Cosmic factors in evolution of biosphere and geosphere. (review of the Interdisciplinary colloquium, May 21-23)

V.N. Obridko

Sixth Workshop
Solar Influences on the Magnetosphere, Ionosphere and Atmosphere
First **SEE/VarSITI kickoff meeting**
Meeting of the BBC Regional Network for Space Weather Studies
Sunny Beach, Bulgaria, 26-30 May 2014

SEE summary slide

Name: Solar Evolution and Extrema (SEE)

Goals and Objectives: 1) Reproduce magnetic activity as observed in the Sunspot and cosmogenic records in dynamo simulations, 2) Amalgamate the best current models and observations for solar spectral and wind output over the Earth's history, and 3) Determine the size and expected frequency of extreme solar events such as flares and coronal mass ejections (CMEs).

Questions: 1) Are we at the verge of a new grand minimum? If not, what is the expectation for cycle 25? 2) Does our current best understanding of the evolution of solar irradiance and mass loss resolve the "Faint Young Sun" problem? What are the alternative solutions? 3) For the next few decades, what can we expect in terms of extreme solar flares and storms, and also absence of activity? Another Carrington event? What is the largest solar eruption/flare possible? What is the expectation for periods with absence of activity?

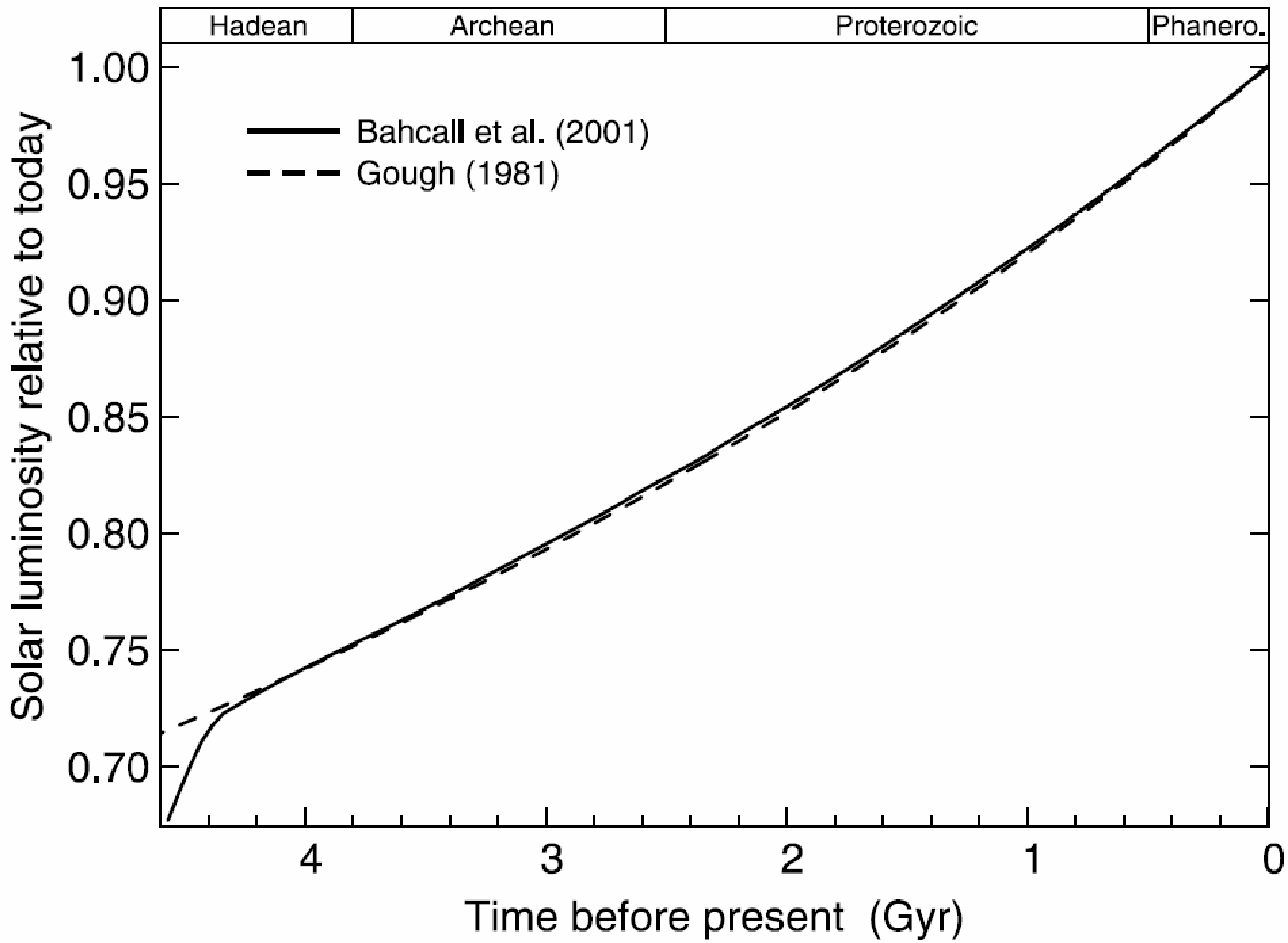
Data/Theory Model: Dynamo models, stellar evolution calculations including mass loss and rotation, early solar wind simulations, observations of solar - type stars, observations of very large events on stars, statistical analysis of event distributions.

Key Members: Piet Martens, Vladimir Obridko, Dibyendu Nandi

•**YU.I.Zetser.** **(Institute of Geosphere Dynamics,**
•**RAS**). *Vernadsky: the notion of geosphere*
•**V.N.Obridko (IZMIRAN)** *The young Sun:*
• *paradoxes and hypotheses*
•**L.M.Gindilis (Sternberg Astronomical Institute**
•**of Lomonosov Moscow State University)**
•*A review of ideas of life origin: from ancient times*
•*to the present day.*
•A.V.Markov (Institue of Paleontology RAS, MSU)
•***The early stages of life evolution: archaeon, early proterozoic***
D.M. Pechersky (Schmidt Institute of Physics of the Earth) *Geomagnetic reversal, its properties, causes, possible impact on biosphere*
L.I.Miroshnichenko (IZMIRAN) *Cosmic rays as a factor of biosphere evolution*

The Faint Young Sun Paradox

The Sun was about 30% less luminous when life developed on Earth, yet geological and biological evidence points to a warm young Earth, 60 to 70 C



Evolution of solar luminosity over the four geologic eons for the standard solar model described in Bahcall et al. [2001] (solid line) and according to the approximation formula [Gough, 1981] (dashed line)

Zircon - the oldest mineral $ZrSiO_4$

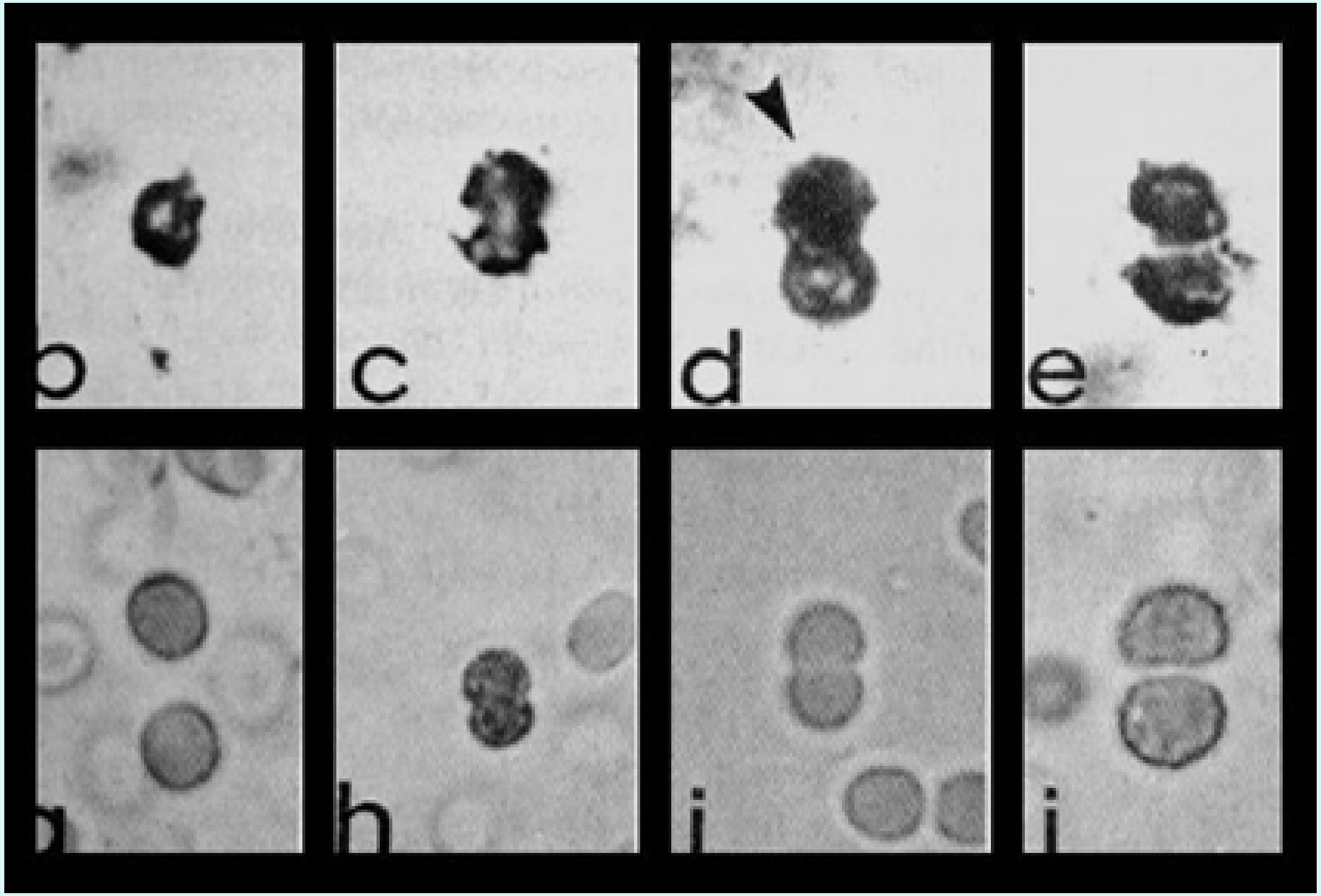
Crystals of zircon age of 4.4 billion years of evidence in favor of the fact that:

1. Earth had a solid (not melted) lithosphere already in **Hadean** ,
2. In **Hadean** already existed hydrosphere (shallow ocean?) Because these crystals, according to most geologists, formed in the aquatic environment (this is judged by the oxygen isotopic composition).

A.V. Markov, 2014

The oldest finds paleoarheyan microfossils (over 3.5 billion years) - controversial

(We can not exclude abiogenic origin of these structures)



A.V. Markov, 2014

The earliest indisputable microfossils:
~ 3.465 billion years ago, west. Australia (Warrawoona group)

FIGURE 2.5 *Primaevifilum amoenum* (Warrawoona Group). Bar = 10 μm. (Courtesy J. W. Schopf.)

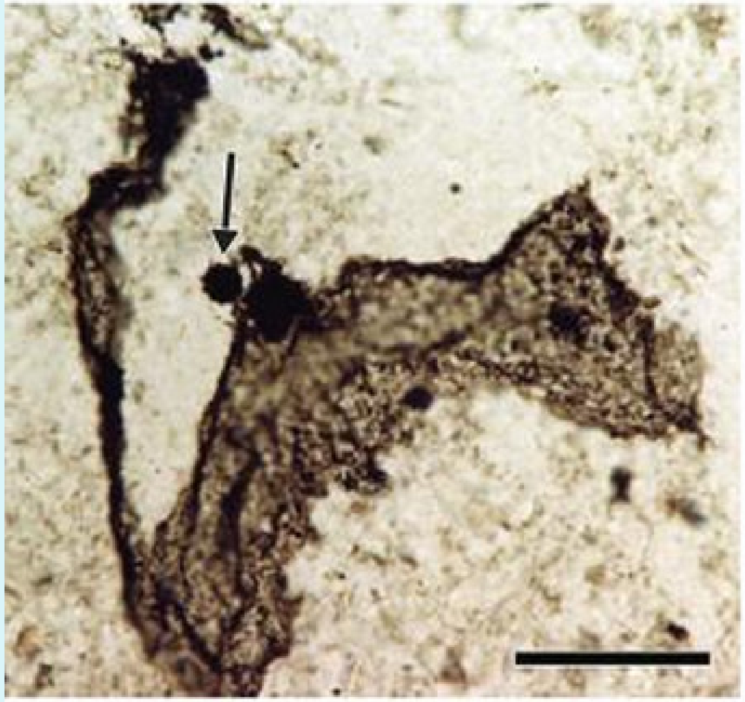


FIGURE 2.7 Film-like microstructures with small sphere (arrow) (Warrawoona Group). Bar = 50 μm. (Courtesy K. Sugitani.)

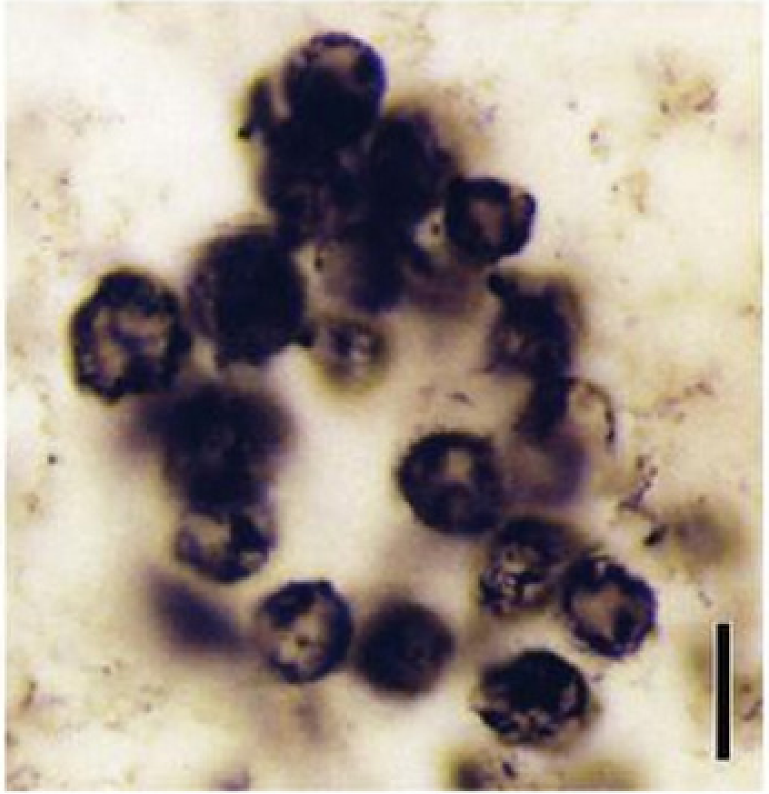


FIGURE 2.6 Colony-like aggregation of small spheroidal microstructures (Warrawoona Group). Bar = 10 μm. (Courtesy K. Sugitani.)

Where to look for a solution?

- Astrophysical Solutions: Young Sun was not faint
- Early Earth Atmosphere: Much more greenhouse gases
- Geology: Much more geothermal energy
- Biology: Life developed on a cold planet
- Fundamental Physics: e.g., gravitational constant has varied

Piet Martens (2013)

Problems with Cold Genesis

- Evidence for liquid water on continents
- Stromatolites live on surface
- Note that there is also evidence for the presence of liquid water during several periods in the history of Mars, including at very early times [Carr, 1996]. The problem of keeping early Mars warm would be even more profound due to its larger distance from the Sun and considerably smaller mass, if there were indeed extended periods of warm climate on early Mars.

ENHANCED GREENHOUSE EFFECT

In summary, an enhanced greenhouse effect arguably still seems the most likely solution to the faint young Sun problem. Carbon dioxide and methane are the most obvious candidates, although they could face severe diffi-culties in terms of geochemical constraints and low pro-duction rates, respectively, and their respective contribution remains uncertain. Ammonia appears less likely than CO_2 and CH_4 because it would have to be shielded against pho-todissociation by ultraviolet radiation and because it would be washed out by rain.

A final assessment of greenhouse gas warming in the early atmosphere, however, is complicated by uncertainties in the radiative transfer functions and the lack of spatially resolved and fully coupled climate models for the early Earth comprising the full range of feedbacks in the Earth system. Finally, other climatic factors like changes in cloud cover could in principle at least have contributed to a warming of the Archean Earth. (Georg Feulner, 2012)

Was the young Sun really faint?

Solar luminosity is a strong function of solar mass: $L_\odot \sim M_\odot^4$

Planetary orbital distance varies inversely with solar mass: $a \sim M_\odot^{-1}$

Solar flux varies inversely with orbital

distance: $S \sim M_\odot^2 \sim a^{-2}$

Flux to the planets therefore goes as $S \sim M_\odot^6$

Piet Martens (2013)

Mass Loss of a Younger Sun

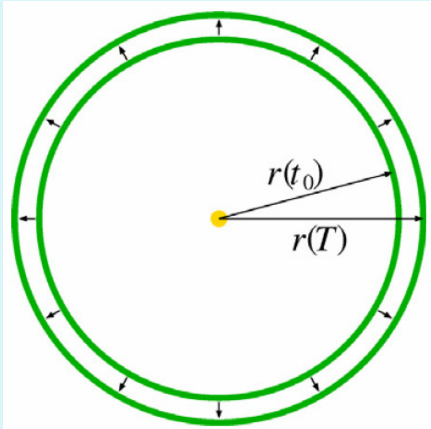
- Solar flux to the planets goes as

$$S \sim M_{\odot}{}^{6}$$

- So an early Sun that was ~5% more massive would yield 30% more irradiance, needed to have warm planetary atmospheres
- Hence, required solar mass loss is ~1% per billion years, i.e. $\dot{M}_{sun} = 10^{-11} M_{sun} / yr$
- Current (observed) mass loss $\dot{M}_{sun} = 3x10^{-14} M_{sun} / yr$
- Factor 300 off!

An absolutely new approach to this problem was presented I n the recent papers [3, 4]. Their authors have shown that the effect of reduced luminosity of the Sun in the past might be compensated by the decreased radius of the Earth's orbit due to the local Hubble effect, which is associated with the uniformly distributed Dark Energy. Although the hypothesis of Hubble expansion at the scale of the Solar system is not commonly accepted, the performed quantitative estimates show that two above-mentioned effects could compensate each other very well and, therefore, to provide an almost time-independent flux of the solar energy to the Earth in the entire course of its geological and biological evolution (namely, 3-4 Gyr both before and after the present time).

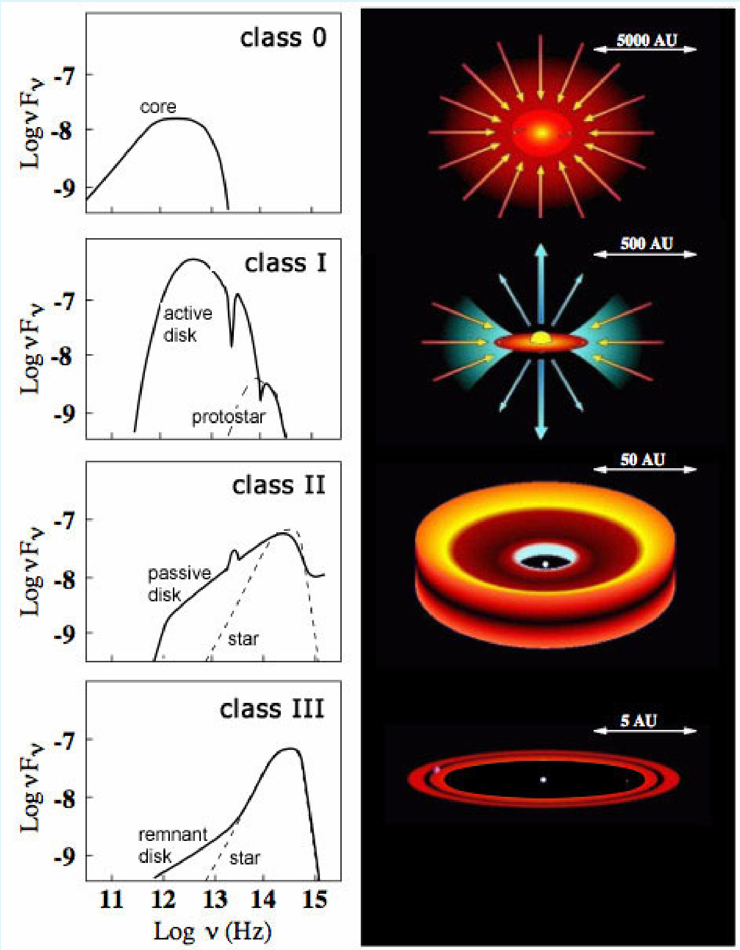
3. M. Krizek. New Astr., v.17, p.1 (2012).
4. M. Krizek and L. Somer, in press (2014).



Mass Loss of a Younger Sun

- Depending on the assumed mass-loss history, a young Sun with an initial mass 4% higher than today would be bright enough to explain the presence of liquid water on Mars 3.8 Ga [Sackmann and Boothroyd, 2003], and an initial mass of 6% higher than today makes the Sun as bright as today 4.5 Ga, although the solar luminosity would still drop below today's levels during the Archean [Guzik et al., 1987; Sackmann and Boothroyd, 2003].

The initial stages of star formation with solar mass



10 000 yr   submm protostar

100 000 yr   IR protostar

1 000 000 yr   T Tau (CTTS)

10 000 000 yr   T Tau (WTTS)

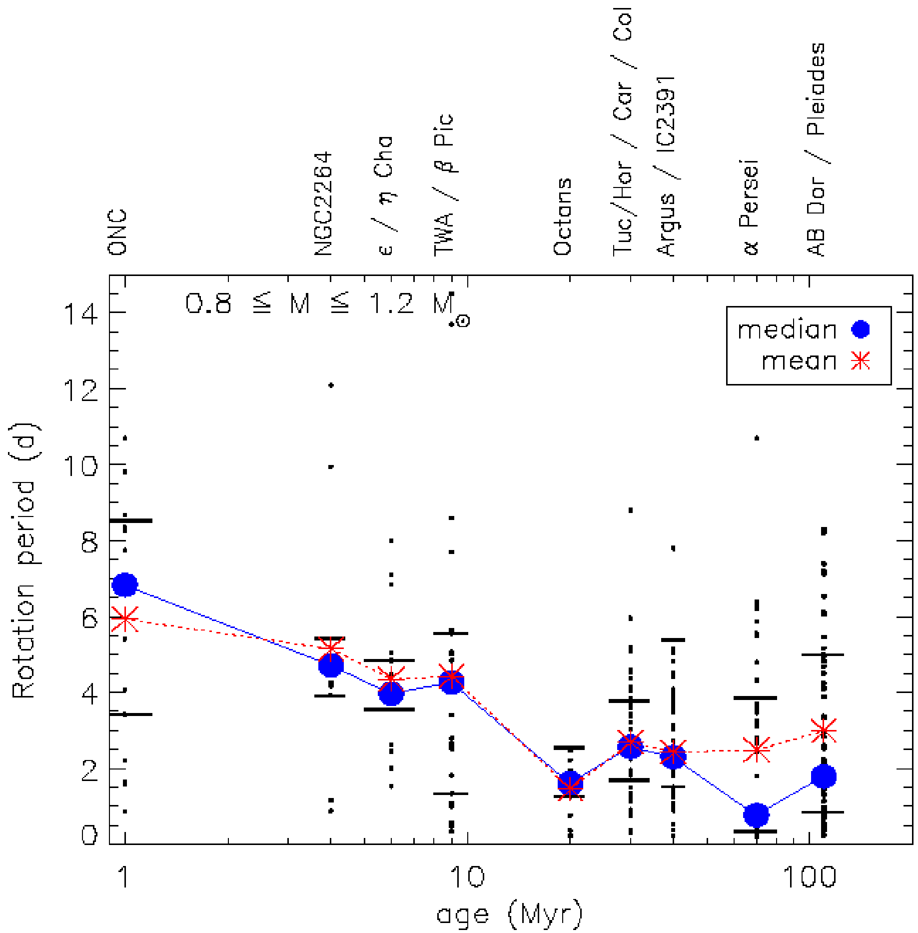


Fig. 7 Rotation period evolution versus time in the 0.8-1.2 solar mass range. Small dots represent individual rotation period measurements. Bullets connected by solid lines are median periods, whereas asterisks connected by dotted lines are mean periods. Short horizontal lines represent the 25th and 75th percentiles of rotation period. This plot updates the right panel of Fig. 12 of Paper I.

Rotation of stars at the stage of gravitational compression

Rotation Period Evolution versus Time in the 0.8-1.2 M_Sun range

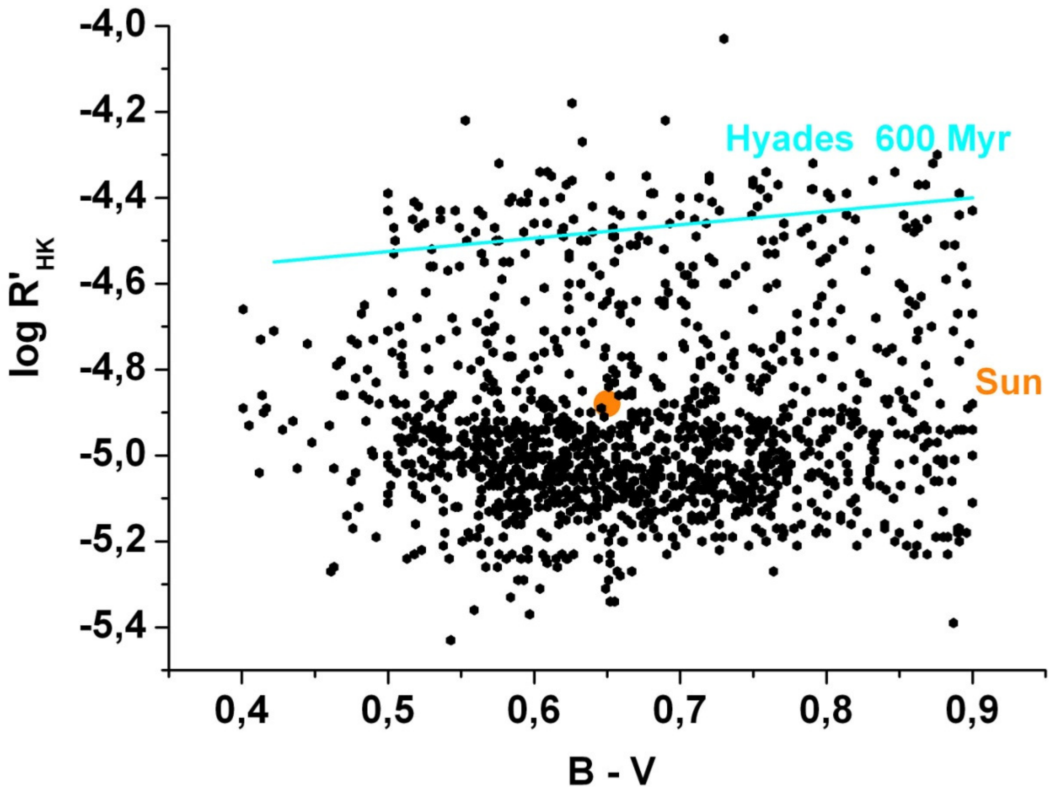
Messina et al. 2011

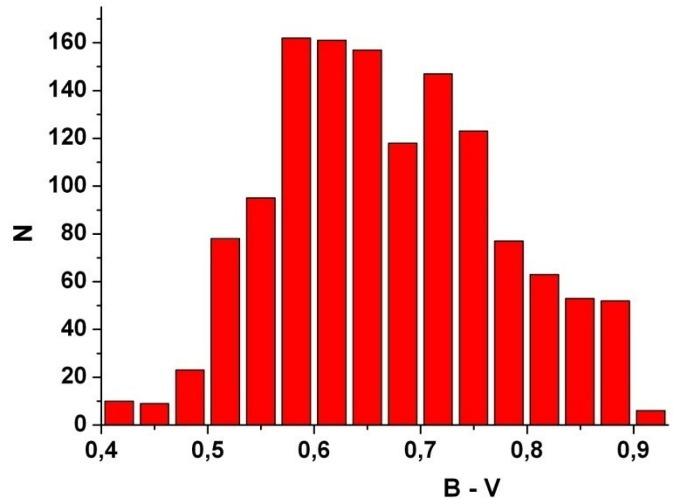
Solar activity today

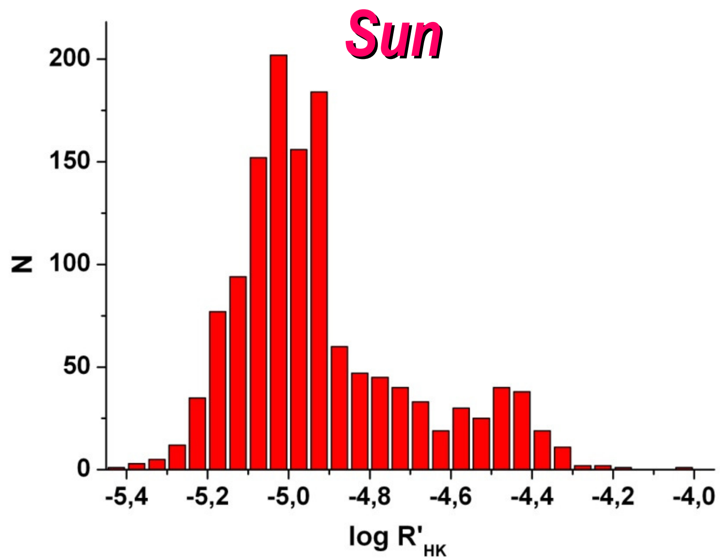
- *The Solar activity is clearly an effect of magnetic fields of various scales - global dipole, large scale elements and local fields.*
- *Most quasi-stationary and non-stationary processes in active regions associated with the evolution of the local fields.*
- *Large scale is connected with the existence of a global dipole, coronal holes, the sector structure of the IMF ...*
- *There are reasons to believe that large-scale fields control activity on different horizontal scales and heights in the solar atmosphere*

Activity of solar-type low-mass stars

Chromospheric Activity of Northern and Southern Stars from California, Carnegie & Magellan Planet Search Programs







1334 stars

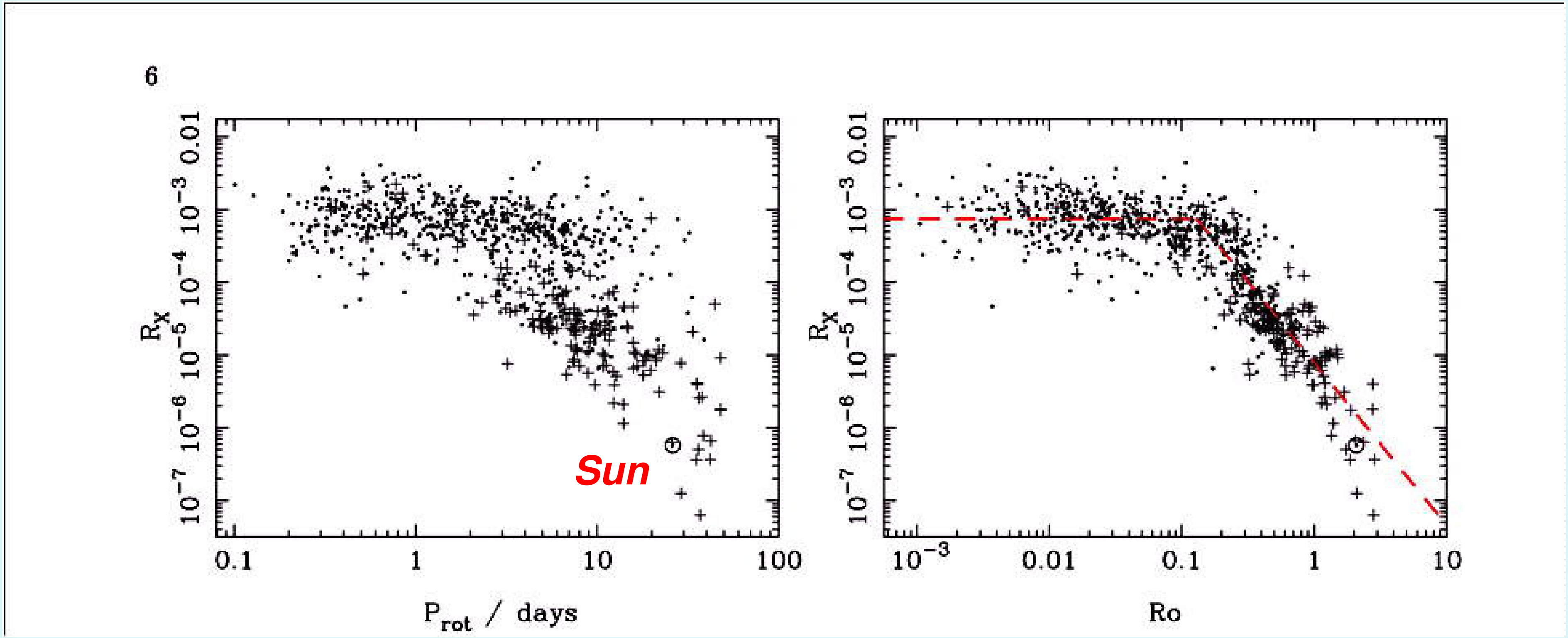
Jason Wright et al. 2004;

Pamela Arriagada 2011

The main factors determining the character Solar-type activity

Вращение

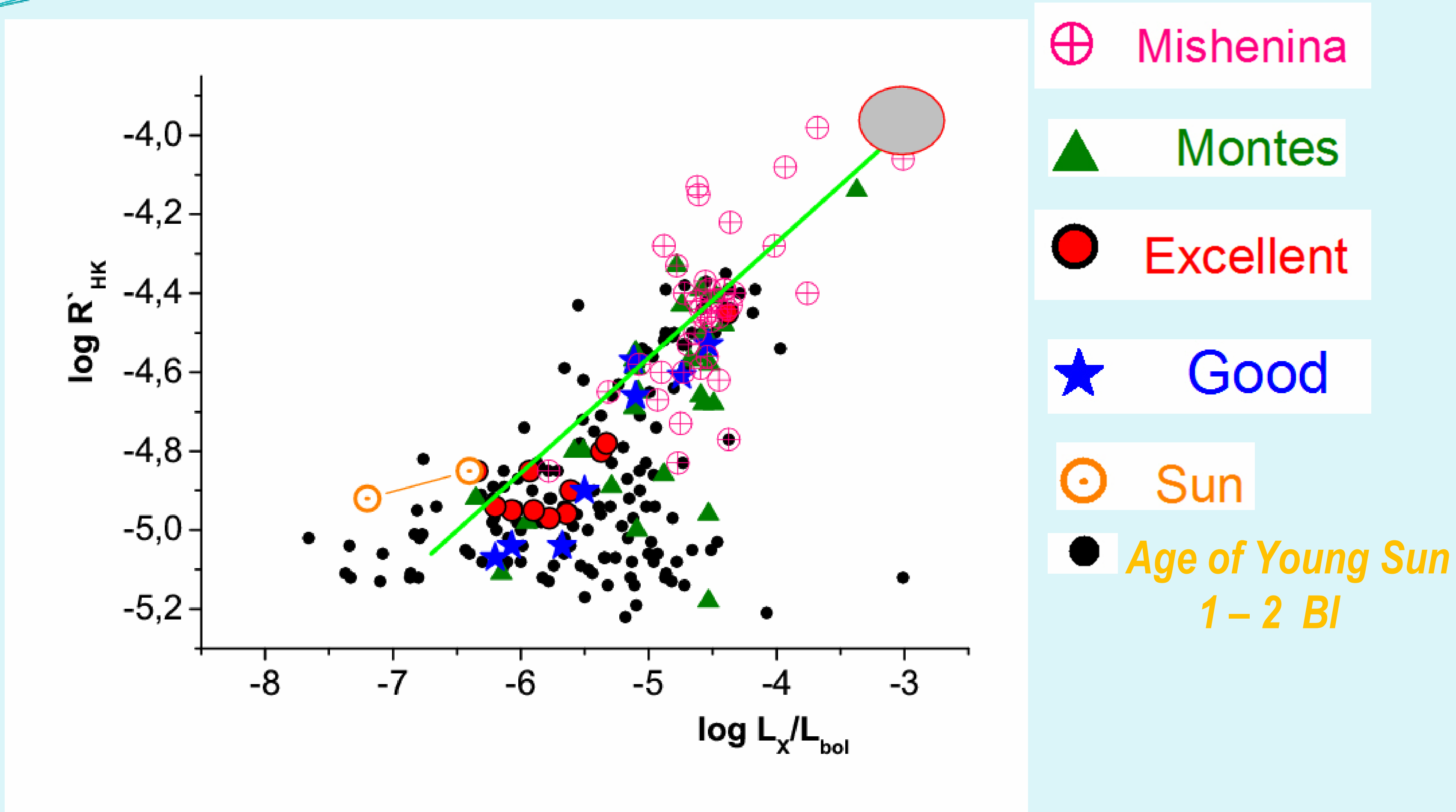
Rx= log (L_x / L_bol) vs Rossby number



Wright N. et al. 2011

Ro = P_rot /tau

« Chromospere – corona » diagram



Possible ways of solar-type activity evolution

Girochronology   Different Magnetic Field Scales ?

M.M. Katsova, M.A. Livshits 2011 AR;   M. Katsova JENAM-2011,

T. Mishenina, C. Soubiran, V. Kovtyukh, M. Katsova, M. Livshits, A& A 547 A106 2012

Main parameters of the Yuong Sun activity

« Sun-in-Time »: Hot corona DEM(T) 5 – 8 MK

Density at corona base 3 – 5 x 10^9 cм^{-3}

Sunspots	P_rot	S, %	L_x, erg/s	R_x
Act Sun (G2 V)	25 d	0.3	10^27	-7
Young Sun	10 d	3	10^29	-4.4

Main parameters of the solar analogues in activity

BE Cet	G2 V	8 d	3	10^29	-4.4
k Cet	G5 V	9d		10^29	-4.4
EK Dra	G0 V	3 d	10–20	10^30	-3

Main parameters of the Young Sun activity

- *Magnetic field increase with the transition from slow to fast rotating stars . The total magnetic flux of active sun-type stars larger than on the Sun in a maximum.*

- *Total magnetic flux of the Sun at the cycle maximum is*

  10^24 Mx and at the minimum 10^23 Mx (e.g., Solanki et al. 2002; Vieira and Solanki 2010) .
- *The estimation fot Young Sun is 3 × 10^24 ~10^25 Mx*

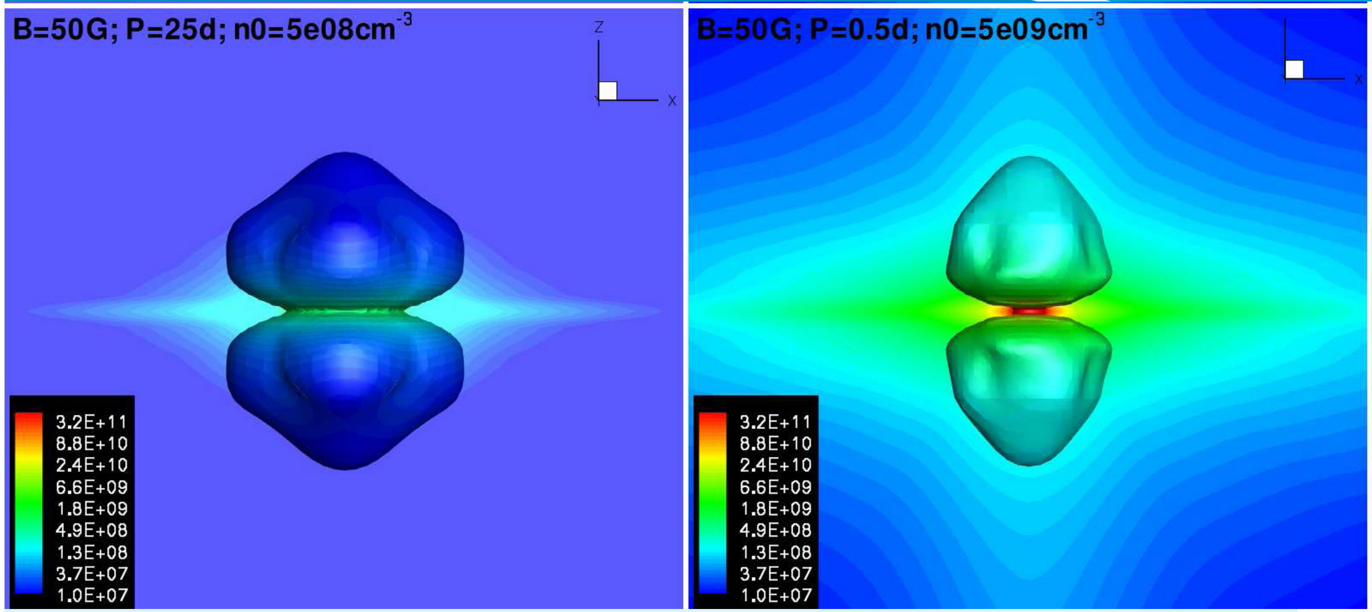
- *The magnetic fields in starspots on sun-type stars are about 3 – 5 кGs (spectropolarimetric observations).*

Young Sun mass loss

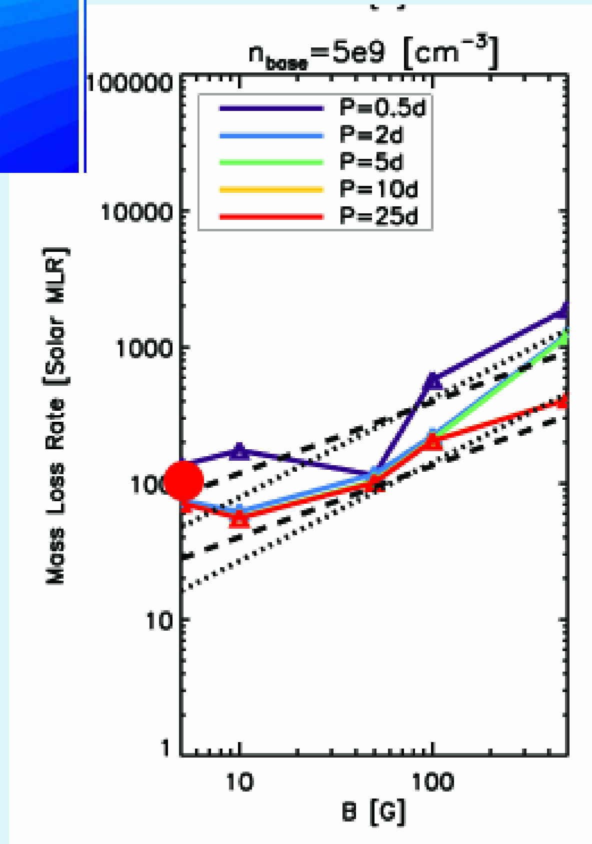
Today Sun loses in the form of wind 3 x 10^{-14} *Msun/year*

Corona of the yuong Sun is 20-25 denser

Magnetic fields order of magnitude larger



Star wind



A GRID OF MHD MODELS FOR STELLAR MASS LOSS AND SPIN-DOWN RATES OF SOLAR ANALOGS

O. Cohen, J.J. Drake, 2013

The red dots mark unphysical cases with the Alfven surface located inside the star.

So the estimate of the mass loss young Sun is 300 x 3 x 10^{-14 } = 10^{-11} Msun/year

Some conclusions

- Most likely, the young Sun is close to the typical stars type BY Dra. Fast braking is then followed by a slower, that should be considered when analyzing the loss of angular momentum and the evolution of solar-type activity.

- Although the luminosity of the young Sun is only 20% less than it is now, the nature of the activity in all the atmosphere height s was significantly different: the spots area is larger 10 times or more,

- Soft X-rays was 2 - 3 orders of magnitude greater.

- The mass loss of the young Sun 2 orders of magnitude more than the present value .

- Analysis of activity of the young Sun shows that in this period there were a strong perturbations of the Earth magnetic field. Fluxes of accelerated partiles (protons with energies of tens of MeV) from longtime flares and CMEs are likely to have been extremely high.

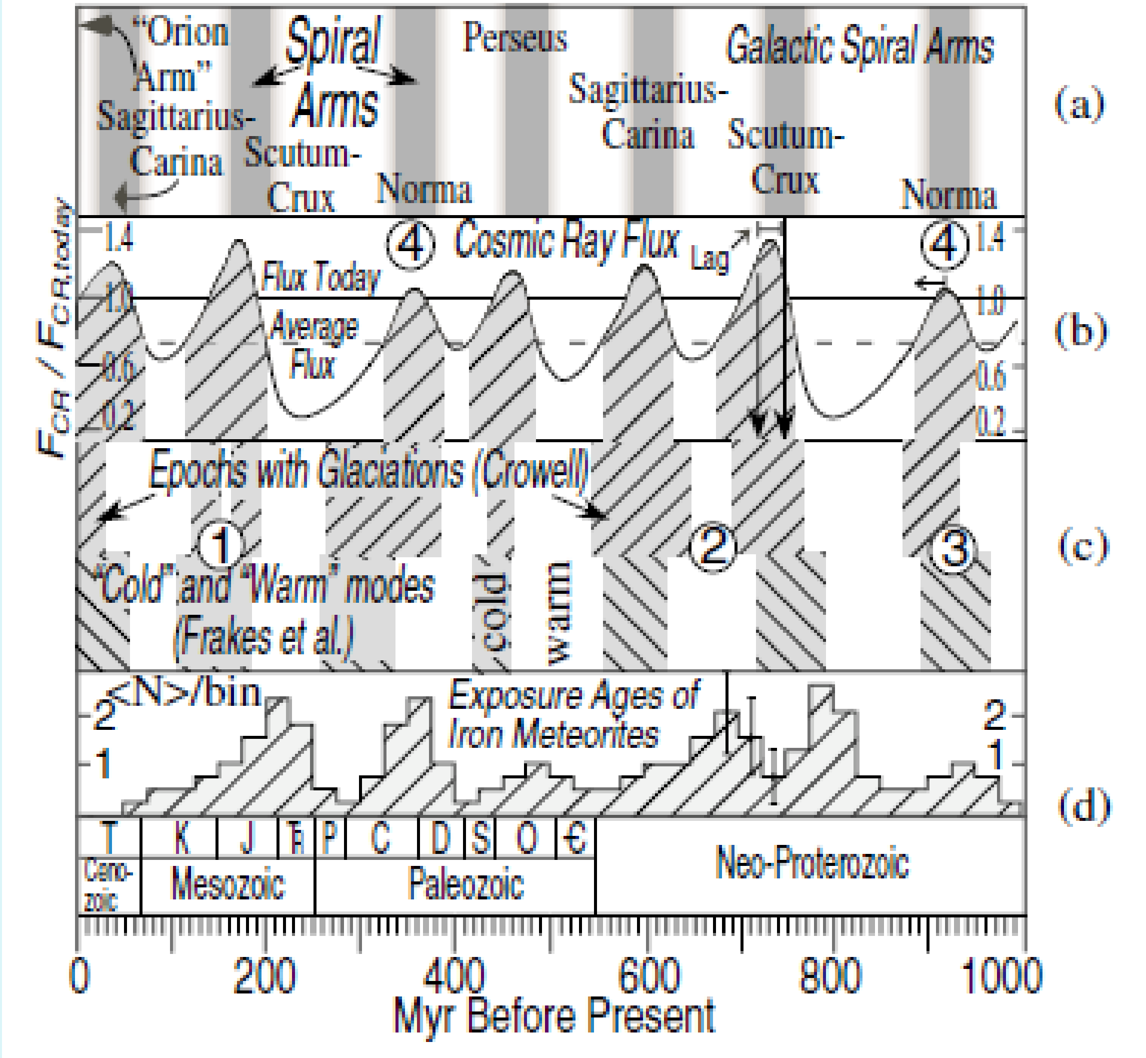
Now other period in the Sun and Earth life

2 billion years ago and up to the present day.

Both the Sun and the Earth are now not young.

But the strong variation in the biosphere and geosphere still observed.

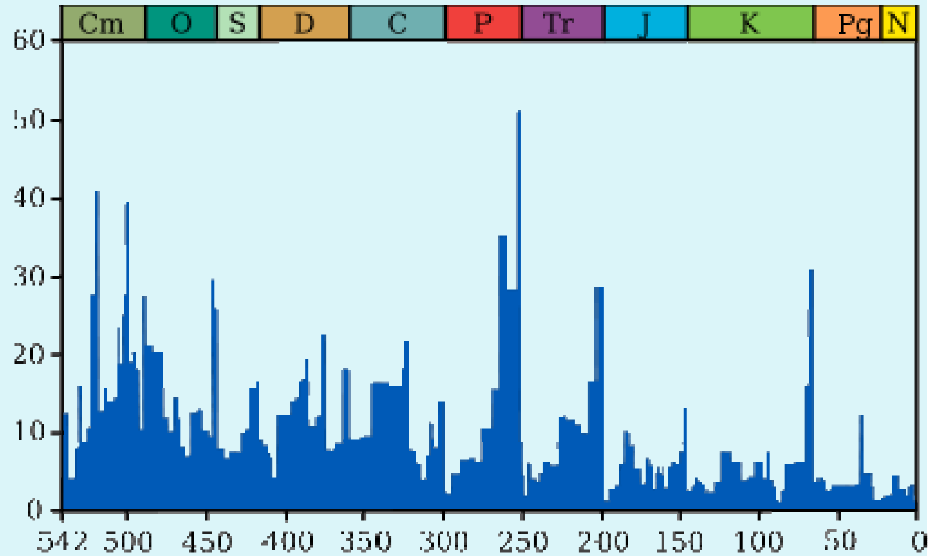
Past Galactic arm crossings



A compilation of 74 iron meteorites which were K(41)/K(40) exposure dated (Voshage & Feldman, 1979).
To avoid real clustering in the data (due to one parent body generating many meteorites) N.J. Shaviv has removed all occurrences of Fe meteorites of the same classification that are separated by less than 100 Myr and replace them by the average. This left him with 42 meteorites.
(Nir J. Shaviv, 2002).

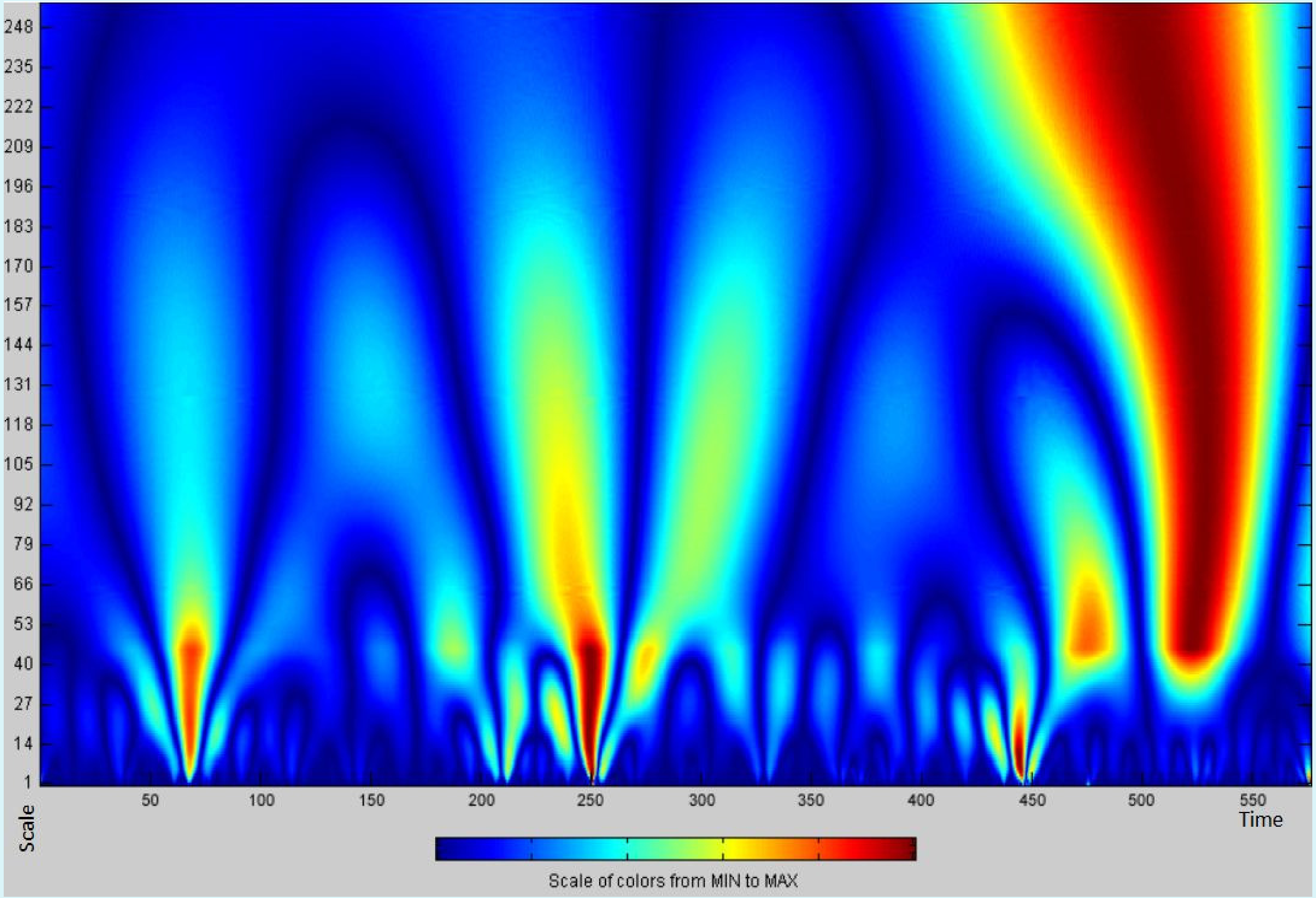
Interconnection of processes

The intensity of extinction of marine organisms on the timeline. Clearly distinguished the five mass extinctions, called Big Five by (Rohde & Muller, 2005).



Endogenous evolution of events in the mantle and crust. Total endogenous activation peaks for the upper mantle and crust in the range of geological time. (Balashov, 2002)

Skalogramma (MHAT-wavelet) intensity series of extinctions of marine biota. Cambrian explosion (500 - 540 million years ago)

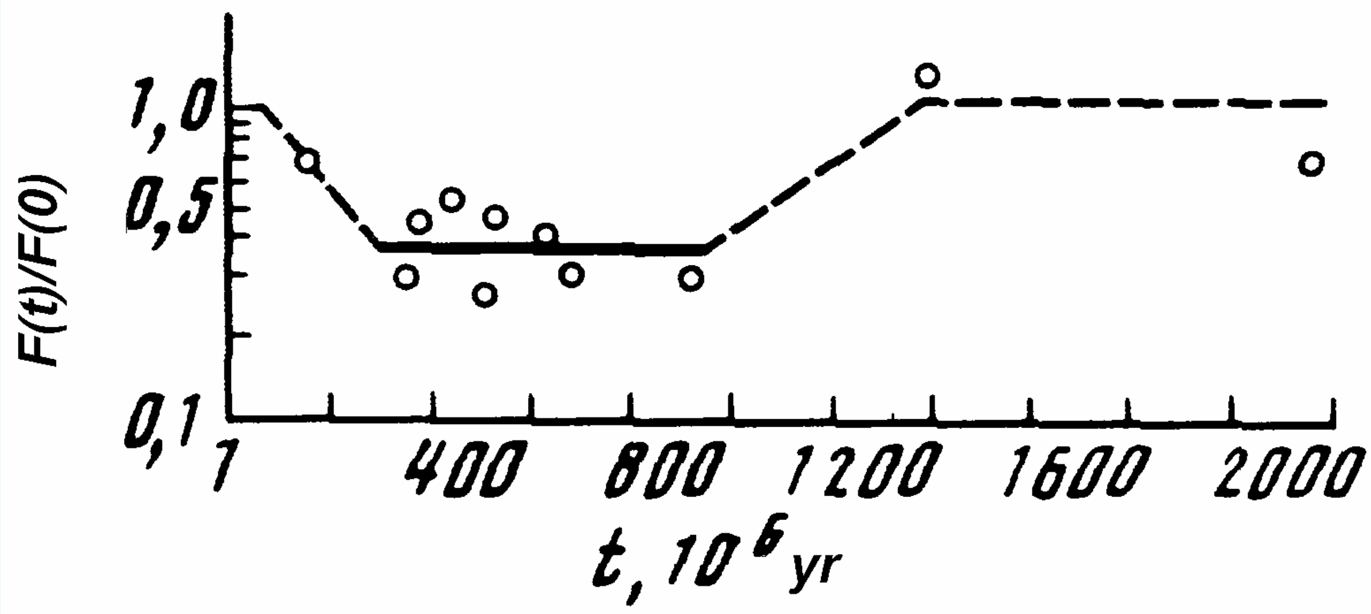


GCR and Meteorites

Isotopes in meteorites:

K-40, T(1/2) = 1.3 Billion years.
Cl-36, T(1/2) = 3.08×10^5 years.

A.K. Lavrukhina, 1969;
A.K. Lavrukhina, G.K. Ustinova, 1990.
(V.I. Vernadsky Geochemistry Institute, RAS Moscow).



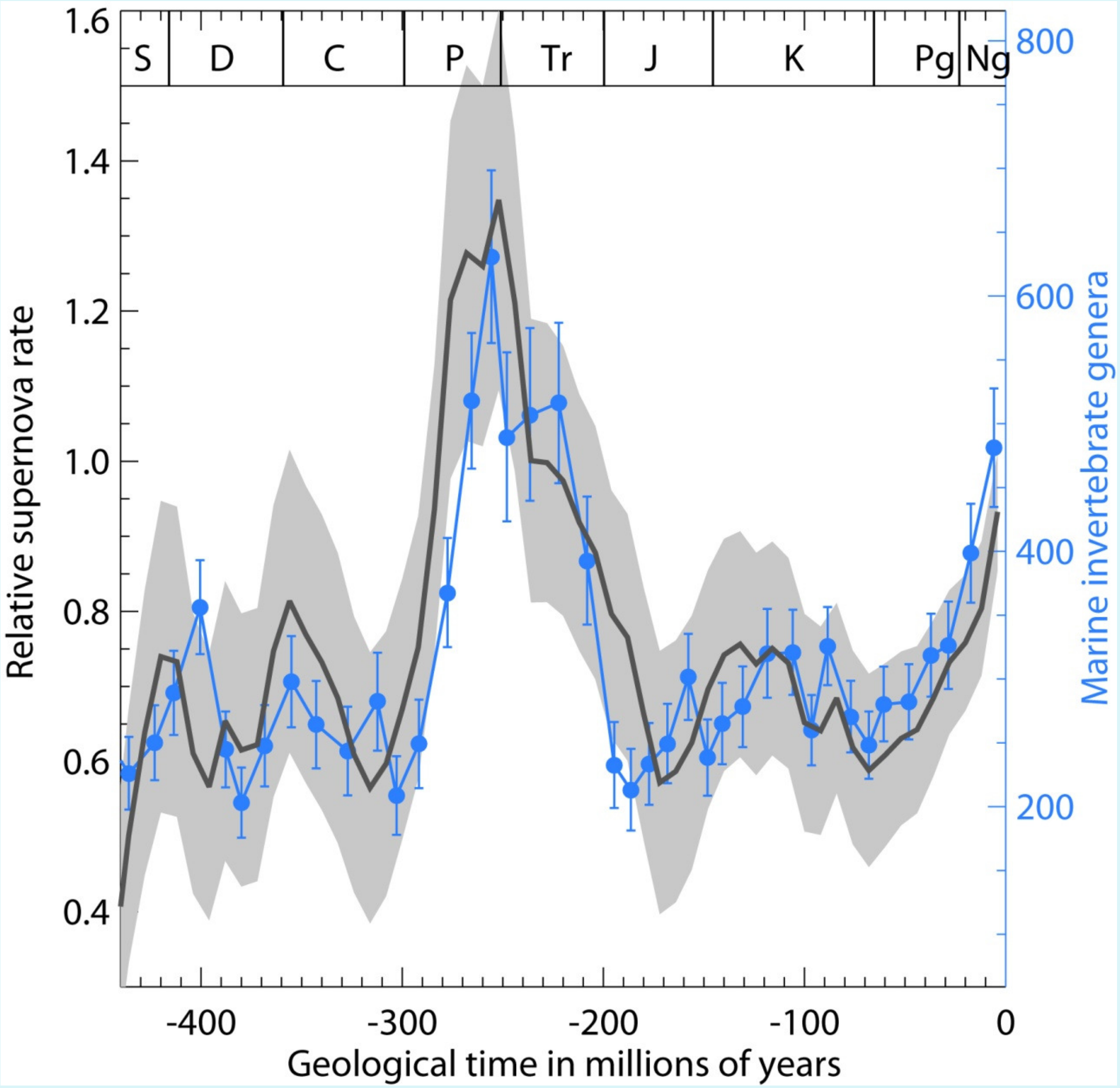
Relative GCR variations in the past by long-lived products of nuclear reactions in meteorites due to CR bombardment: ***F(t)*** **– CR flux at remote time** ***t, F(0) – modern level (data for 11 iron meteorites)*****.**

Cambrian Period, 550-510 MYA (Million Years Ago)…

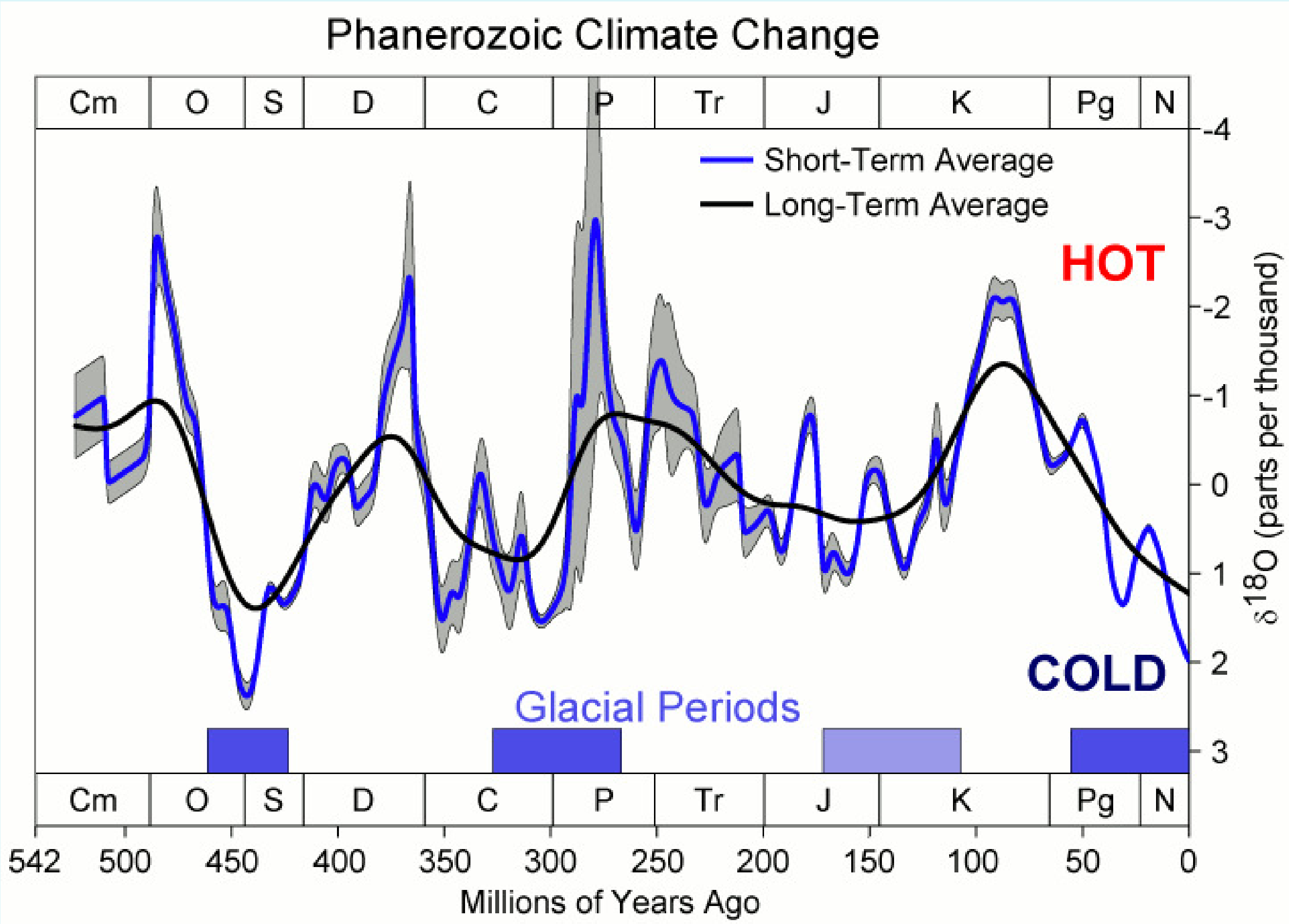
Between ~300-900 Myr ago a summary flux of GCR in the Solar system was ~1/3 of modern level.

SN bursts and biotic extinctions

- **Relative occurrence rate of Supernova bursts (solid curve) in comparison with a number of marine animal genera becoming extinct during any given time interval.**
- **According to Svensmark (2012), the Galaxy let the reptiles down. However, the author's correction for the ocean level changes rather significantly the original set of data and should be undergo to additional verification.**



Terrestrial Climate in the Phanerozoic Eon



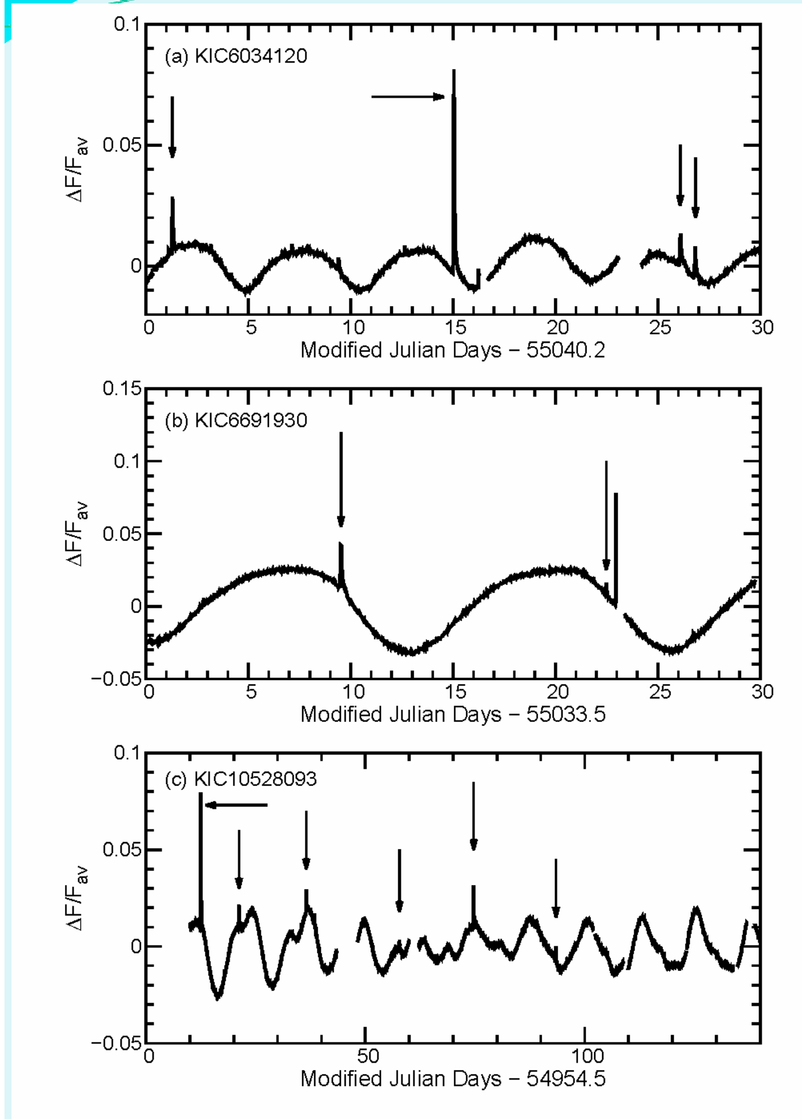
Variations of the concentration of the oxygen isotope 18O (Veizer et al., 1999).

On the other hand, there are independent climatic data (Veizer et al., 1999) that points to the variations of the concentration of the oxygen isotope 18O (as one of the best climatic index) at large time scale. All maximums obtained by Veizer et al. (1999) coincide with the Svensmark's curve.

PAMELA Results: New Challenge?

- Protons and helium nuclei are the most abundant components of the cosmic radiation. Precise measurements of their fluxes are needed to understand the acceleration and subsequent propagation of cosmic rays in our Galaxy. Adriani et al. (2011) reported precision measurements of the proton and helium spectra in the rigidity range from 1 GV to 1.2 TV performed by the satellite-borne experiment PAMELA (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics).
- It was found that the spectral shapes of these two species are different and cannot be described well by a single power law.
- These data challenge the current paradigm of cosmic-ray acceleration in Supernova remnants followed by diffusive propagation in the Galaxy. More complex processes of acceleration and propagation of cosmic rays are required to explain the spectral structures observed in PAMELA data (Adriani et al. Science. 2011, Apr 1; 332(6025):69-72. E-pub. 2011, March 3).
- Stozhkov's hypothesis: In our Galaxy, side by side the Supernovas, there are other sources of CR in the PAMELA energy range. The main candidates of this kind are so-called dwarf stars.

Flares on G stars (from Kepler)



Kepl ID	6034120	6691930	10528043
T_eff	5407	5348	5143
Log g	4.7	4.5	4.5
R/R_sun	0.77	0.95	0.88
P_rot	5.6	13.1	12.9
Ampl	4.45 e-3	1.29 e-2	6.52 e-3

Y. Notsu, T. Shibayama, H. Maehara

Superflares on Solar-Type Stars Observed with Kepler. II Photometric Variability of Superflare-Generating Stars: A Signature of Stellar Rotation and Starspots

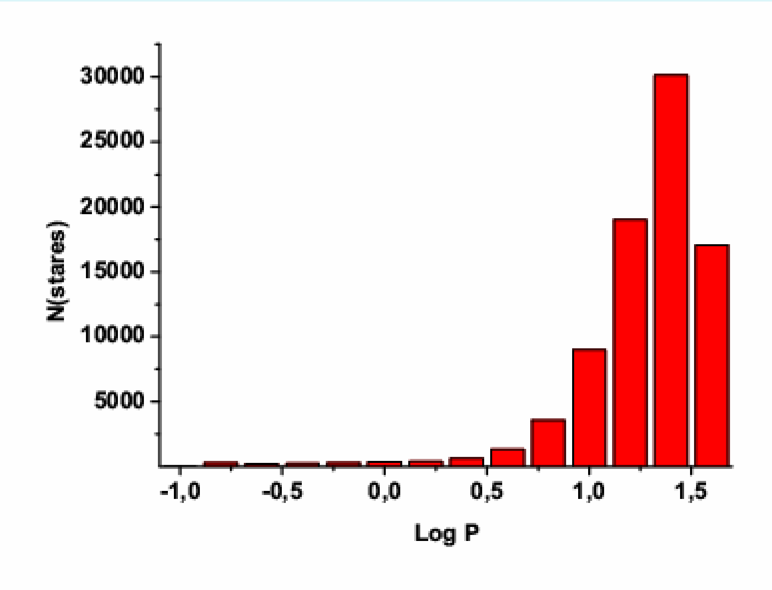
arXiv: 1304.7361, 27.Apr 2013

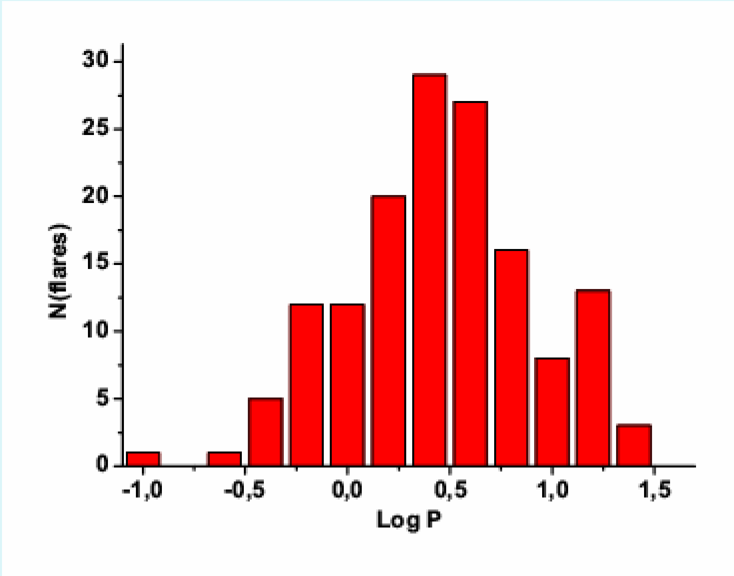
Flares on G stars from Kepler

- *160 000 звёзд*

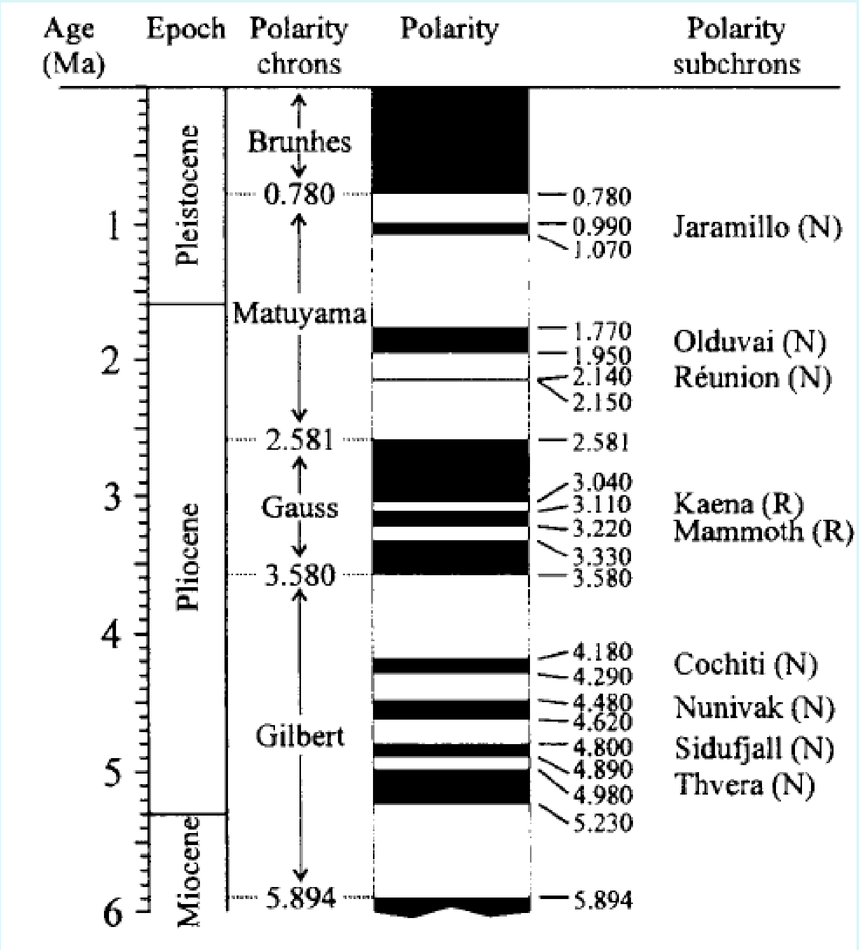
H. Maehara et al. 2013

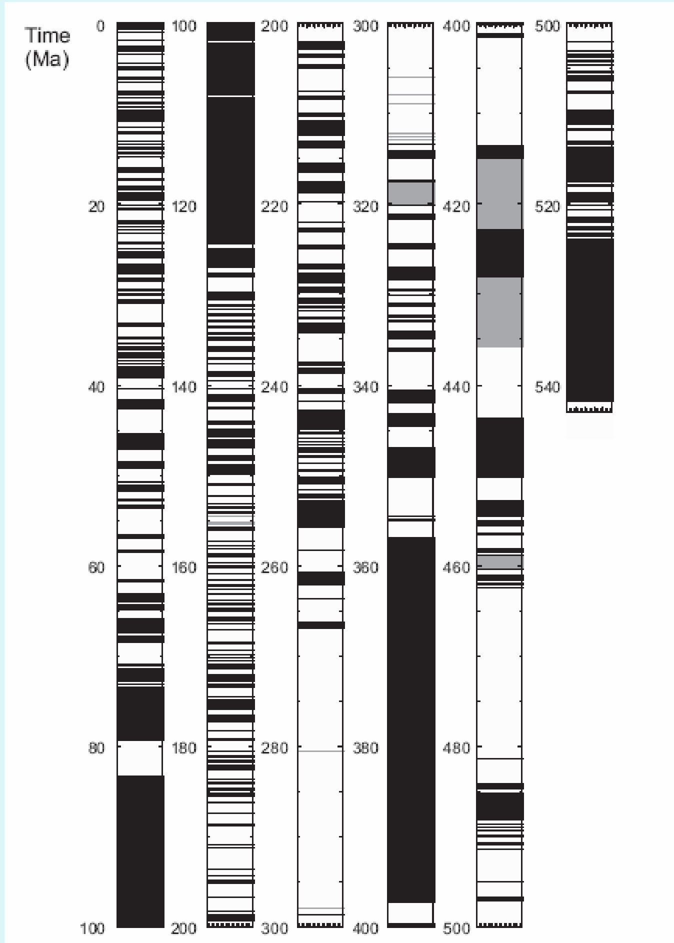
1547 superflares (upto 5 x 10^33 ergs) at 279 G dvarfs, Incluging 44 superflares at the solar-type stars at long term monitoring or .>57 superflares at 500 years





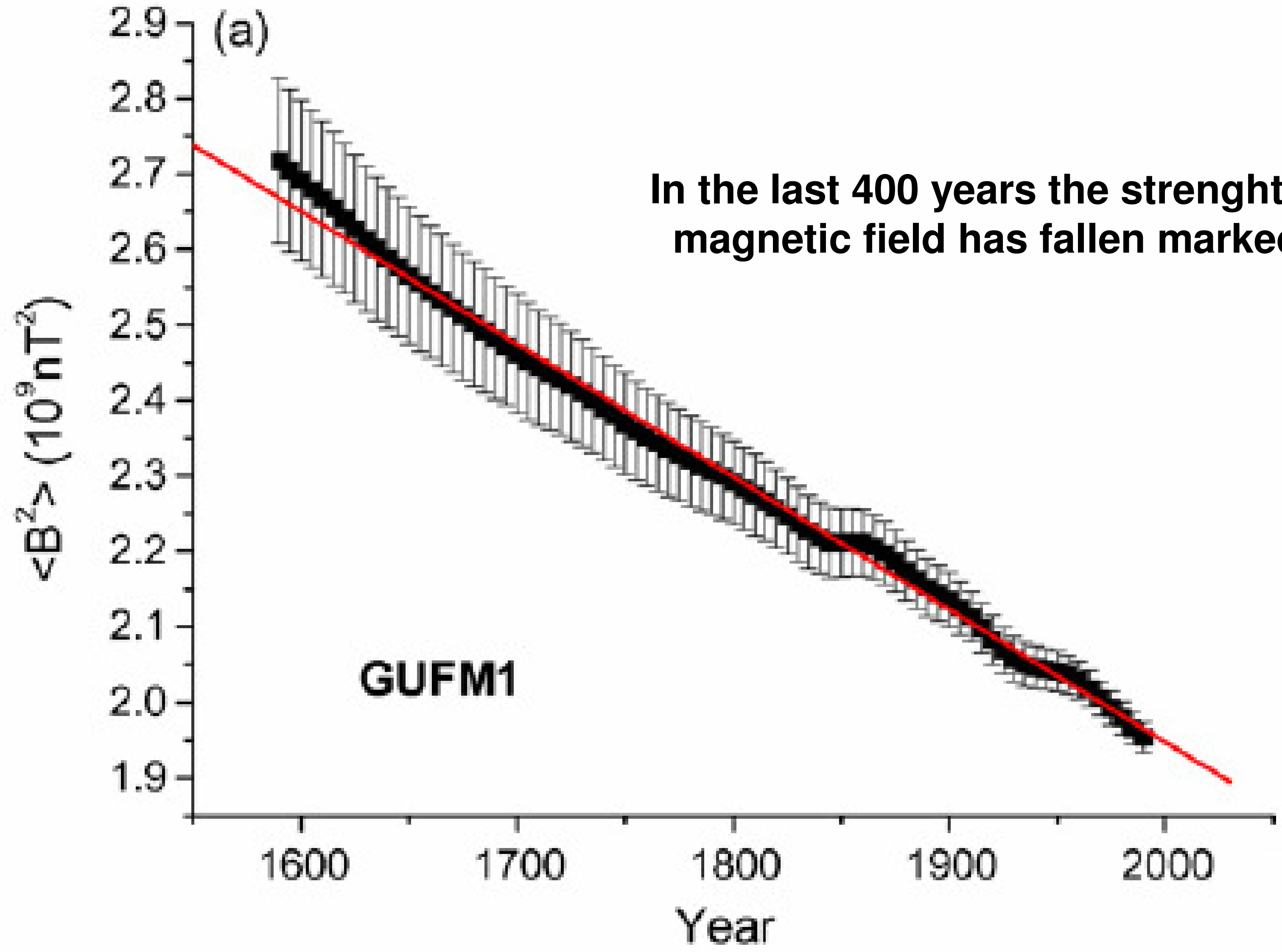
Geomagnetic polarity scale
Gradstein et al., 2008
Inversion- stochastic process
Mean time between inversions ≈ 200 000 years





When will be the next inversion ?

Constant polarity Brunhes epoch lasted for 780,000 years, which is 4 times higher than the average life expectancy of such intervals.



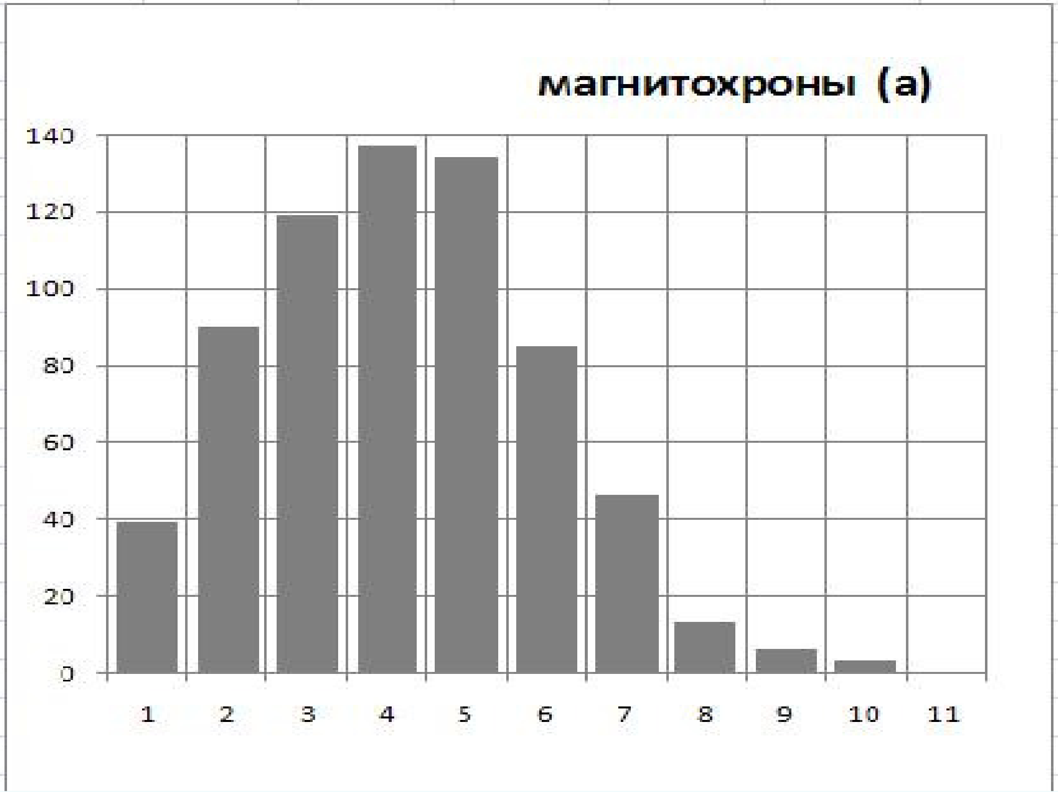
In the last 400 years the strenght of magnetic field has fallen markedly

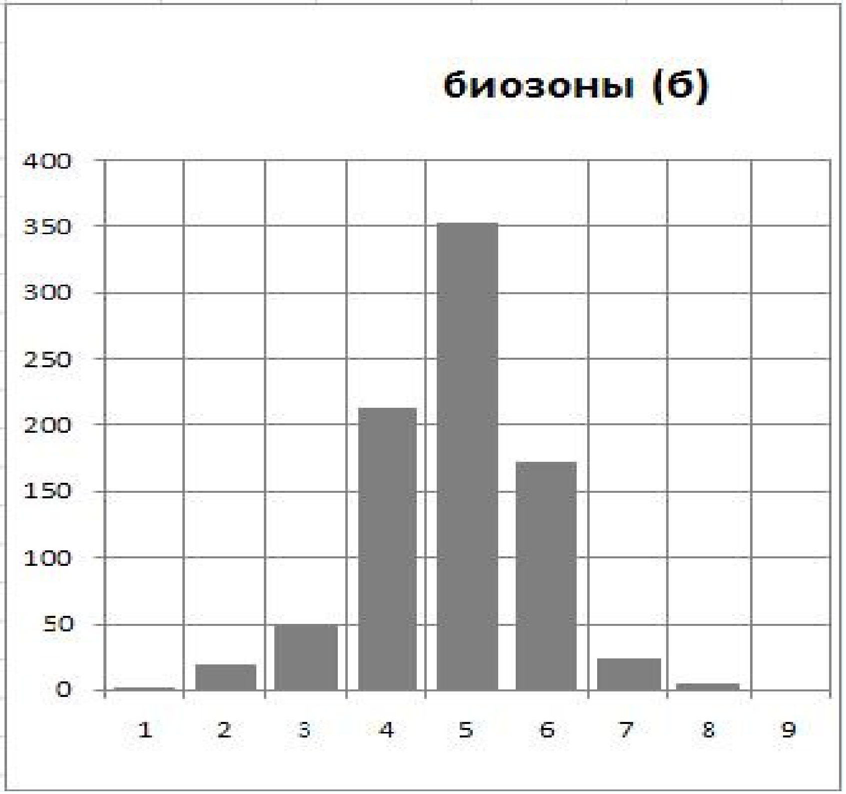
N, инверсии, сглаживание 9 млн. лет
12
10
8
6
4
2
0
0
50
100
150
200
250
300
350
400
450
500
550
Время, млн. лет назад
N, биозоны, сглаживание 9 млн. лет
20
15
10
5
0
0
50
100
150
200
250
300
350
400
450
500
550

Histograms of the duration magnitohronov (a) and biozones (b).

The abscissa intervals million years:

1 – 0-0.05; 2 – 0.05 – 0.1; 3 – 0.1-0.2; 4 – 0.2-0.4; 5 – 0.4-0.8; 6 – 0.8-1.6; 7 – 1.6-3.2; 8 – 3.2-6.4; 9 – 6.4-12.8; 10 – 12.8-25.6.



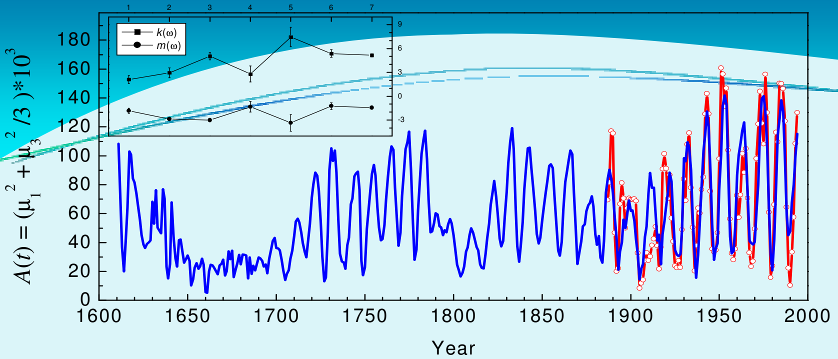


THE HIGHEST LEVEL OF SUNSPOT ACTIVITY AS OBSERVED OVER A LONG TIME INTERVAL

Nagovitsyn Yu.A., Obridko V.N., Kuleshova A.I.

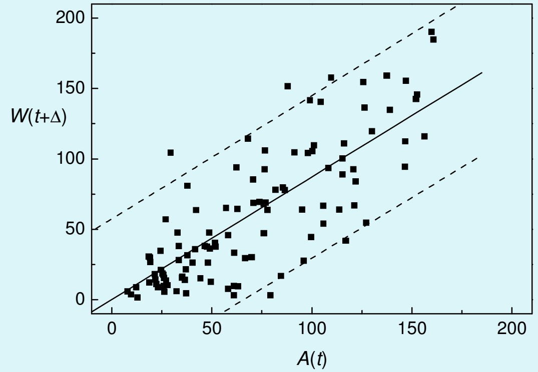
Having analyzed observational manifestations of the α- and ω-effects of the dynamo theory and using the modified Waldmeier rule, we have shown that the annual mean Wolf numbers at the maximum of the 11-year cycle have an upper limit amounting approximately to 220 at 95% confidence. This conclusion is corroborated both by examination of high level probabilities of solar activity using reconstruction (Usoskin, 2014) of its variations over 3000 yr time interval and by approach of empirical mathematical simulation of the cyclicity process based on the Duffing equation.

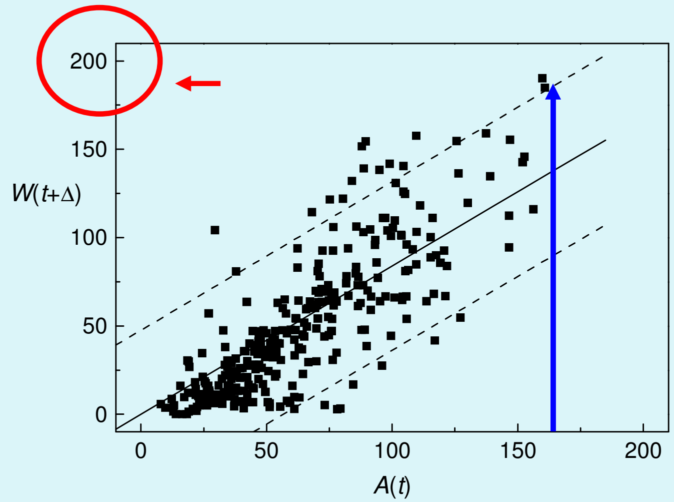
W, *A* (D-O index) and nonlinearity of alfa-effect of dynamo theory



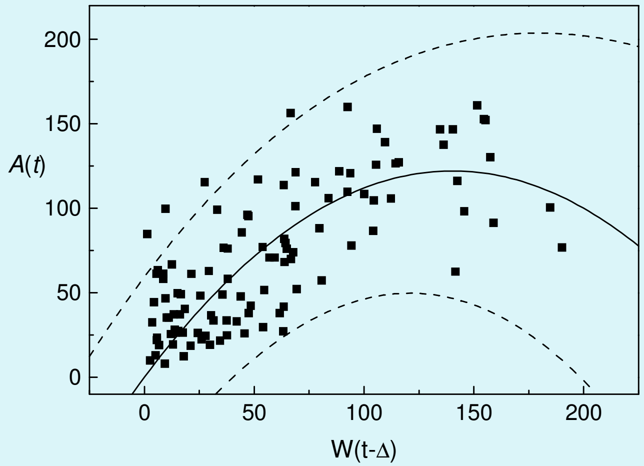
Observational data (red) – Makarov&Tlatov (2005) and 400-yr reconstruction (blue) – Nagovitsyn etal (2008)

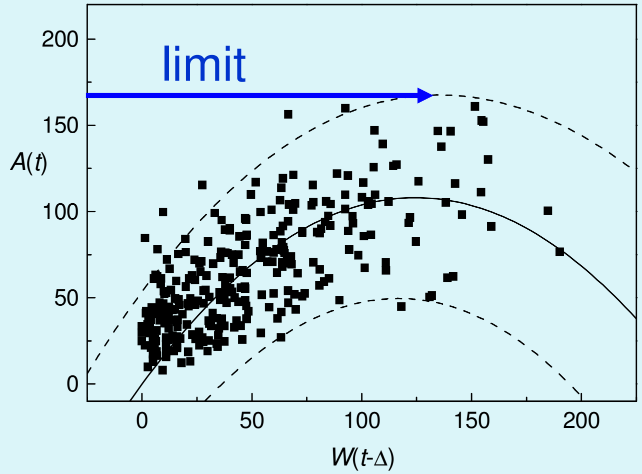
ω-effect





α-effect

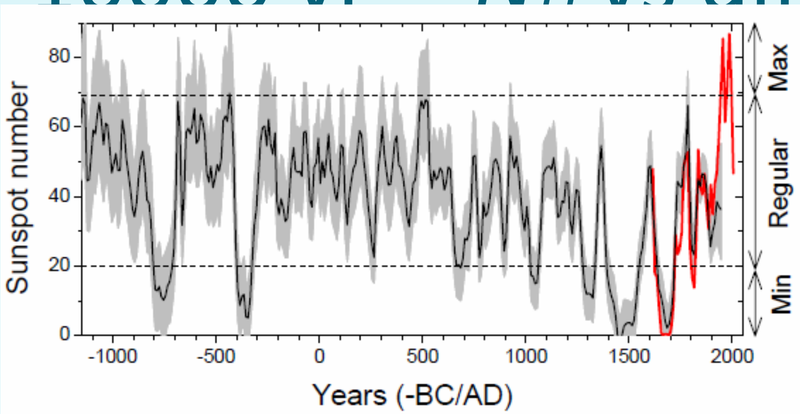




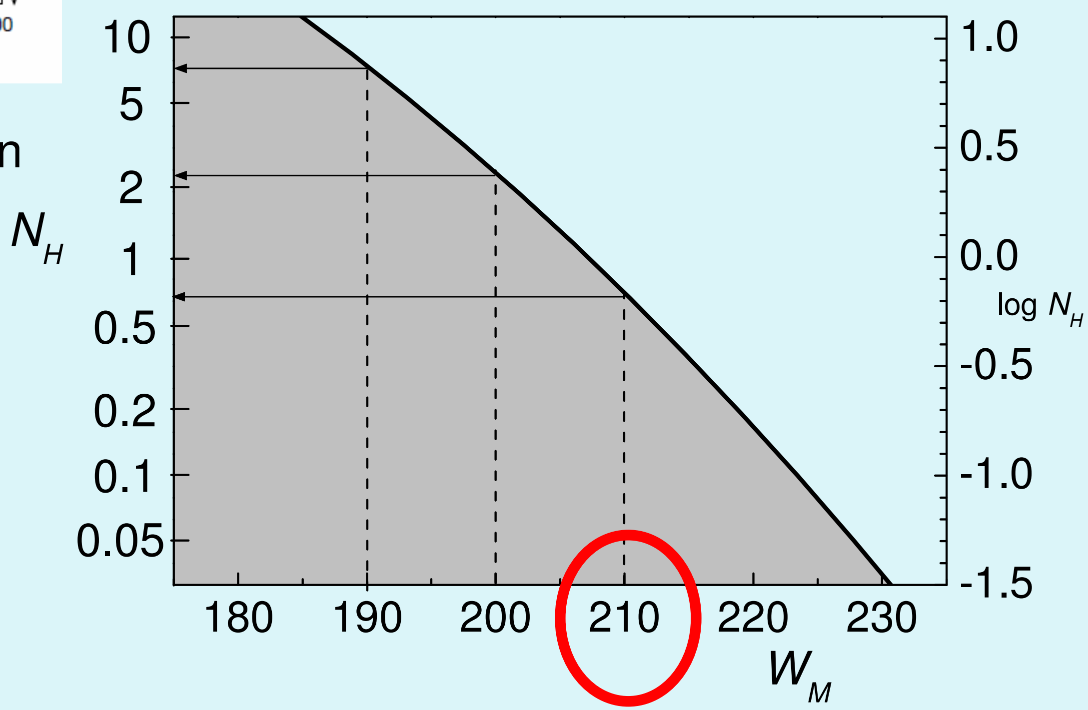
Observational data

Reconstruction (Nagovitsyn etal, 2008)

Maximal number of events over 10000 yr -- N_H vs differing W_M



Usoskin etal (2014) reconstruction




Thank you for attention!