# The limits of the solar events amplitudes: the occurrence of strong flares from the point of view of the underlying dynamo mechanism

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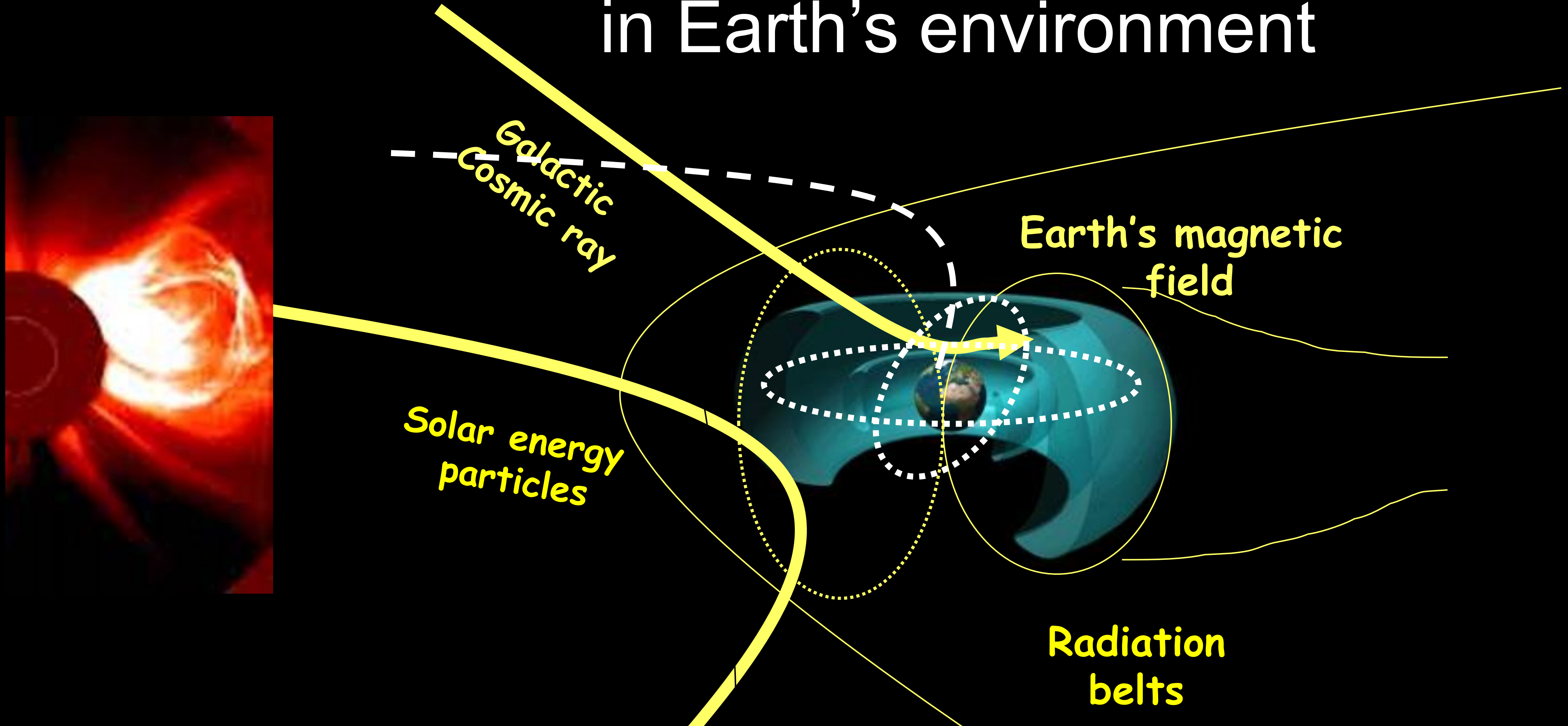
# Space radiation in Earth's environment




Powerful solar flares with energy releases much above of 10 in 32 erg are very rare events compared to habitual display of Solar activity, routine monitoring of which is already within the reach by the existing Space Weather network (even with a certain degree of predictability). However, much less is known about the scenarios of the Superflares on other stars (or about hypothetical possibility of them on the Sun). Such events could extend the energy limits of Flares by orders of magnitude higher. For many other stars presence of Superflares is normal phenomenon (Zuo-Lin Tu et al, 2020 ApJ 890 46).

# The Search for Superflares in Solar Activity History

- So far the Carrington event stays as the strongest among recorded
- Attempts to look for suspicious traces in the deposits

of Cosmogenic Isotopes like C14

(Miahara at all)

- Two cases found in $8^{th}$ century AD, $10^{th}$ Century AD
- Some supporting evidence in ancient Chinese chronicles
- No deposits associated with Carrington Event found
- Emerging consensus that Carrington still was stronger

To date, more than 5,000 exoplanets have been discovered and are considered "confirmed."

On November 4, 2013, astronomers reported, based on Kepler space mission data, that there could be as many as 40 billion Earth-sized planets orbiting in the habitable zones of Sun-like stars and red dwarf stars within the Milky Way Galaxy. The nearest such planet could be expected to be within 12 light-years of the Earth, statistically.

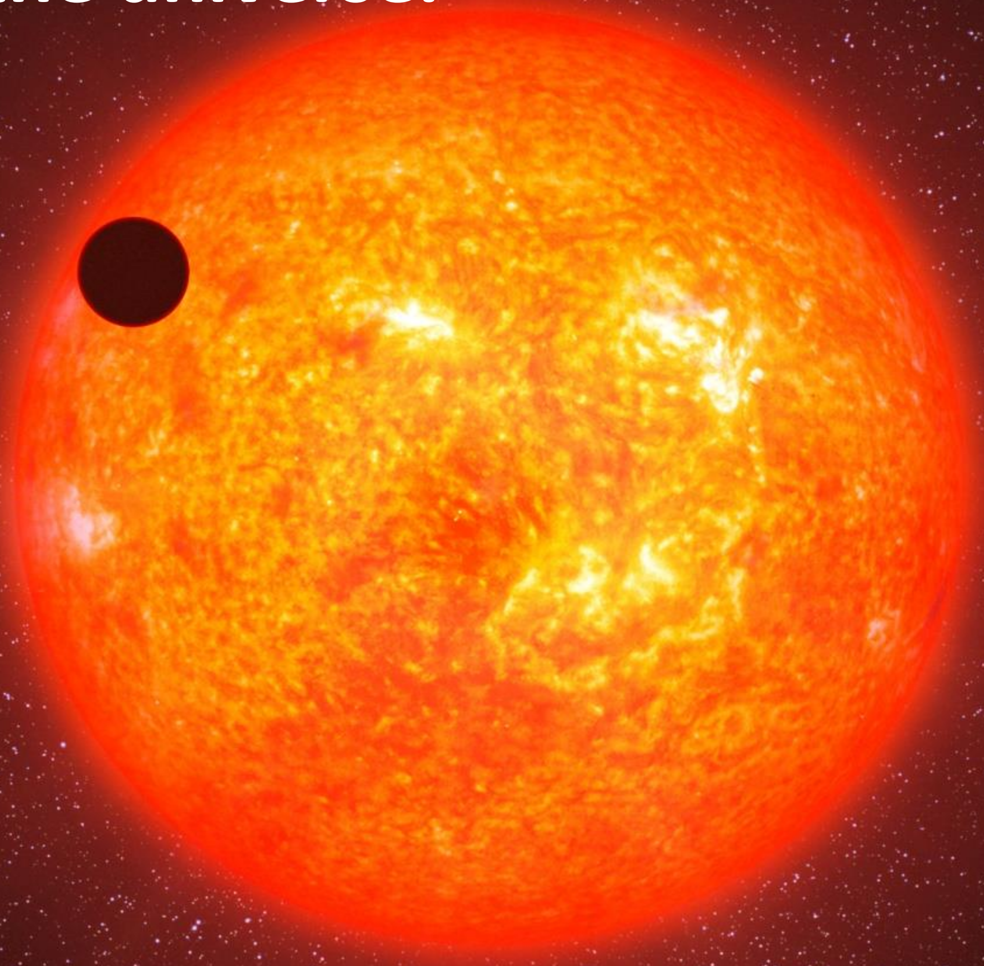
Of the 2,326 candidates discovered by Kepler, 207 are roughly Earth-sized, 680 are super-Earth-sized, 1,181 are Neptune-sized, 203 are Jupiter-sized, and 55 are larger than Jupiter.

In September 2020, astronomers identified 24 superhabitable planet (planets better than Earth).

NASA/JPL-Caltech

- ***Space weather around the Exoplanets***
- One of the main goal of very active program of seach for the exoplanets is focused those among them with habitabity criteria based on the important parameters of thermal conditions and liquid water favorable, similar to those on Earth.
- Also, a task arises in the spirit of Chizhevsky: how a host-star affects the its planets:
- The detection of superflares on many stars, as hosts of planets, makes it important to take into account also the flares intensity criterion. On the one hand, too high flare activity might destroy the atmosphere, but on the other hand, too low flare activity may be insufficient to provide a critically needed radiation for prebiotic chemistry and thus preclude the emergence of life. Studies of the nearest red dwarf star, Proxima Centauri have led a few years ago to the seemingly lucky discovery of nearest valuable object for Astrobiology. However, more recently observations have shown that this star has a fairly high flare activity (Ward S. Howard et al 2018 ApJL 860 L30), which can be incompatible with chance for the emergence of life there.

Red dwarfs are the most common stellar-type objects in the universe.



ESO/L. Calçada

# Red dwarfs

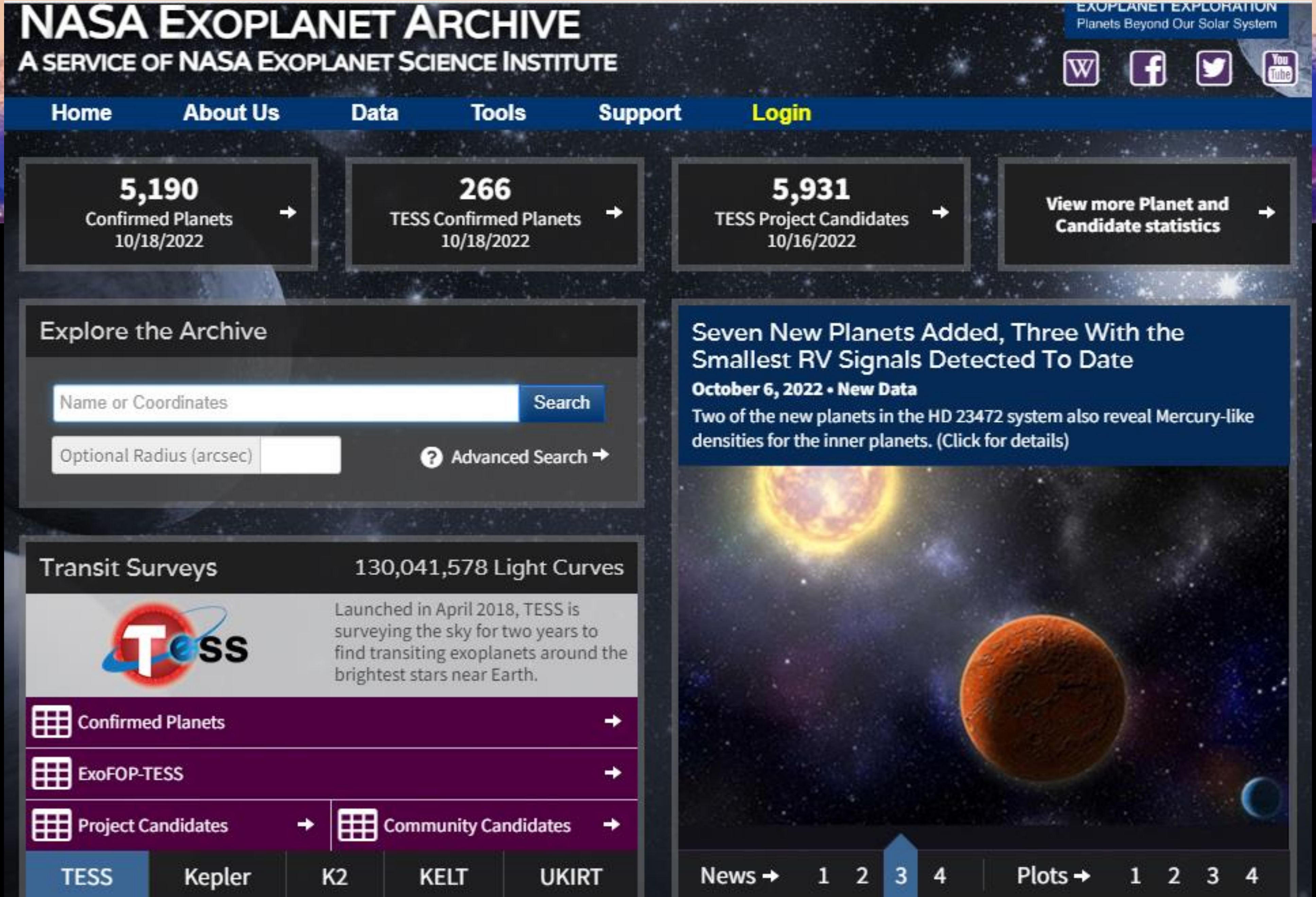
Mass $0.08M_\odot<M<0.5M_\odot$, luminosities $L \sim 10^{-3}-10^{-4}L_\odot$ and radius $0.1-0.9R_\odot$.

From thermonuclear reactions, only the combustion of hydrogen in the nucleus occurs.

Red dwarfs with $M<0.3M_\odot$ appear to be fully convective.

The pressure in the core is supported by a partially degenerate gas, the role of which increases in stars of lower masses (degenerate helium dwarfs).

Most red dwarfs are main sequence stars.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TESS
Launched in April 2018, TESS is surveying the sky for two years to find transiting exoplanets around the brightest stars near Earth.
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Community Candidates
TESS
Kepler
K2
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UKIRT
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Two of the new planets in the HD 23472 system also reveal Mercury-like densities for the inner planets. (Click for details)
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| ☑ | GJ 143 b | GJ 143 | 1 | 1 | 2 | Transit | 2019 | Transiting Exoplar | Published Confirmed | 0 | Dragomir et al. 2019 |
| ☑ | GJ 3090 b | GJ 3090 | 1 | 1 | 1 | Transit | 2022 | Transiting Exoplar | Published Confirmed | 0 | Almenara et al. 2022 |
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| ☑ | GJ 367 b | GJ 367 | 1 | 1 | 1 | Transit | 2021 | Transiting Exoplar | Published Confirmed | 0 | Lam et al. 2021 |
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| ☑ | HD 108236 b | HD 108236 | 1 | 1 | 5 | Transit | 2020 | Transiting Exoplar | Published Confirmed | 0 | Bonfanti et al. 2021 |
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| ☑ | HD 110082 b | HD 110082 | 1 | 2 | 1 | Transit | 2021 | Transiting Exoplar | Published Confirmed | 0 | Tofflemire et al. 2021 |
| ☑ | HD 110113 b | HD 110113 | 1 | 1 | 2 | Transit | 2021 | Transiting Exoplar | Published Confirmed | 0 | Osborn et al. 2021 |
| ☑ | HD 1397 b | HD 1397 | 1 | 1 | 1 | Transit | 2018 | Transiting Exoplar | Published Confirmed | 0 | Nielsen et al. 2019 |
| ☑ | HD 152843 b | HD 152843 | 1 | 1 | 2 | Transit | 2021 | Transiting Exoplar | Published Confirmed | 0 | Eisner et al. 2021 |
| ☑ | HD 152843 c | HD 152843 | 1 | 1 | 2 | Transit | 2021 | Transiting Exoplar | Published Confirmed | 0 | Eisner et al. 2021 |

The First Naked-Eye Superflare Detected from Proxima Centauri

Authors: Ward S. Howard, Matt A. Tilley, Hank Corbett, Allison Youngblood, R. O. Parke Loyd, Jeffrey K. Ratzloff, Octavi Fors, Daniel del Ser, Evgenya L. Shkolnik, Carl Ziegler, Erin E. Goeke, Aaron D. Pietraallo, Joshua Haislip, Nicholas M. Law

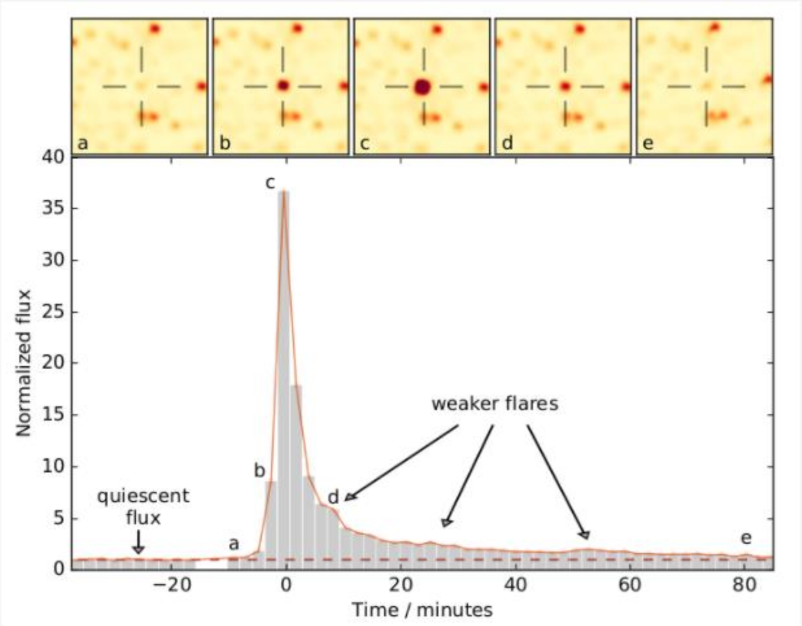
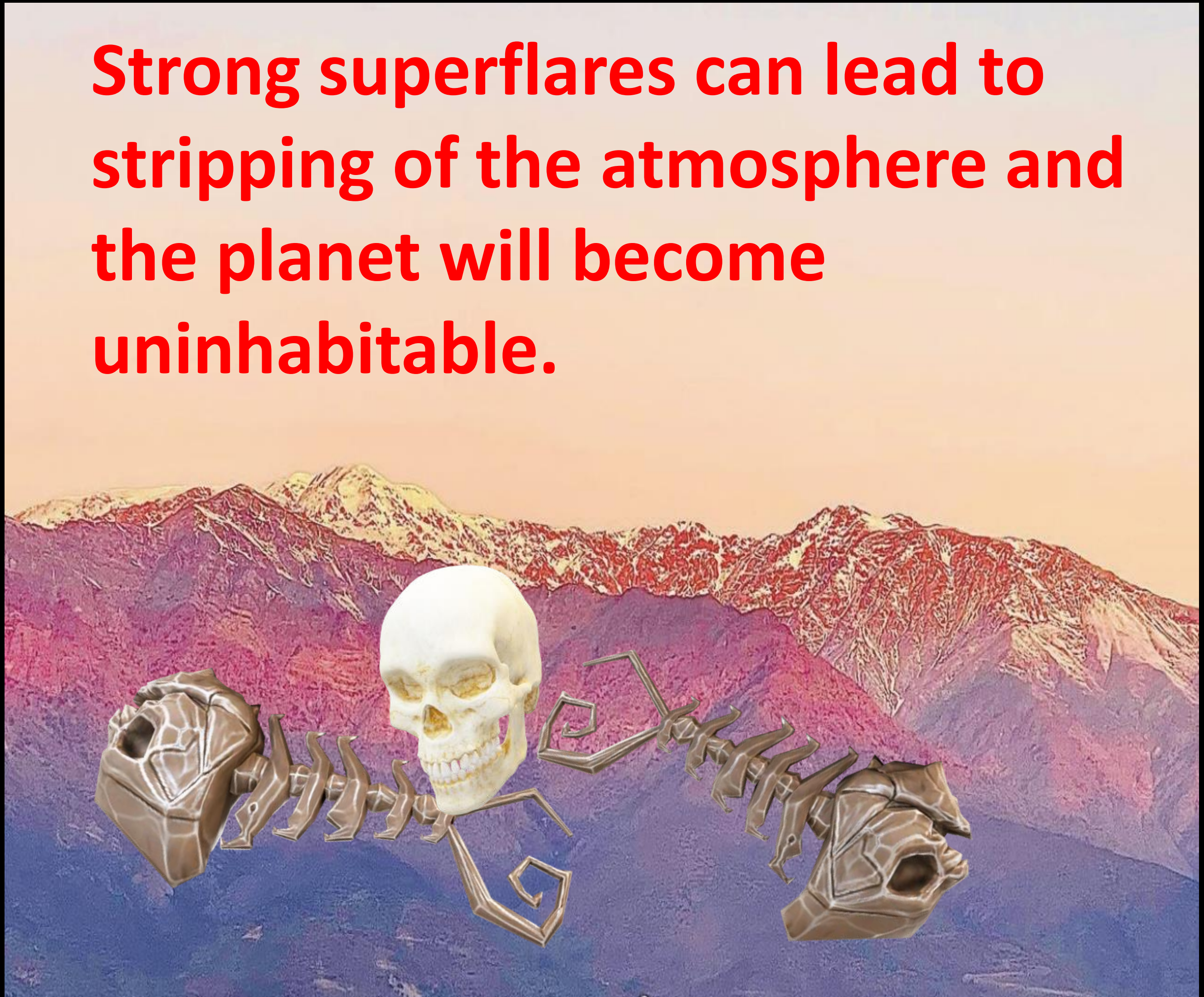



**Figure 1:** The light curve of Proxima Centauri as seen by the Evryscope around the time of the superflare. Three weaker (but still strong) flares were detected in the aftermath of the superflare, marked by arrows. *Figure 1 in the paper.*



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doi.org/10.1002/syst.201900039

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# Meteorite-Assisted Phosphorylation of Adenosine Under Proton Irradiation Conditions

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The abiotic phosphorylation of nucleosides is a major hurdle in origin-of-life studies. We suggest a plausible pathway for the synthesis of adenosine nucleotides from adenosine and $NaH_2PO_4$ under radiative conditions mimicking the solar wind in the presence of a meteorite of the aubrite-type. Hydroxyapatite also performed as a mineral heterogeneous phosphorus source. Adenosine polyphosphate derivatives and inorganic polyphosphates were detected in the reaction mixture, highlighting the high reactivity of the system. Both the total yield of adenosine nucleotides and the conversion of adenosine increased upon performing the irradiation in the presence of formamide ($NH_2CHO$) and aubrite. These experiments simulate conditions in space or on an early Earth fluxed by protons from the solar wind, potentially mimicking a plausible prebiotic phosphorylation scenario.

# Basic scenario of Solar (stellar) Flare

The Dynamo process of a magnetic field generation (via e.g. αΩ coupling accumulates the magnetic energy (of the toroidal field) inside the convective zone. Some of this magnetic energy can be carried by magnetic flux tubes floating up to the surface of the star and popping up in forms the spots (like in case of the Sun). The configuration of the magnetic field in the sunspot evolves over time and a flare appears when it becomes unstable. Then the Flare (as an expression of explosive instability) releases a part of the free energy of the magnetic field through the mechanism of reconnection of field lines. From general considerations, the energy yield of the flare must be related to the size of the magnetic spot. There are stars with much larger spots than on the Sun, thus, with more powerful Flares. (Solar Flare Magnetic Fields and Plasmas 2012th Edition, by Yuhong Fan, George Fisher, 2012). Such stars must exhibit faster rotation in order to support stronger αΩ-dynamo coupling.


Solar Flare: Definition & Effects | Study.com

# Model of Solar (stellar) Flare with nonlinear turbulent diffusion

- Following the line of spots related Superflares one might conclude that it could explain the origin of a wide class of observed Superflares on the numerous main sequence stars. Just assuming they are result of a faster rotation, which makes stronger $\alpha\Omega$ coupling generating higher fields in convection zones. Then the magnetic flux tubes carrying stronger field up to photo- and chromospheres would expand under the inner magnetic pressure to larger sizes of resulting spots. Data from KEPLER, TESS and EVRY provide a lot of room to specify the plausible scenarios of Flares including for occurring on the red dwarfs. For the latter case the target stars are likely all convective. That is requiring to broaden the arsenal of dynamo process kitchen, for example extending $\alpha\Omega$ coupling into $\alpha\alpha\Omega$ or into pure $\alpha\alpha$ version.
- The upper limit of energy yield for the spot related Superflares should be expected when the spot is too large. Then further way to interpret the origin of even stronger Superflare (SuperSuper Flare) is to invoke the generation of magnetic fields as high as capable to suppress the amplitude of turbulence in convective zone, thus, blocking the heat transfer routine vital for thermal balance of the star. Emergence of the thermal convection block would open the mechanism of "overheated boiler explosion". In such extreme cases our nonlinear scenario of dynamo required introduction of nonlinear quenching for the turbulent magnetic diffusion coefficient.

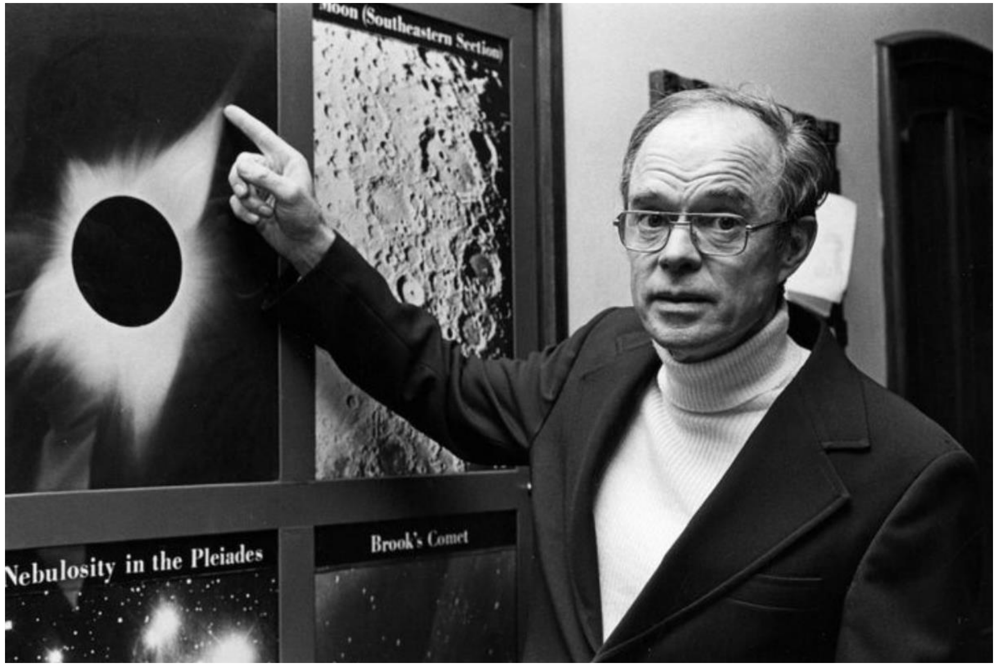
# PARKER DYNAMO

$$B_P \xrightarrow{\Omega} B_T$$

Differential rotation

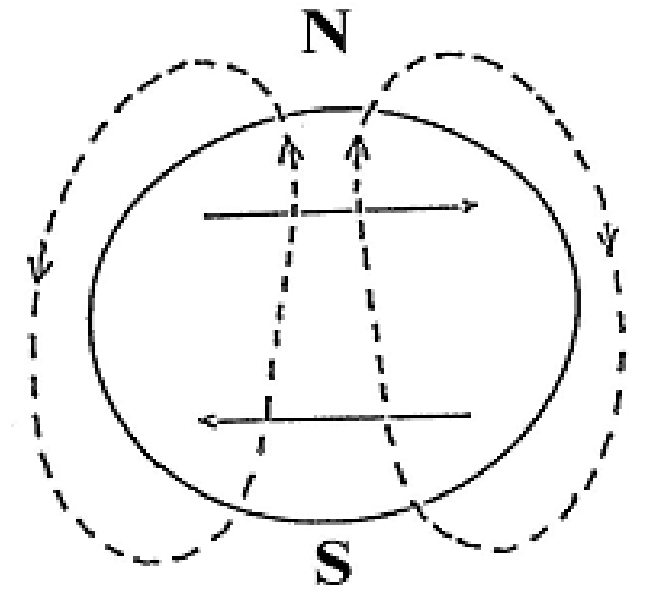
$$B_T \xrightarrow{\alpha} B_P$$

Helicity




Parker presented a scheme for such dynamo as follows.

A toroidal magnetic fields is produced from the poloidal field by the action of differential rotation. The inverse process of transforming toroidal magnetic field into poloidal field is realized by the action of alpha-effect.



# Mean Field Dynamo Equation

**Mean field**

**Coefficient of turbulent magnetic diffusivity**

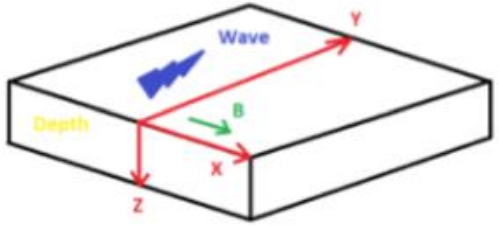
$$\frac{\partial \vec{B}}{\partial t} = \mathrm{rot}\left(\alpha \vec{B}\right) + \mathrm{rot}\left[\vec{V} \times \vec{B}\right] + \beta \Delta \vec{B}$$

**Average coefficient of α-effect**

$$u_r(r,\theta,t)\mathbf{e}_r + u_\theta(r,\theta,t)\mathbf{e}_\theta + \Omega(r,\theta) r \sin(\theta)\mathbf{e}_\phi$$

**Meridional circulation**

**Differential rotation**




$$\frac{\partial A}{\partial t} = \langle\alpha\rangle B + \langle\beta\rangle \frac{\partial^2 A}{\partial y^2},$$

$$\frac{\partial B}{\partial t} = -\langle\frac{dV_x(y)}{dz}\rangle \frac{\partial A}{\partial y} + \langle\beta\rangle \frac{\partial^2 B}{\partial y^2}.$$

$$\alpha = \frac{\alpha_0}{1 + B_0 B^2}$$

$B_0$ – constant

We introduce nonlinear turbulent diffusion

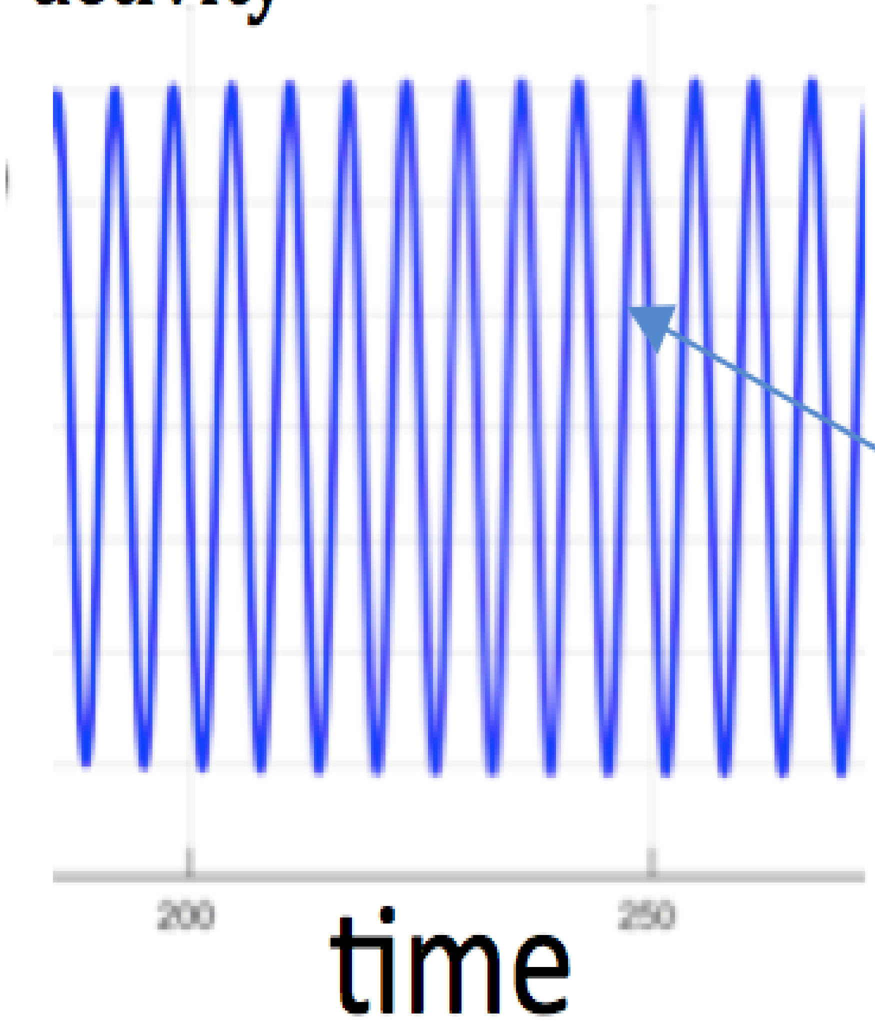
$B_1$ – constant

$$\beta = \frac{\beta_0}{1 + B_1 B^2}$$

## *Space weather around the Exoplanets*

One of the main goal of very active program of seach for the exoplanets is focused those among them with habitabity criteria based on the important parameters of thermal conditions and liquid water favorable, similar to those on Earth. The detection of superflares on many stars, as hosts of planets, makes it important to take into account also the flares intensity criterion. On the one hand, too high flare activity might destroy the atmosphere, but on the other hand, too low flare activity may be insufficient to provide a critically needed radiation for prebiotic chemistry and thus preclude the emergence of life. Studies of the nearest red dwarf star, Proxima Centauri have led a few years ago to the seemingly lucky discovery of nearest valuable object for Astrobiology. However, more recently observations have shown that this star has a fairly high flare activity (Ward S. Howard et al 2018 ApJL 860 L30), which can be incompatible with chance for the emergence of life there.

Regime of periodical magnetic activity




Amplitude of magnetic field

Regime of fast increasing of magnetic field - Superflare