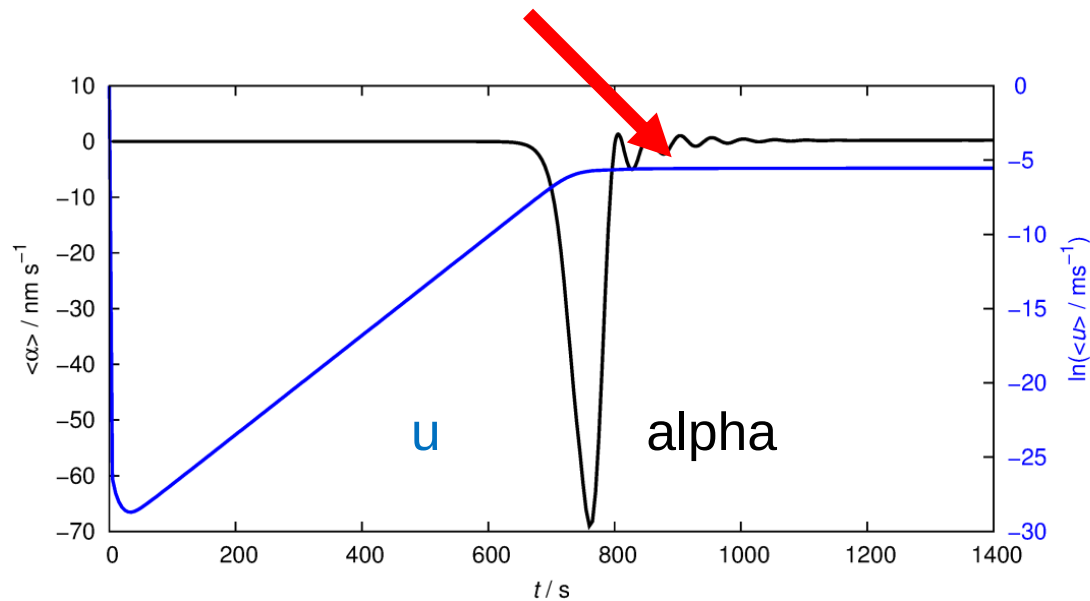
1800 s

Example: $h/d=1.25$, $Ha=55$

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

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

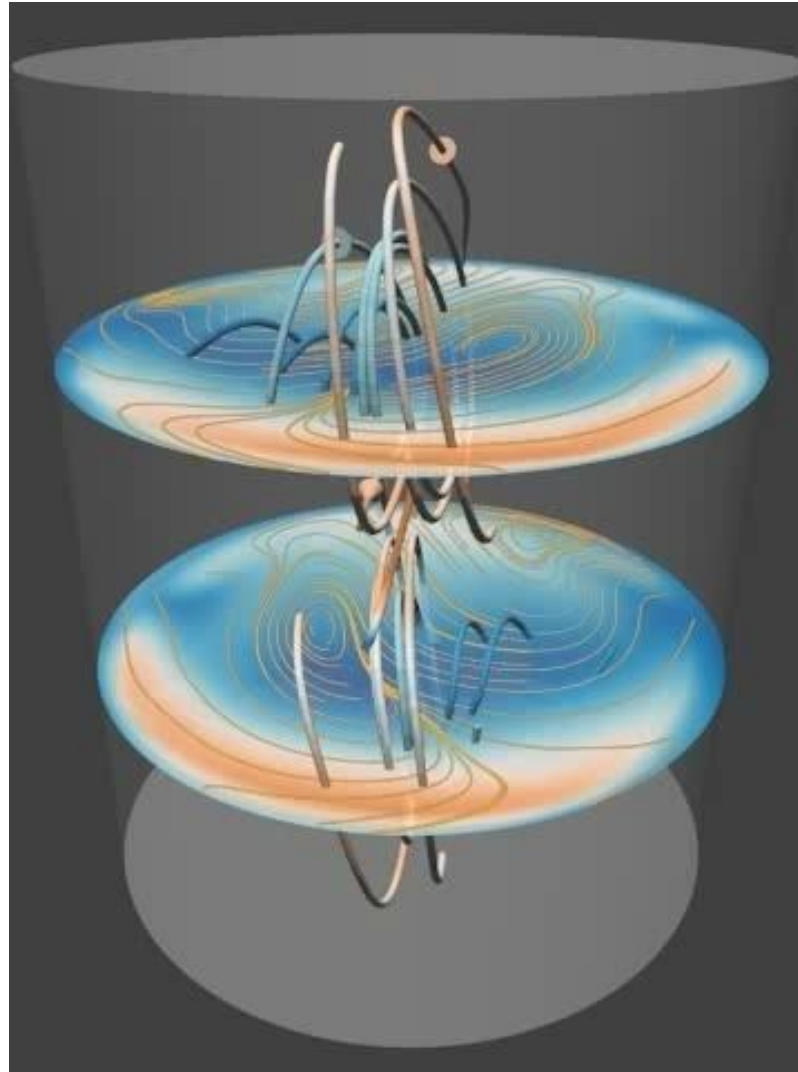
(Damped) helicity oscillations $Ha = 70$



$Ha = 100$

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

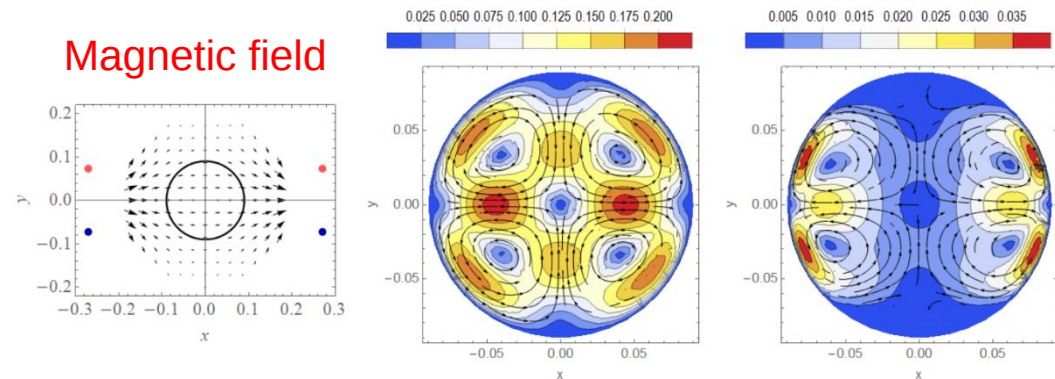
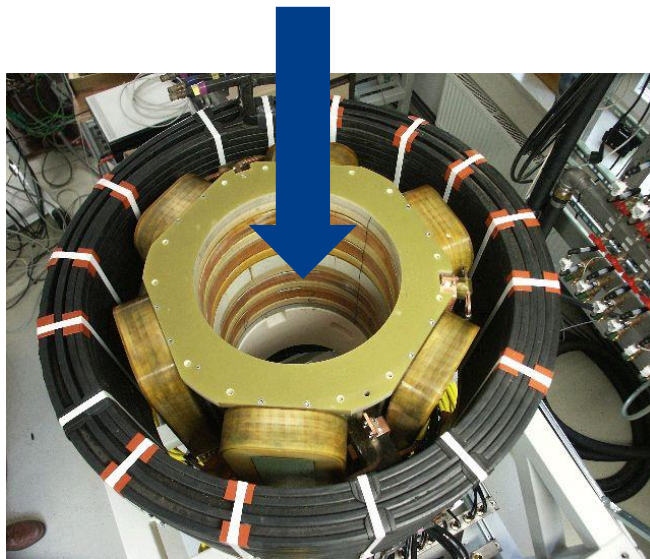
Rayleigh-Bénard experiment: helicity synchronization with $m=2$ forcing



- 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

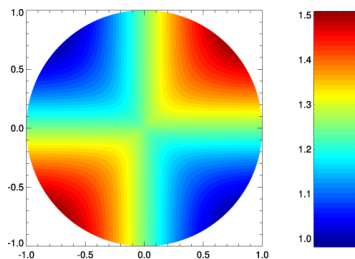
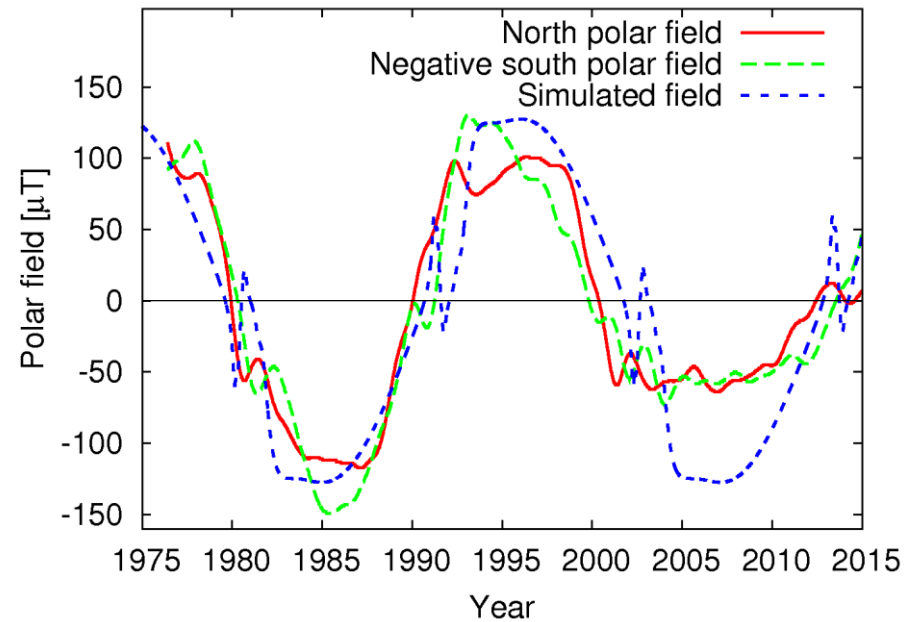
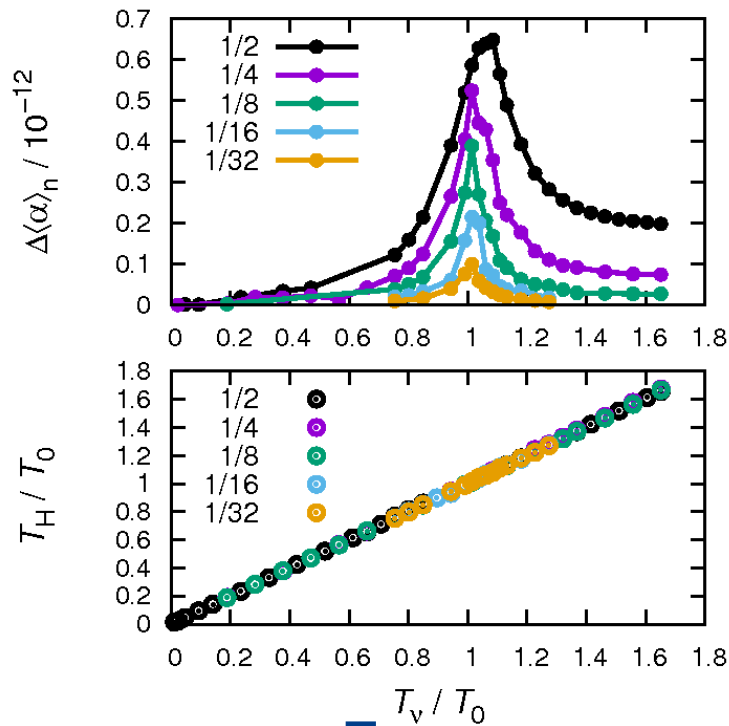
- Generic Rayleigh-Bénard experiment to show **resonant excitation of helicity by an $m=2$ perturbation**.
- How to realize this: Magnetic pressure by coils.



**$m=2$ 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!

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

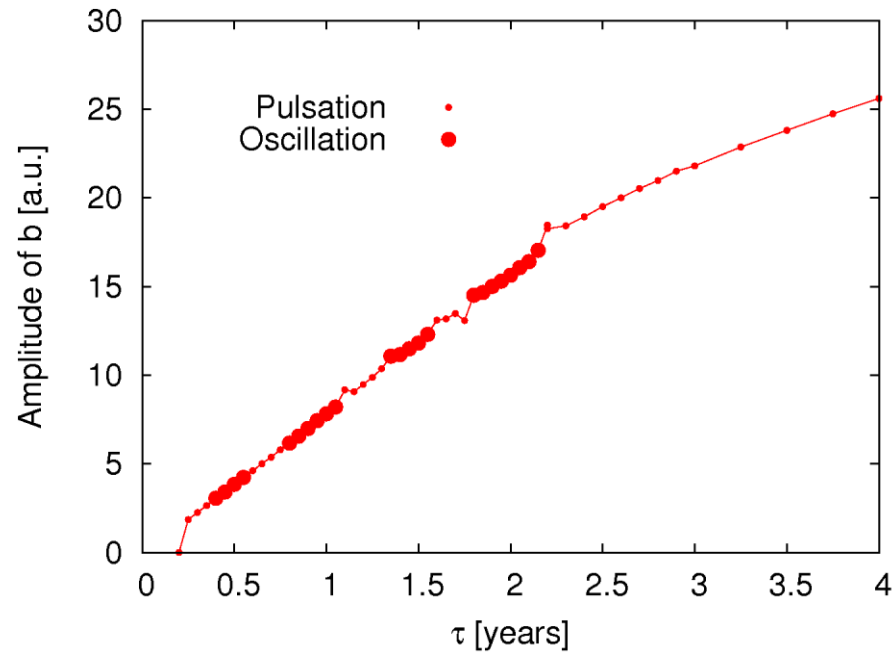
$$\dot{B}(t) = \omega A(t) - \tau^{-1}B(t)$$

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

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

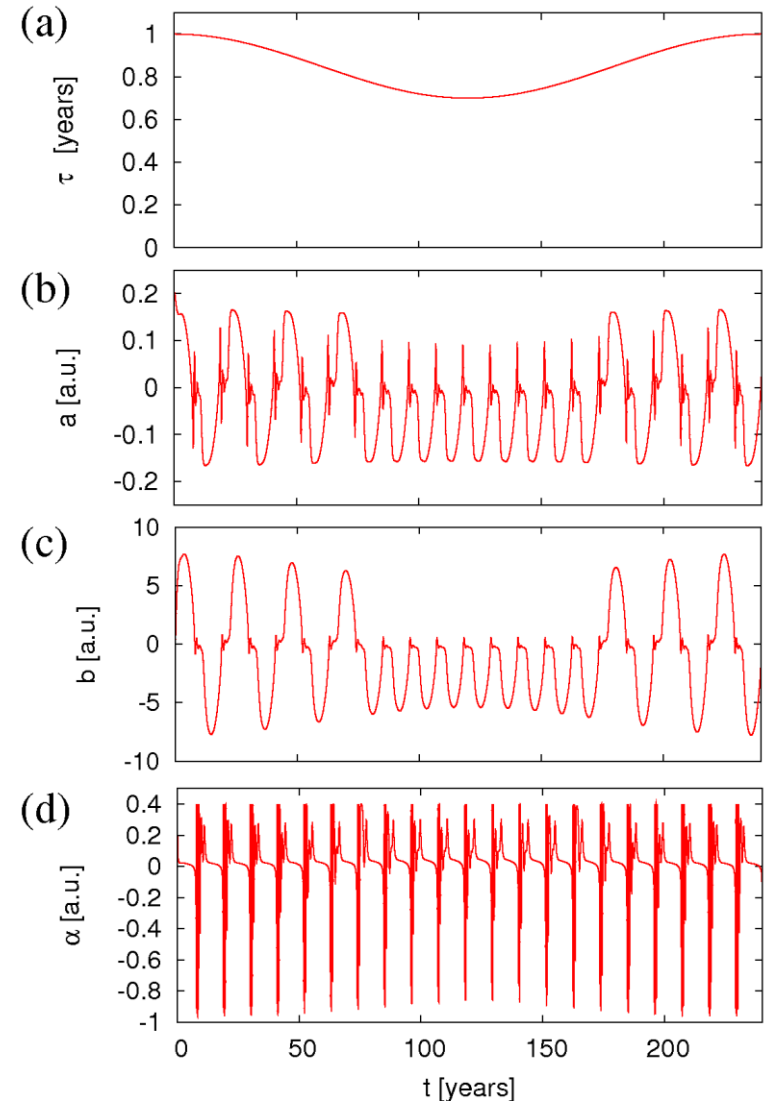
Transitions between oscillations and pulsations → „Grand minima“ ?

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):

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

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

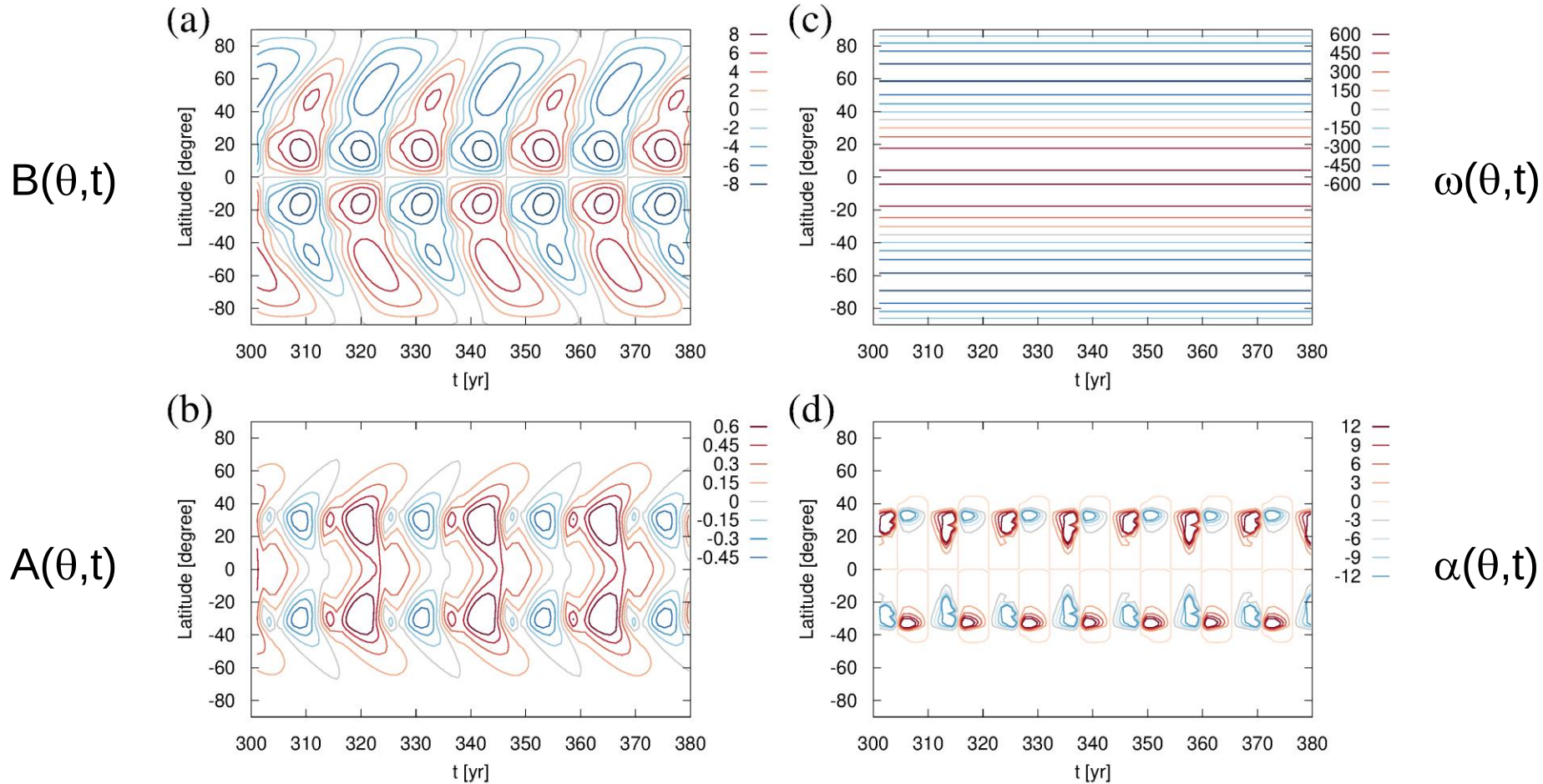
$$\omega(\theta, t) = \omega_0 (1 - 0.939 - 0.136 \cos^2(\theta) - 0.1457 \cos^4(\theta)) \sin(\theta),$$

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

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

$$\frac{\partial B(\theta, t)}{\partial t} = \omega(\theta, t) \frac{\partial A(\theta, t)}{\partial \theta} - \frac{\partial^2 B(\theta, t)}{\partial \theta^2} - \kappa B^3(\theta, t) \quad \omega(\theta, t) = \omega_0(1 - 0.939 - 0.136 \cos^2(\theta) - 0.1457 \cos^4(\theta)) \sin(\theta),$$

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



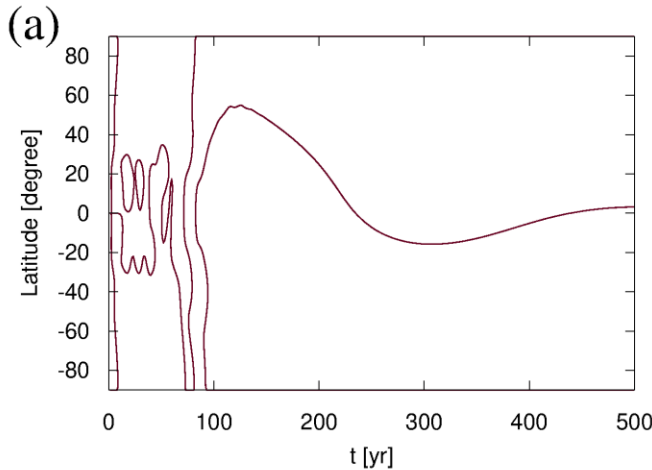
$$\omega_0=10000, \kappa=0.2, q_\alpha^p=0.2, \alpha_0^p=100$$

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

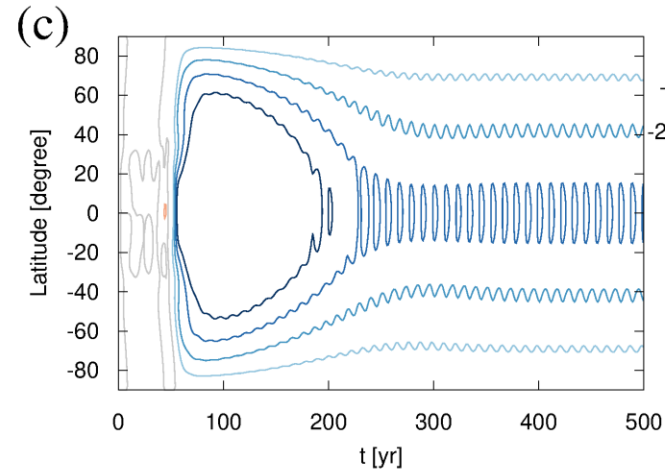
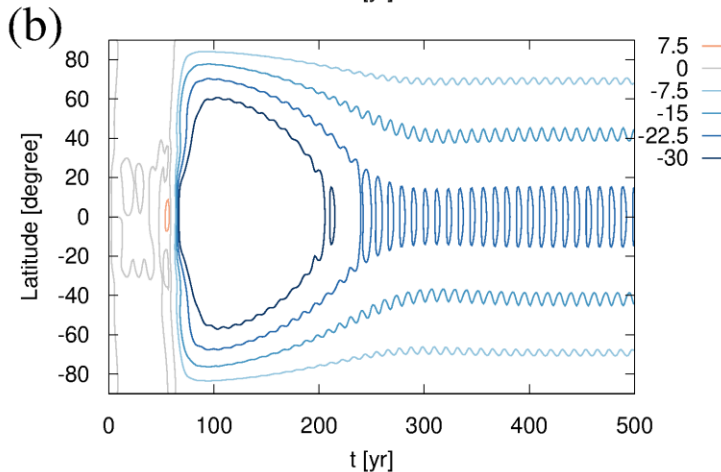
A pure Tayler-Spruit dynamo with periodic α forcing

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

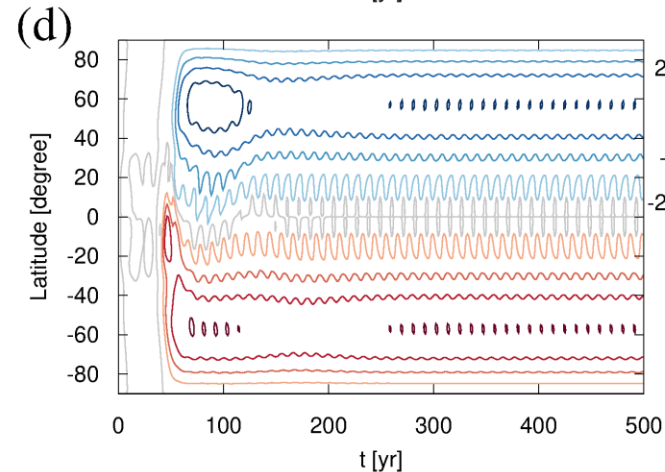
0.707



0.708



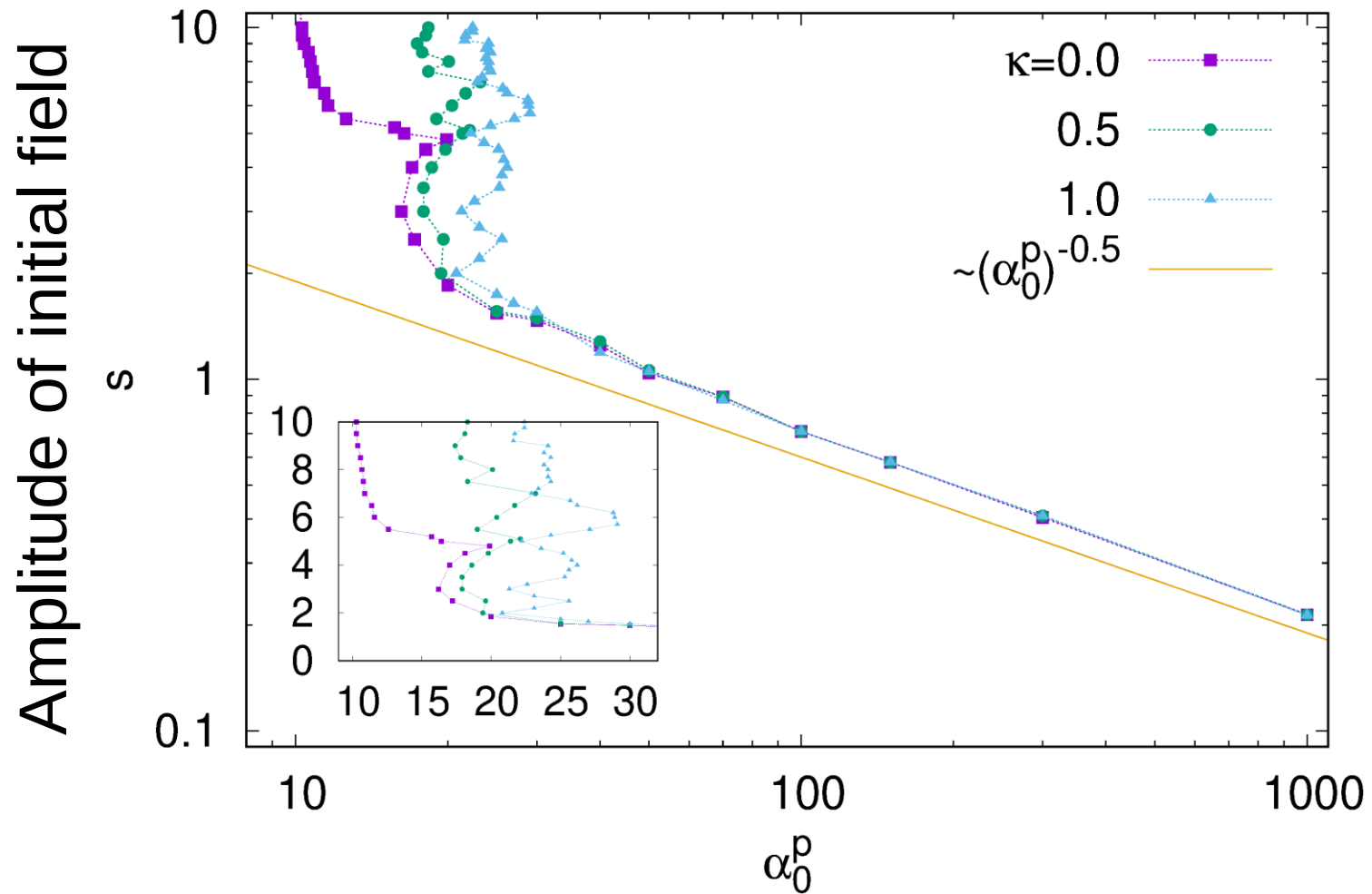
0.729



0.73

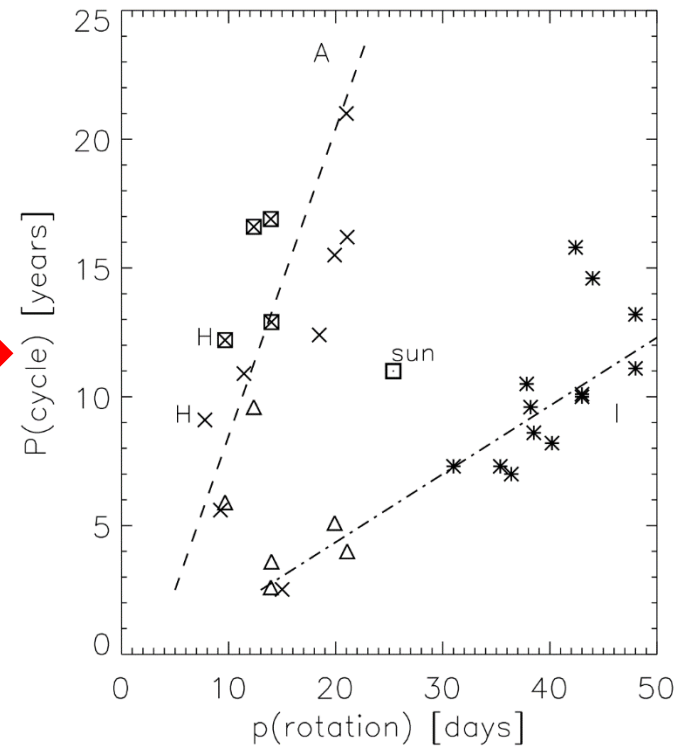
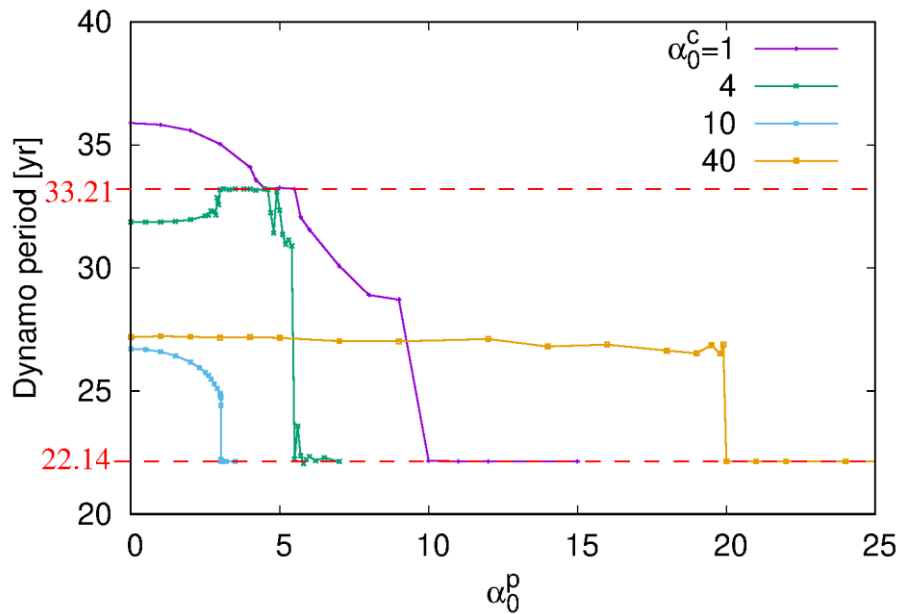
$$\omega_0=10000, \kappa=0.0, q_\alpha^p=0.2, \alpha_0^p=100$$

A pure Tayler-Spruit dynamo with periodic α forcing



Amplitude of periodic α term

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



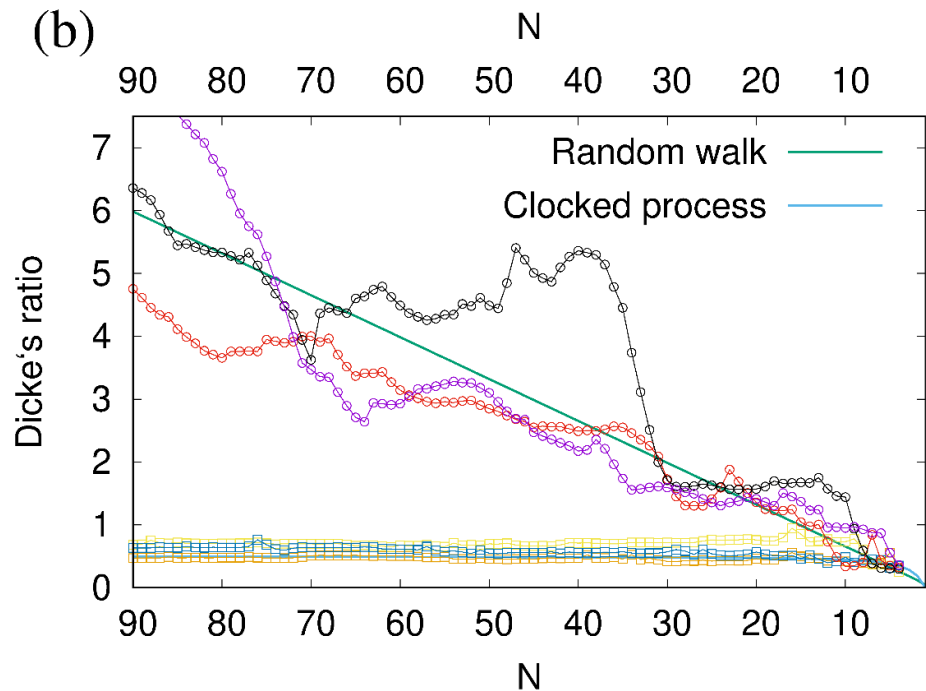
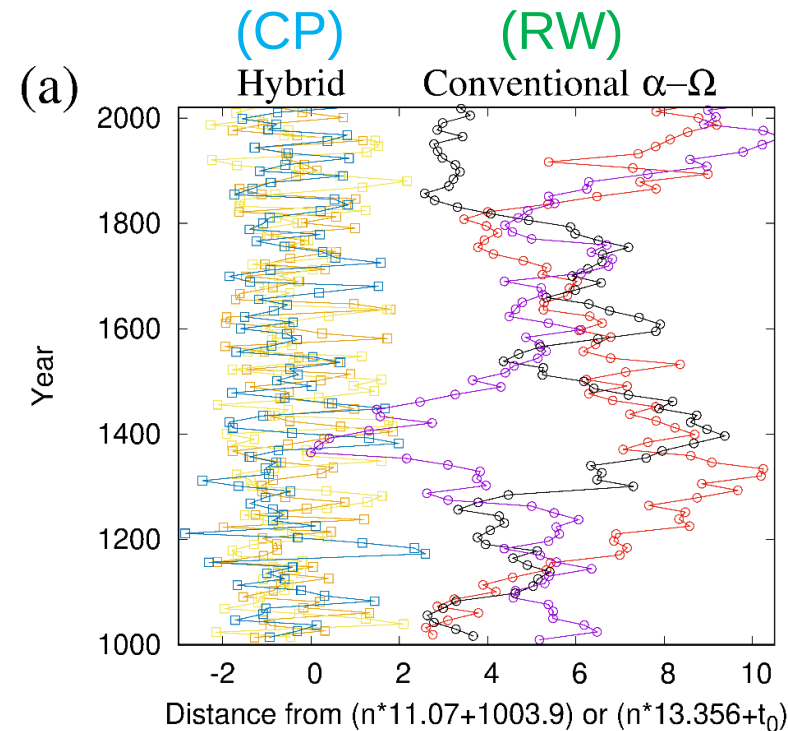
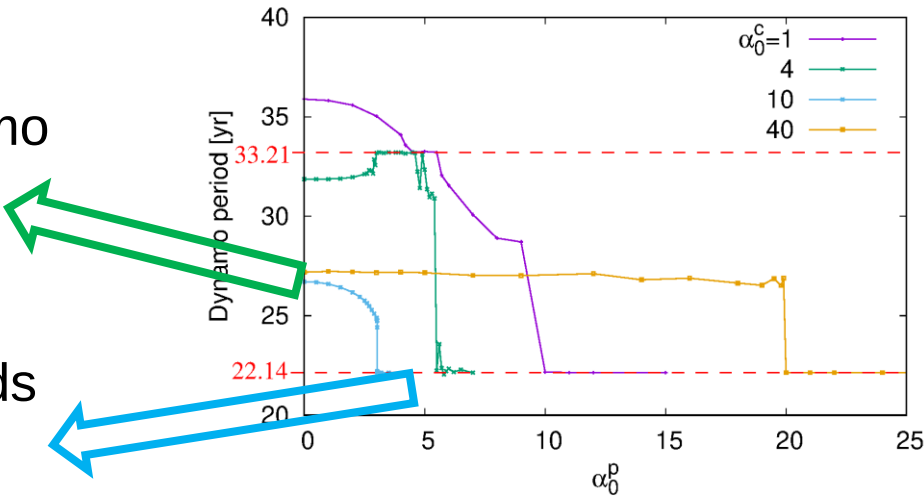
Conventional α - Ω dynamo can be synchronized (via parametric resonance) by the periodic α term (less than 1 m/s needed, which may be realistic)

Böhm-Vitense, ApJ 657 (2007), 486

Hybrid model with noise

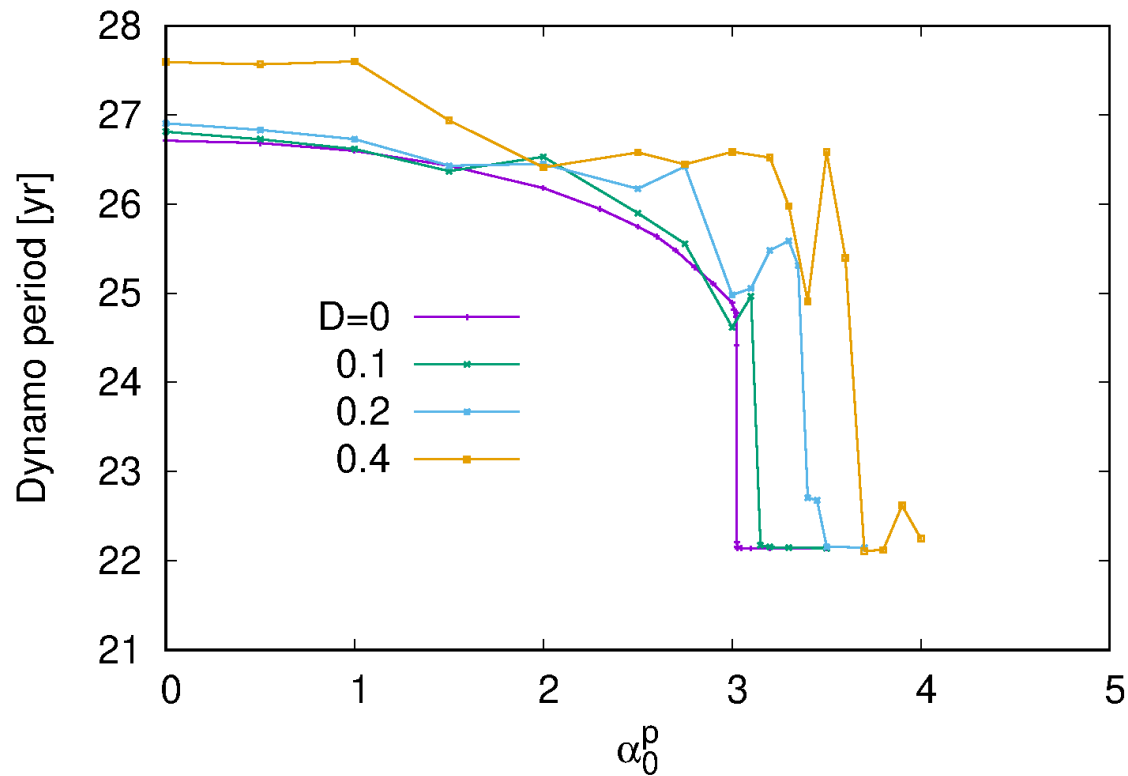
Conventional alpha-Omega dynamo yields **random walk (RW)**

Synchronized (hybrid) model yields **clocked process (CP)**



Hybrid model with noise

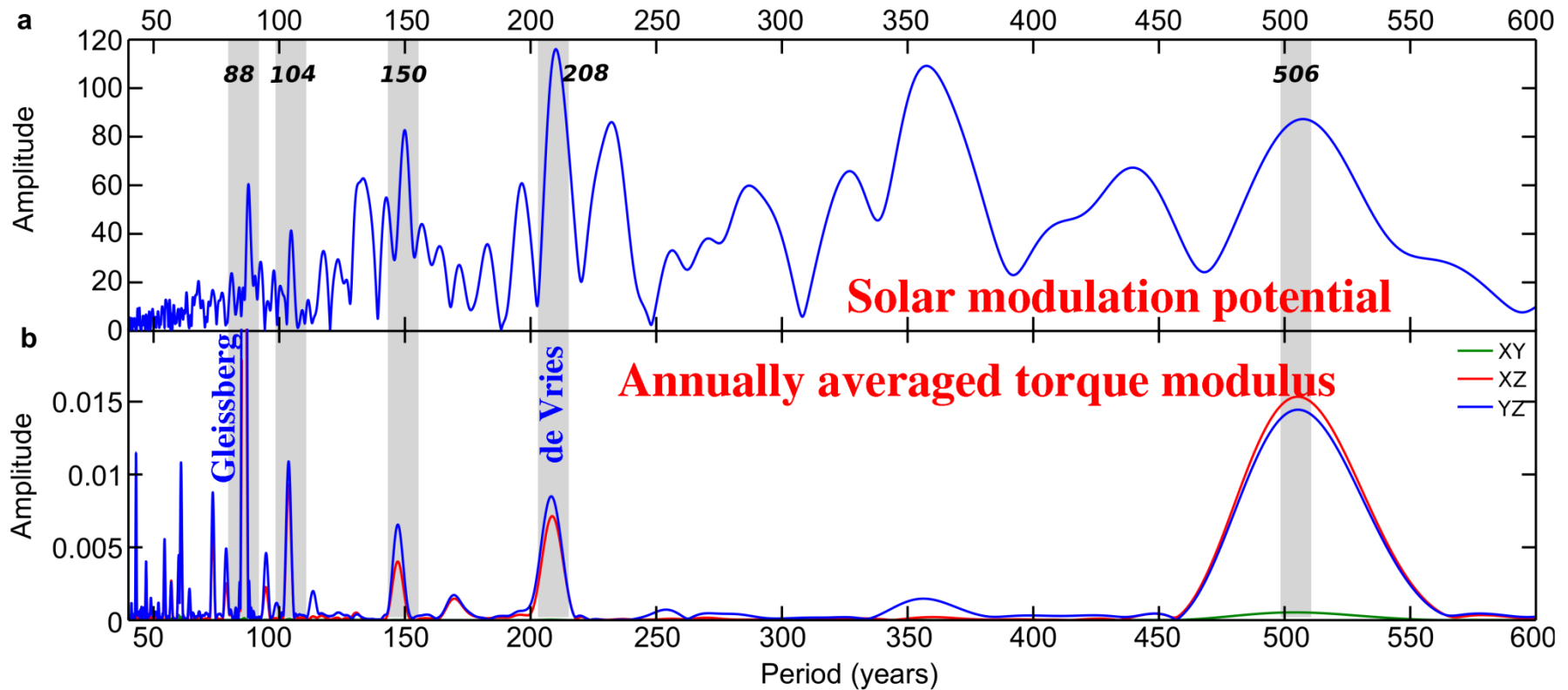
Can noise (D) foster the parametric resonance?



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

Suess-de Vries

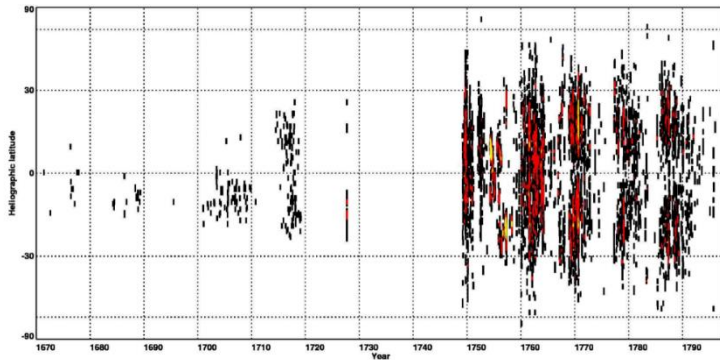
Planetary motion and long periods



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

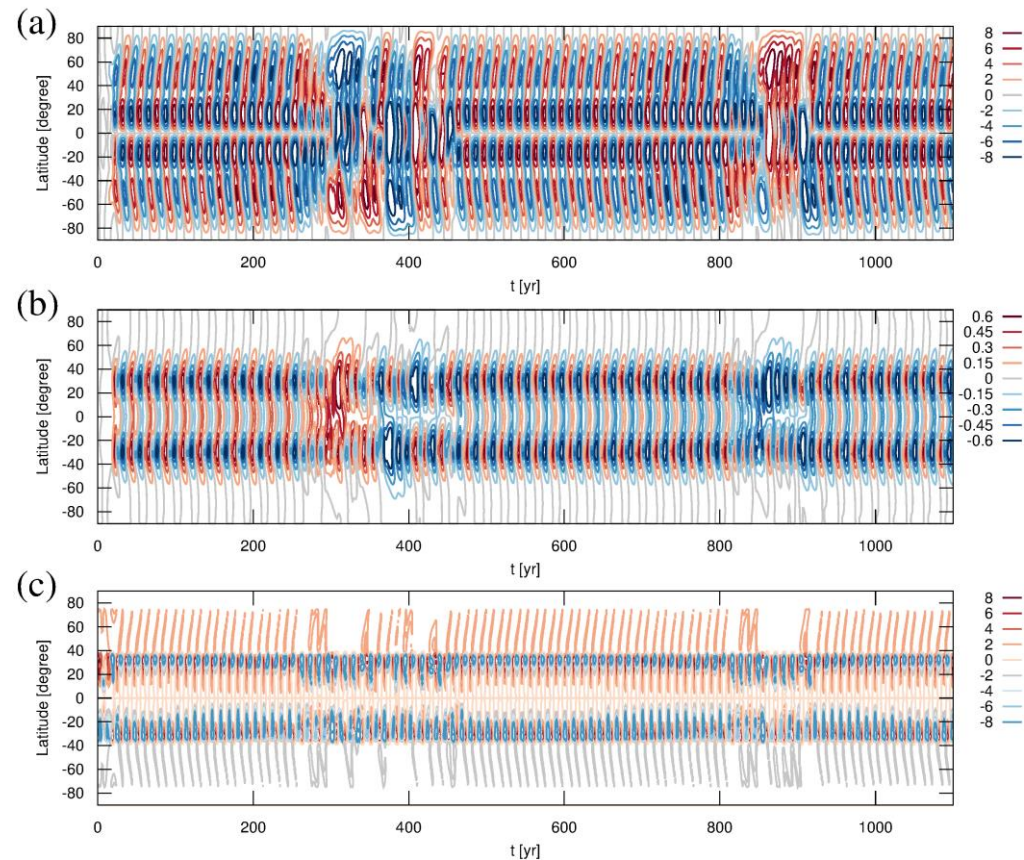
Long term periods from long term parameter variations

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

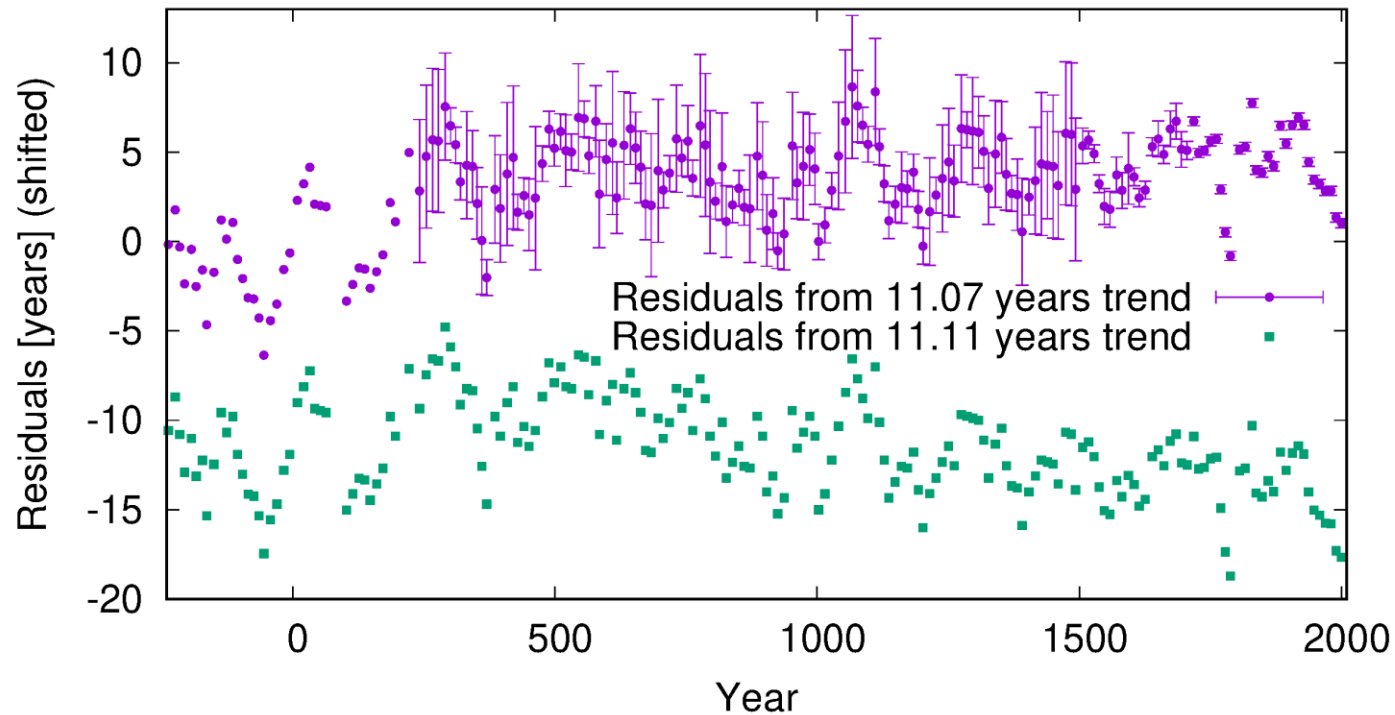
$B(\theta, t)$ (a), $A(\theta, t)$ (b), and $\alpha(\theta, t)$ (c) showing transitions between dipole and quadrupole fields when varying κ according to $\kappa(t) = 1 - 0.6\sin^2(2\pi t/1100)$.



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

Planetary motion and long periods

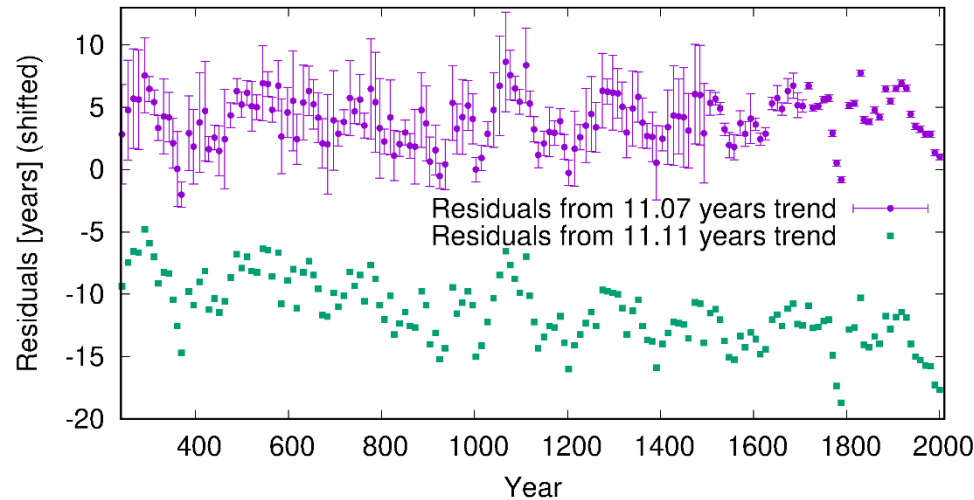
Schove's maxima data, with two different trends subtracted...



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

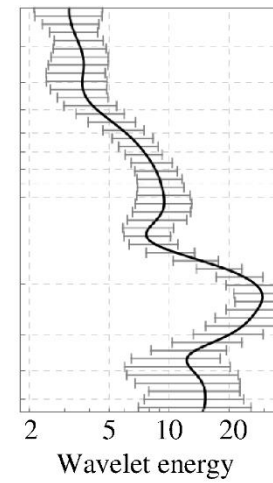
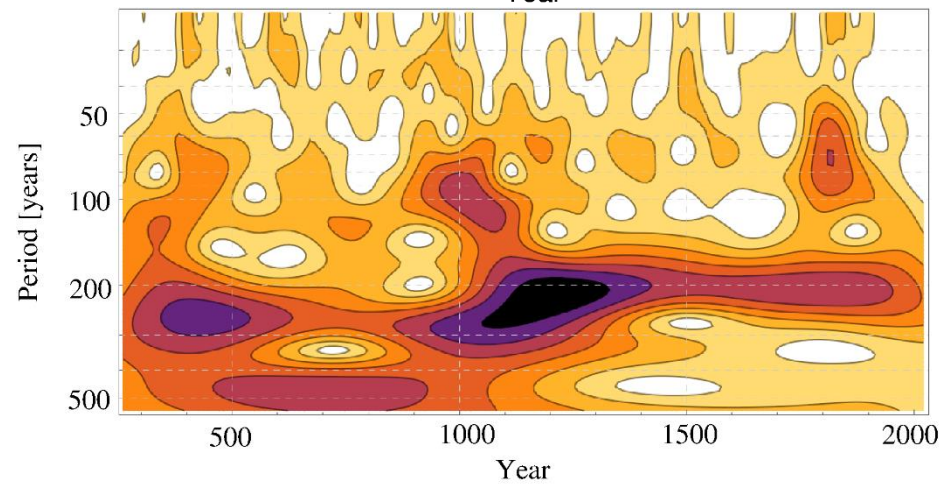
Stefani et al., arXiv:1910.10383

Planetary motion and long periods

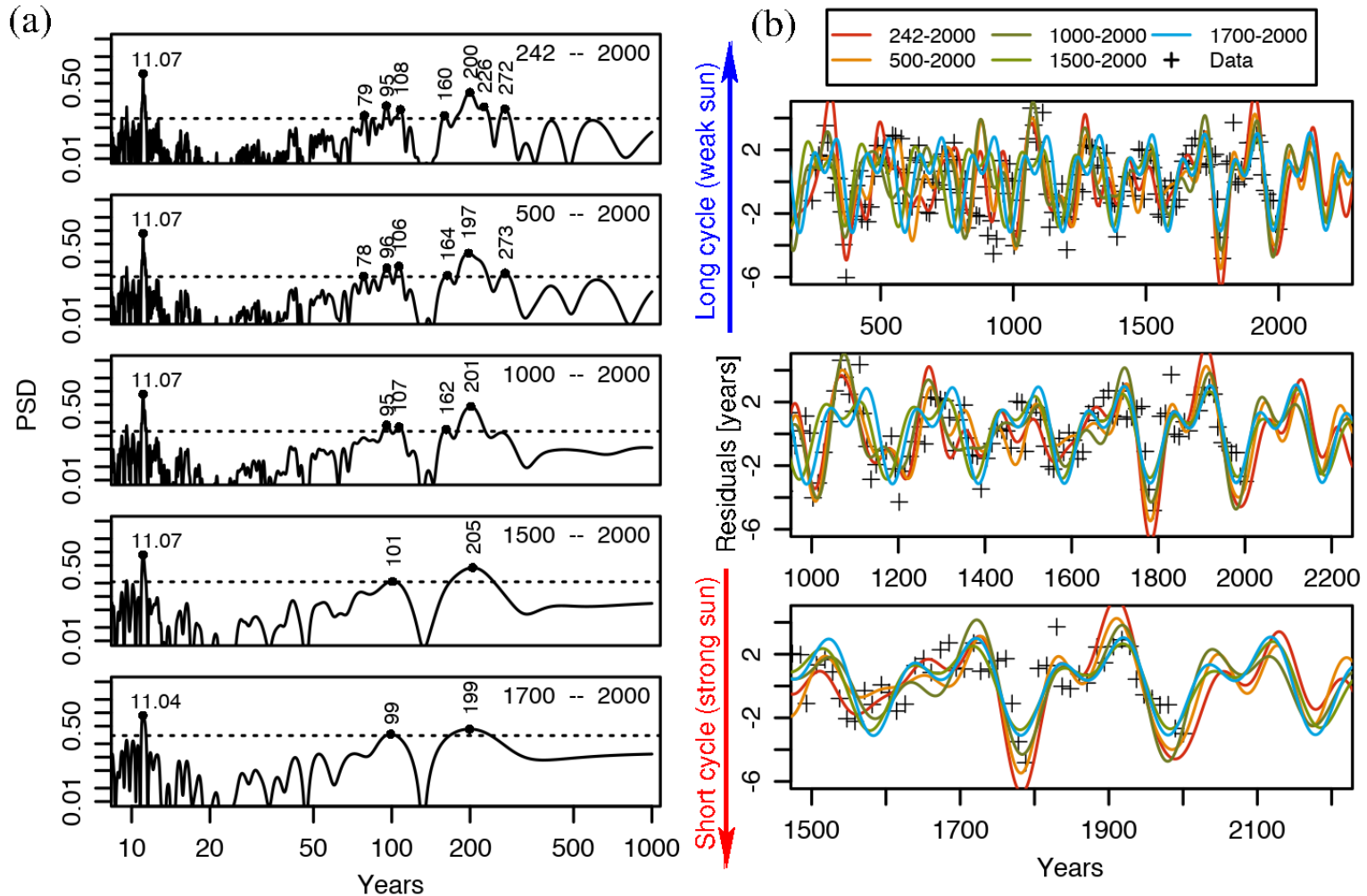


Schove's maxima data,
with two different trends
subtracted...

...and wavelet analysis



Detailed analysis with different underlying time intervals



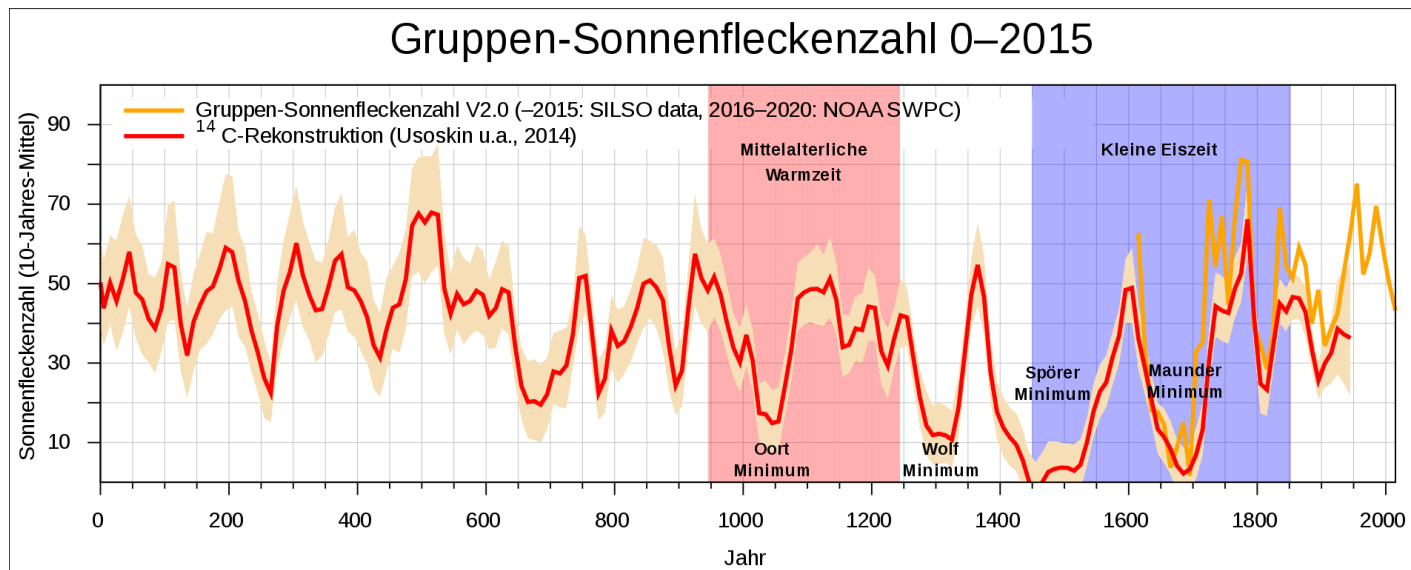
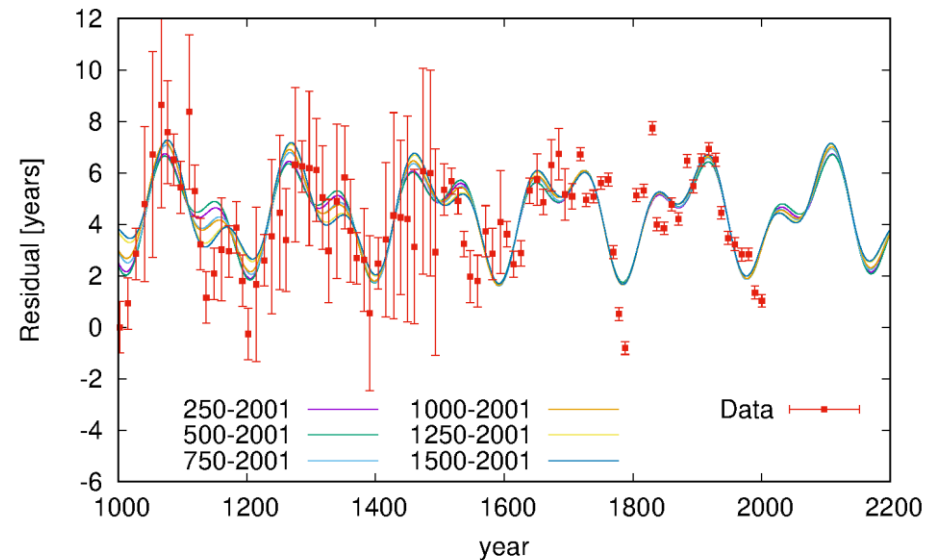
Lomb-Scargle periodograms
based on different intervals

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)

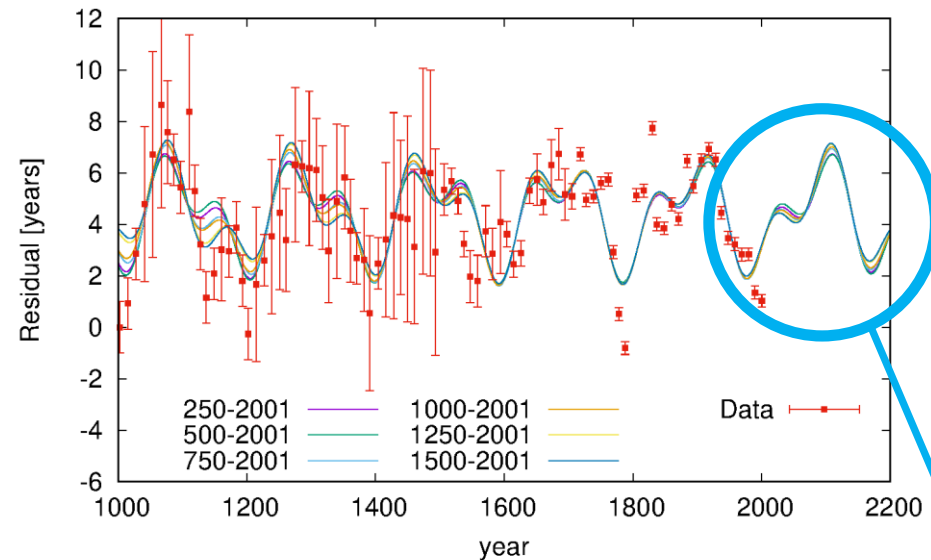
- Long cycle
 - Weak dynamo
 - Cold ???
-
- Short cycle
 - Strong dynamo
 - Warm ???



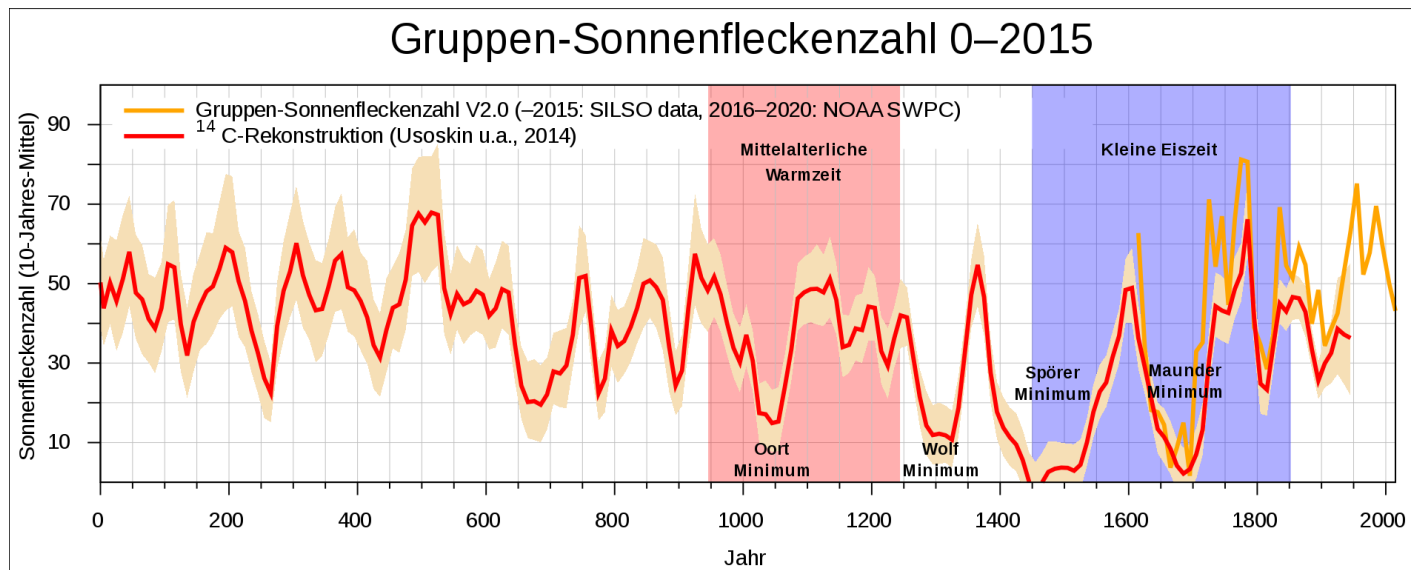
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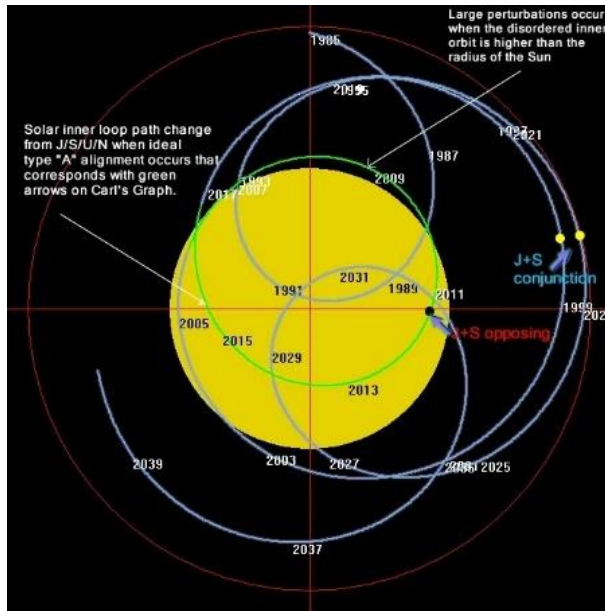
- Long cycle
- Weak dynamo
- Cold ???
- Short cycle
- Strong dynamo
- Warm ???



Forecast:
New „Grand
Minimum“ ?



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

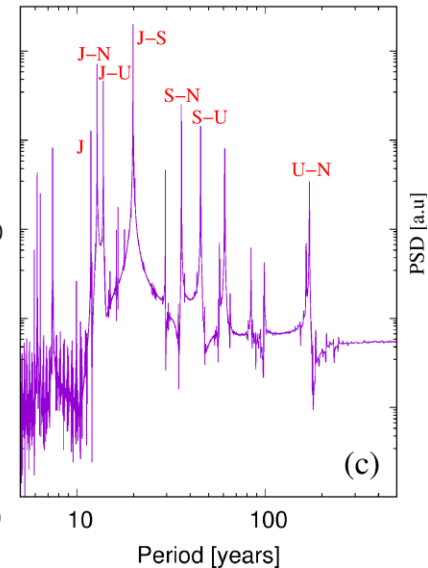
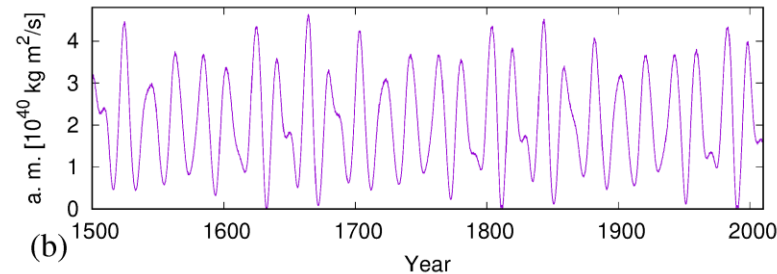
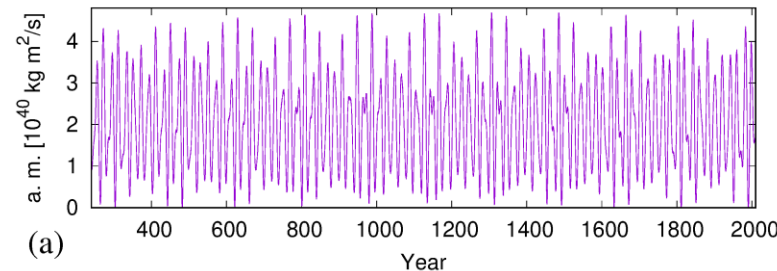


Sharp, Int J. Astron. Astrophys., vol. 3 (2013), 260

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
 $19.86 \times 22.14 / (22.14 - 19.86)$

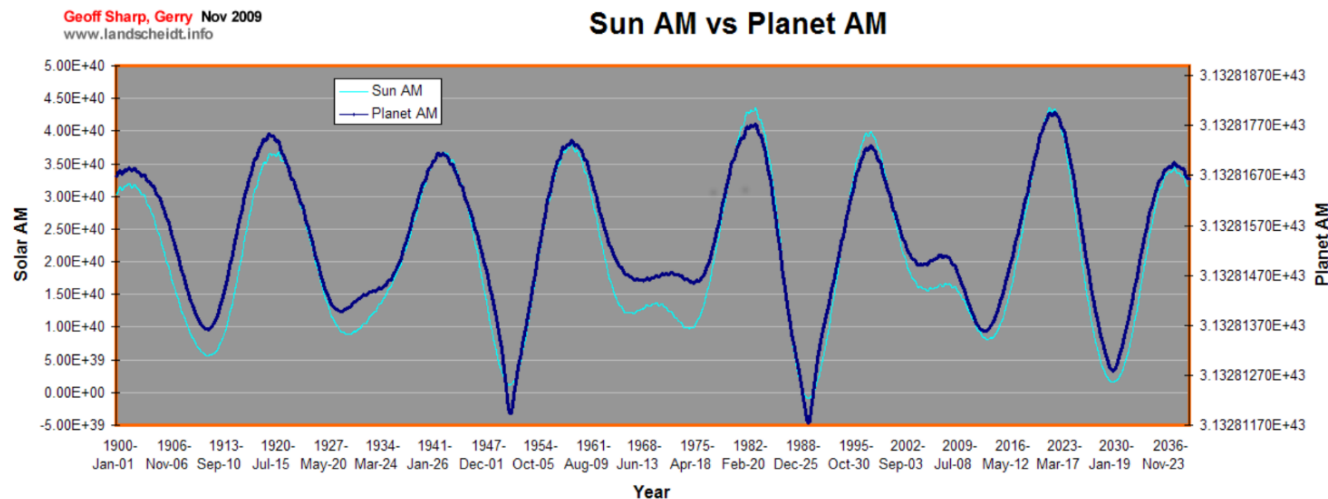


Warning: Spin-orbit coupling is not really understood...

...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; Juckett, 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; **Makarov et al., MNRAS 456 (2016), 665**

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

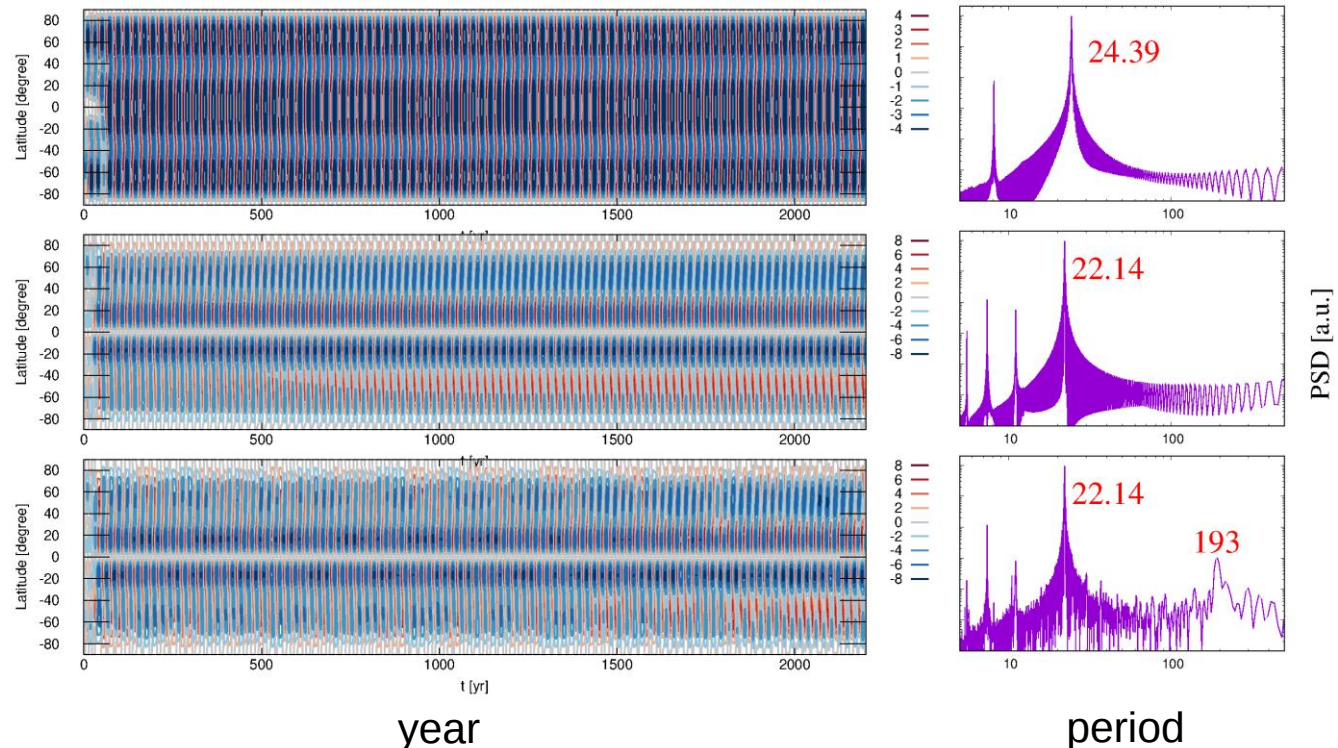
α - Ω -dynamo with tidal synchronization (11.07 years)

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



$$\kappa(t) = 0.5 + 0.5 \text{ am}(t)/\text{am}_{\text{max}}$$

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



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)

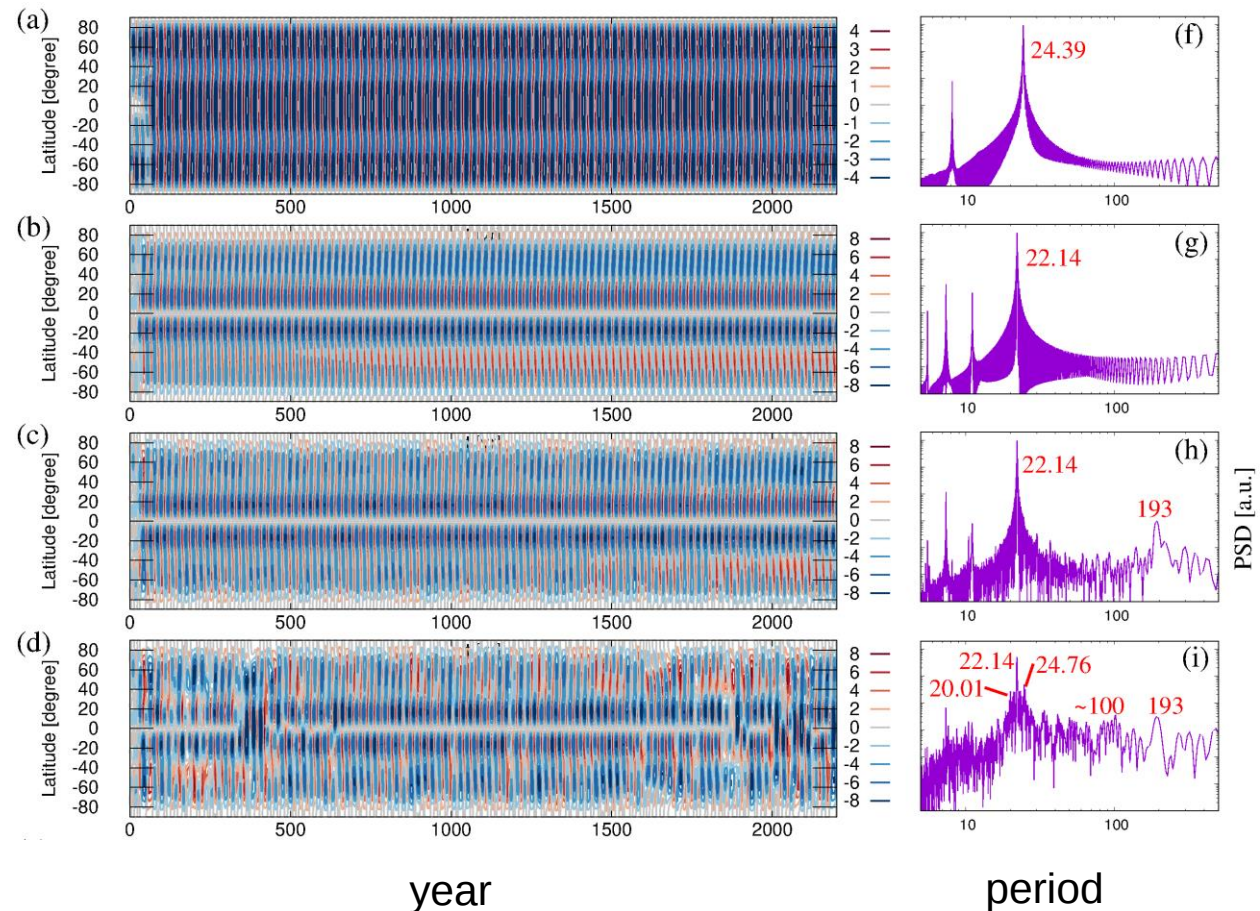
α - Ω -dynamo with tidal
11.07-years
synchronization +
~19.86-year modulation

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

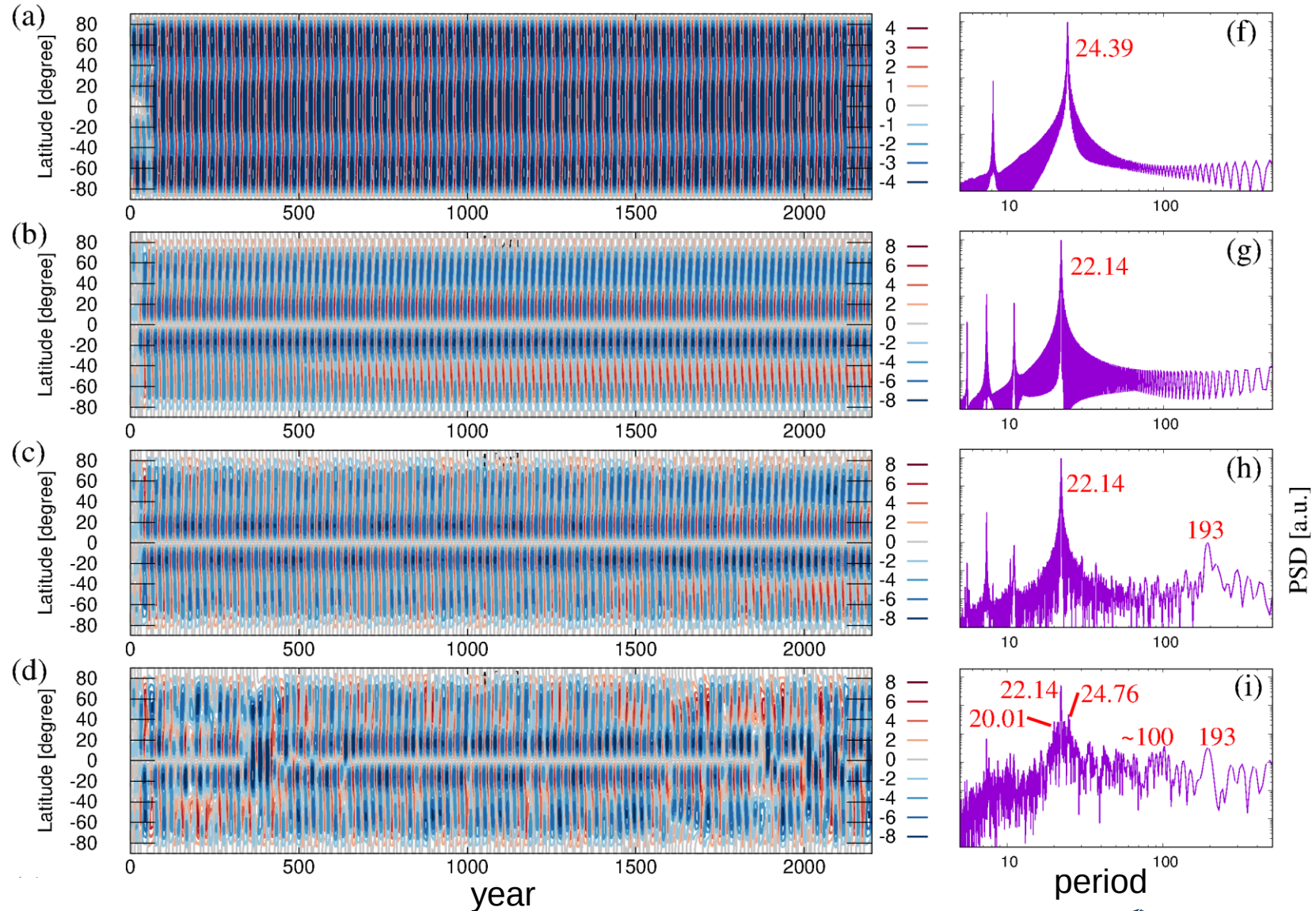


$$\kappa(t) = 0.18 + 1.0 \text{ am}(t)/\text{am}_{\text{max}}$$

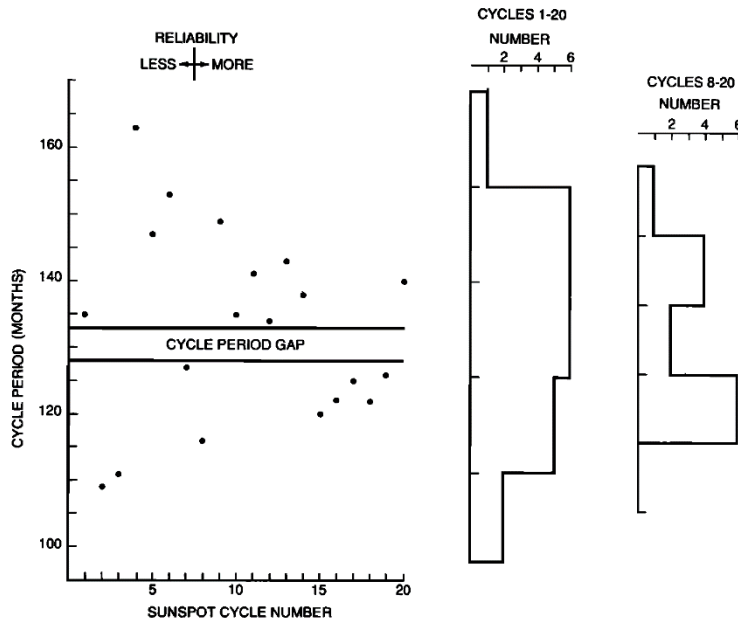
Stefani et al., Magnetohydrodynamics (submitted),
arxiv.org/abs/1910.10383



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

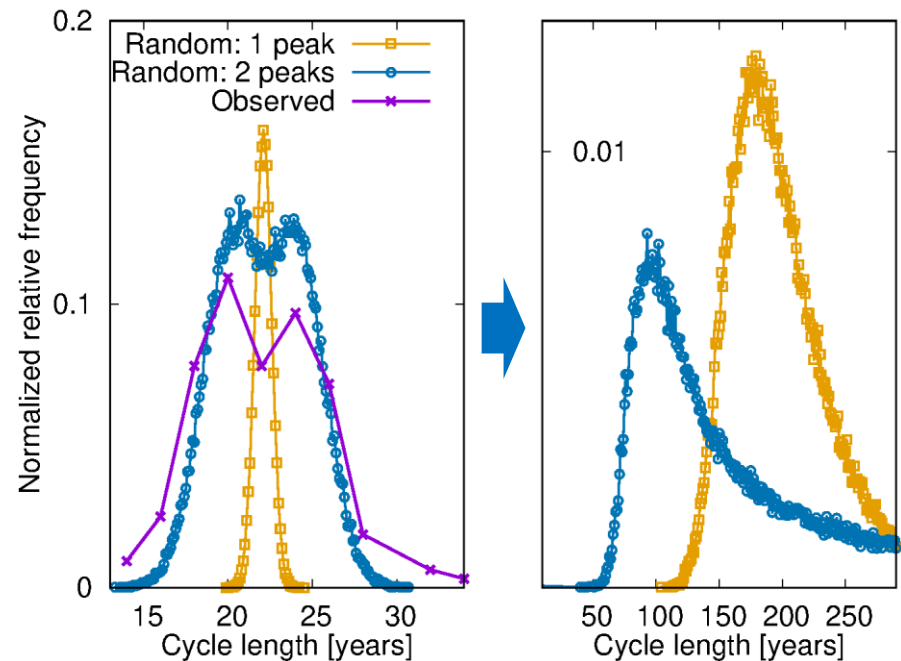


The Wilson gap: a consequence of synchronization+modulation?



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

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



Observed and 2 synthetic distributions of cycle lengths T_c

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

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

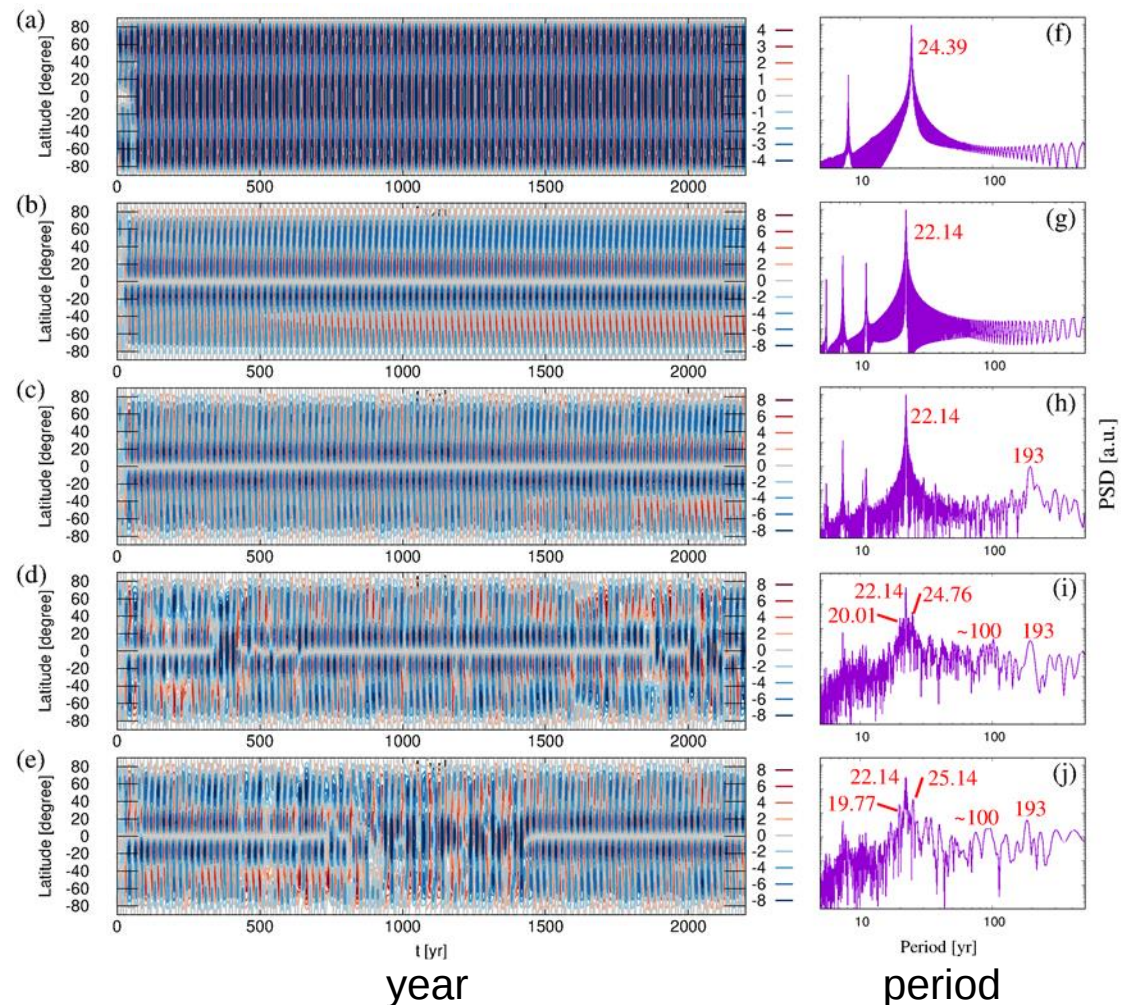
α - Ω -dynamo **without**
synchronization

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



Summary of our model

Conventional α - Ω dynamo without synchronization

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

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

Hybrid α - Ω dynamo, synchronized to 22.14 years period

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

Beat period 193 years (Suess-de Vries?)

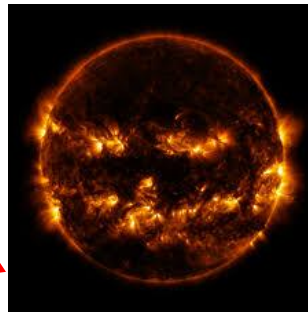
Some spin-orbit coupling (poorly understood!) with dominant 19.86 years period affects field storage capacity in the tachocline (κ -parameter)

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Thank you!