Lattice Energy LLC

Mechanism for ultrahigh energy cosmic rays

Widom-Larsen-Srivastava first published physics in 2008

Many-body collective effects in magnetic flux tubes accelerate particles

Herein we calculate one-shot, center-of-mass mean acceleration energies for protons in collapsing protoneutron stars (5.5×10^{18} eV), two cases for black hole accretion disks (2.2×10^{17} eV and 0.9×10^{19} eV), and for the jet base of a supermassive black hole (2.2×10^{21} eV)

Supernova blast remnant

Cat's Eye nebula - NASA (Hubble)

Lewis Larsen

President and CEO

January 1, 2016

Magnetic flux tubes on Sun

Image in ultraviolet - TRACE/NASA

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Summary

W-L-S equations for calculation of center-of-mass acceleration energy

Accelerated particles center-of-mass energy for exploding flux tube

$$e\mathcal{V} \approx (30\ \mathrm{GeV}) \left(\frac{B}{\mathrm{kG}}\right) \left(\frac{\pi R^2}{\Lambda - \mathrm{km}}\right)$$

Eq. (20) in *Pramana* paper (2010)

- ✓ In 2008 (*arXiv*) and 2010 (*Pramana*), we derived and published approximate, rule-of-thumb formulas for calculating estimated one-shot, mean center-of-mass acceleration energies for charged particles present in plasma-filled magnetic flux tubes (also called "coronal loops") for two cases: (1) steady-state and (2) explosive destruction of a flux tube (this second case is a subset of "magnetic reconnection" processes)
- ✓ These relatively straightforward relationships were discovered in the process of elaborating and extending our theory of many-body collective effects and electroweak reactions involving protons and electrons in condensed matter systems on small length-scales (where short-range, ultra-high strength electric fields dominate) to analogous, much larger-scale electromagnetic systems in which magnetic fields dominate and provide input energy required to drive certain types of electroweak processes, produce pair plasmas, and create elemental nucleosynthesis
- ✓ Our simple equations for magnetic flux tubes are robust and scale-independent. They consequently have broad applicability from exploding wires (which in early stages of explosion comprise dense dusty plasmas), lightning, to solar flux tubes and other astrophysical environments that are characterized by vastly higher magnetic fields; these include many other types of stars besides the Sun, neutron stars, magnetars, and regions located near black holes and active galactic nuclei

Summary

Many-body collective effects enable electron-proton electroweak reactions

Collective many-body electroweak reactions require input energy

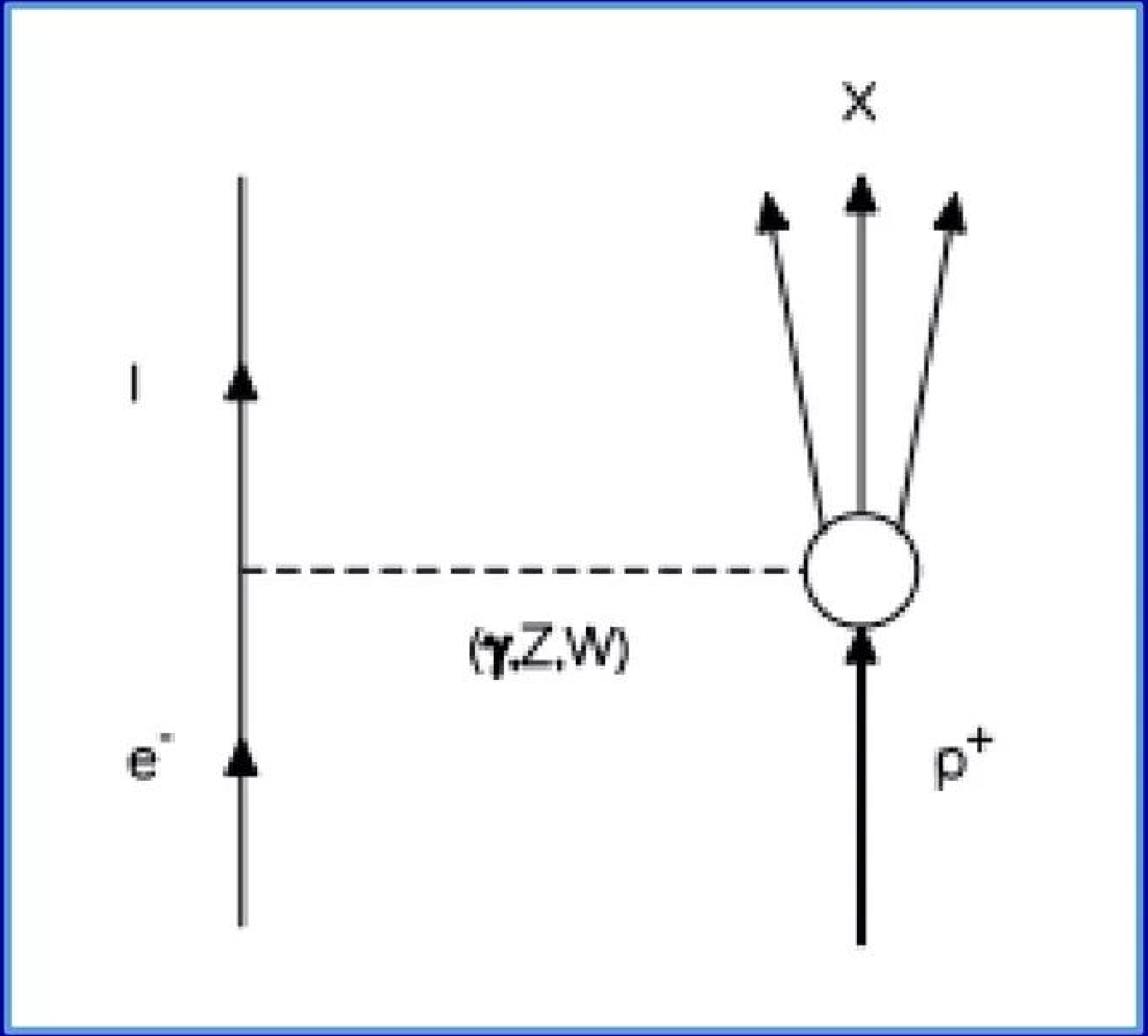
$$e^{-*} + p^{+} \rightarrow n + \nu_e$$
$$e^{-} + p^{+} \rightarrow lepton + X$$

When electric fields dominate

Magnetic fields dominate at very high energies in plasmas

- ✓ FIG.2 shows the electro-weak boson exchange Feynman diagram for electron-proton scattering in colliding electron and proton beams inside a plasma-filled magnetic flux tube at high energies
- ✓ Expression { $e^{-} + p^{+} \rightarrow l + X$ } includes photon γ and Z exchange wherein the final state lepton is an electron for the case of photon γ or Z exchange and the final state lepton is a neutrino for the case of W^{-} exchange. On an energy scale of ~300 GeV, all of these exchange processes have amplitudes of similar orders of magnitude
- ✓ Solar flare or coronal mass ejecting event is thereby accompanied by an increased emission of solar neutrinos over a broad energy scale as well as relativistic protons, neutrons and electrons. Full plethora of final X states including electron, muon and pion particle anti-particle pairs should also be present in such events

FIG. 2: Boson exchange diagrams for electron-proton scattering into a lepton plus "anything"



"High energy particles in the solar corona"
A. Widom, Y. Srivastava, and L. Larsen
arXiv:nucl-th/0804.2647v1 (2008)

Summary

Many-body collective effects enable electron-proton electroweak reactions

Collective many-body electroweak reactions require input energy

$$e^{-*} + p^{+} \rightarrow n + \nu_e$$ ← Electric fields dominate

$$e^{-} + p^{+} \rightarrow lepton + X$$ ← Magnetic fields dominate

- ✓ Conversion of magnetic field energy into relativistic particle kinetic energy via a Faraday law voltage pulse is collective in that the magnetic flux in the core of the vortex depends on the rotational currents of *all* of the initial protons and electrons
- ✓ "On the energy scale $W_{\text{magnetic}} \ll 300$ GeV of Eq.(13), the weak interaction $p^{+} e^{-}$ processes Eq.(7) that produce neutrons proceed more slowly than the purely electromagnetic $p^{+} e^{-}$ processes. Nevertheless one finds appreciable neutron production in the solar corona. The production of neutrons among the protons allows for the creation of nuclei with higher mass numbers via neutron capture nuclear reactions and subsequent beta decays." arXiv:nucl-th/0804.2647v1
- ✓ Relativistic neutrons produced by high-energy electroweak $e + p$ reactions in plasma-filled magnetic flux tubes will have low capture cross-sections on seed elements per the 1/v proportionality rule. Nonetheless, neutron-driven nucleosynthesis (albeit at vastly lower rates vs. supernovas) akin to astrophysical *r*- and *s*-processes can occur in and near such commonplace magnetic structures found in varied astrophysical environments including stars' atmospheres, on accretion disks, and near black holes
- ✓ Nucleosynthesis occurs in regions besides stellar cores and supernova explosions

Summary

W-L-S particle acceleration works in many astrophysical environments

- ✓ W-L-S many-body collective particle acceleration mechanism agrees with published experimental data from terrestrial exploding wire experiments, production of low-energy neutrons in atmospheric lightning (Gurevich *et al. PRL* 2012), and energetic particles emitted from the Sun. Successfully explains observations of 300 - 500 GeV protons and GeV neutrons produced in some large solar flares (CERN L3+C group and BAKSAN data). "We do not know of any other process that could accelerate charged particles to beyond even a few GeV, let alone hundreds of GeVs." *Pramana*
- ✓ This "mechanism also naturally explains a variety of observed experimental results such as unexpected nuclear transmutations and high-energy cosmic rays from the exterior of the Sun or any other astronomical object endowed with strong enough magnetic activity such as active galactic nuclei [e.g., Mrk 231]." *Pramana* (2010)
- ✓ Current best estimate for half-life of a free neutron at very low kinetic energy is ~15 minutes. Traveling at 0.999999c, GeV-energy neutrons produced via the collective electroweak $e + p$ reaction will, thanks to relativistic time dilation, have an apparent half-life of ~173 hours from the reference frame of an outside observer. In the case of GeV neutrons emitted from solar flares, 99^{+} % will not decay by the time they reach earth and can thus be detected. By contrast, only 5×10^{-16} of the original flux of GeV-energy solar neutrons will remain after they have traveled a light year away from a given source. By then, almost all of them will have decayed and contributed to the cosmic flux of high-energy electrons, protons, and antineutrinos. GeV-energy neutrons from closest star system, Alpha Centauri, could not be detected on Earth

Summary

W-L-S particle acceleration mechanism useful for understanding sources

- ✓ Identification of ultimate sources and nature of charged particle acceleration mechanisms that create ultrahigh high energy cosmic rays, as well as providing a detailed explanation for distinctive features of the shape of the cosmic-ray energy spectrum, e.g. "knee" and "ankle", have been longstanding questions in astrophysics
- ✓ Herein we show how plasma-filled magnetic flux tubes likely occur in many different astrophysical systems from relatively small objects (neutron stars and magnetars) to relatively large objects (accretion disks and jet bases of supermassive black holes). When these ordered magnetic structures explode (reconnection, flares), enormous amounts of magnetic energy are converted into kinetic energy of charged particles present inside exploding flux tubes. Using reasonable parametric assumptions, we calculate one-shot, center-of-mass acceleration energies for protons in collapsing protoneutron stars (5.5×10^{18} eV), two cases for BH accretion disks (2.2×10^{17} eV and 0.9×10^{19} eV), and finally for the jet base of a supermassive black hole (2.2×10^{21} eV)
- ✓ What all these numbers suggest, including those for the Sun, is that W-L-S particle acceleration mechanism for magnetic flux tubes can create cosmic ray particles at energies that span the entire cosmic-ray energy spectrum from top to bottom. This argues that commonplace flux tubes may well play a significant role in generating the observed cosmic ray energy spectrum and would be consistent with apparent overall anisotropy of sources at all but the very highest particle energies. That said, we think a number of different acceleration mechanisms likely contribute to entire spectrum, including shock acceleration and perhaps exotic mechanisms such as evaporation of gaseous winds from neutron stars (Widom *et al*. arXiv:1410.6498v2 - 2015)

Importance of acceleration mechanisms for UHE cosmic rays

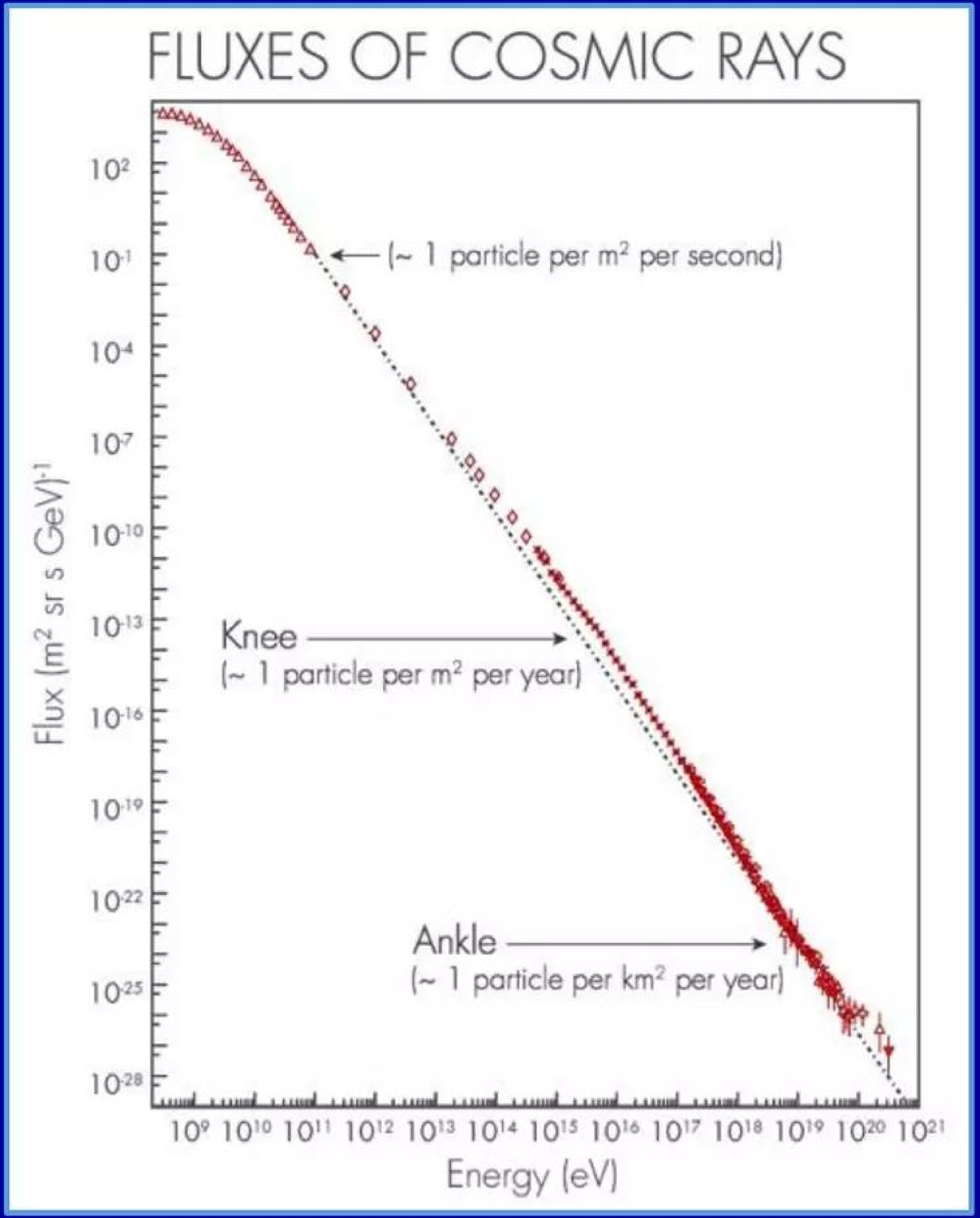
Quotes from Etienne Parizot's 2014 UHE CR paper in Nuclear Physics B

- ✓ "The main reason why the origin of cosmic rays(CRs) is still unknown, one century after their discovery, is that they are charged nuclei isotropized by the turbulent magnetic field in the Galaxy to such a high degree that their observed flux is essentially identical in all directions, with no sources or decisive hot spots identified in any region the sky (cf. below, Sect. 2)."
- ✓ "The longstanding quest for the origin of CRs is not only motivated by the desire to obtain a more complete description of the Galactic ecology. It is also related to the wish to better understand particle acceleration in general, which is a key ingredient of the modeling of high-energy astrophysical sources."
- ✓ "Another way to obtain additional constraints about the cosmic-ray sources is to study the highest-energy end of the spectrum, where the acceleration mechanisms appear to be the most challenging. While the so-called ultra-high-energy cosmic rays (UHECRs), with energies above $\sim 10^{19}$ eV, are most likely to have an extragalactic origin, their much larger magnetic rigidity than the low-energy GCRs may allow the observation of distinct sources in the sky, and provide more direct information about their nature. Moreover, the study of the transition between the Galactic and extragalactic cosmic rays (EGCRs) is important to derive constraints about the highest-energy particles accelerated in our Galaxy, which might in turn challenge the most popular scenarios for the origin of GCRs."

Cosmic-ray energy spectrum: flux vs. energy in eVs

Quoted from review article by A. A. Watson (2014)

"In many books on high-energy astrophysics a plot of the cosmic-ray energy spectrum similar to that of figure 1 [4] will be found: the flux falls by 25 orders of magnitude over 11 decades of energy. By comparison with a plot of the electromagnetic spectrum over the same span, this spectrum is remarkably featureless. There is an increase of slope at about 3 - 5 × 10^{15} eV, known as the 'knee', where the flux of particles is about one per square metre per year. The spectrum flattens again near ~ 4 ×10^{18} eV, the 'ankle', above which only a few particles arrive per square kilometre per year. Recently a second knee in the spectrum of particles with greater than average mass has been reported at ~ 8 x 10^{16} eV, about 26 times higher than the knee and thus consistent with the idea that knee features are rigidity related [5]. In this article I will concentrate on the higher-energy region where the flux becomes even lower. It is commonly maintained that most particles above the ankle have an extragalactic origin although this is by no means well-established and debate rages as to how the ankle can be explained. There is also serious discussion of the possibility that even the highest-energy particles might have been produced in our galaxy, perhaps in association with a gamma-ray burst or a magnetar, about 105 years ago [6, 7]."



Credit: Olena Shmahalo/Quanta Magazine; original data via S. Swordy, U. Chicago

Key reactions in Widom-Larsen-Srivastava theory

Many-body collective processes produce neutrons and other particles

Neutrons are captured by elements which trigger nuclear transmutation reactions

Many-body collective production of neutrons, neutrinos, and other particles:

Collective many-body processes require external input energy

$$e^{-*} + p^{+} \rightarrow n + \nu_e$$ Electric fields dominate

$$e^{-} + p^{+} \rightarrow lepton + X$$ Magnetic fields dominate

Electroweak particle reactions produce neutrons (n) and neutrinos (ν_e)

Transmutation of elements and nucleosynthesis outside of stellar cores:

Neutron capture-driven LENR transmutation reactions

$$n + (Z, A) \rightarrow (Z, A+1)$$ Neutron capture

$$(Z, A+1) \rightarrow (Z + 1, A+1) + e_{\beta}^{-} + \overline{\nu}_e$$ Beta-minus decay

Unstable neutron-rich products of neutron captures will undergo beta$^-$ decay

Create heavier stable isotopes or heavier elements along rows of Periodic Table

LENRs operate like r- and s-process in condensed matter

Electroweak $e^- + p^+$ reactions can occur in domains besides supernovae

- ✓ In our *European Physical Journal C - Particles and Fields* paper (2006) we explained how many-body collective quantum effects in condensed matter can produce ultralow energy neutrons via the electroweak $e^- + p^+$ reaction in tabletop apparatus under very modest microphysical conditions. Results of subsequent neutron-catalyzed transmutation reactions resemble astrophysical s- and r-processes only at temperatures vastly lower than with stars
- ✓ We next analyzed and explained case of LENR transmutation products observed in high pulsed-current exploding wires with cylindrical geometries; note that collective many-body magnetic effects (B-fields) dominate therein. This case differs from condensed matter chemical cells wherein micron-scale, nuclear-strength local E-fields and local breakdown of Born-Oppenheimer are much more important
- ✓ Once one understands LENRs in magnetically dominated collective systems, lightning discharges are conceptually like a big exploding wire up in the sky. Moreover, predicted electroweak $e^- + p^+$ reactions inside solar coronal loops and flares is direct extension of the same physics principles

Russian data supports our e^- + p^+ mechanism in lightning

"Strong flux of low-energy neutrons produced by thunderstorms"
A. Gurevich *et al.*, *Physical Review Letters* 108 pp. 125001 - 4 (2012)

http://prl.aps.org/abstract/PRL/v108/i12/e125001

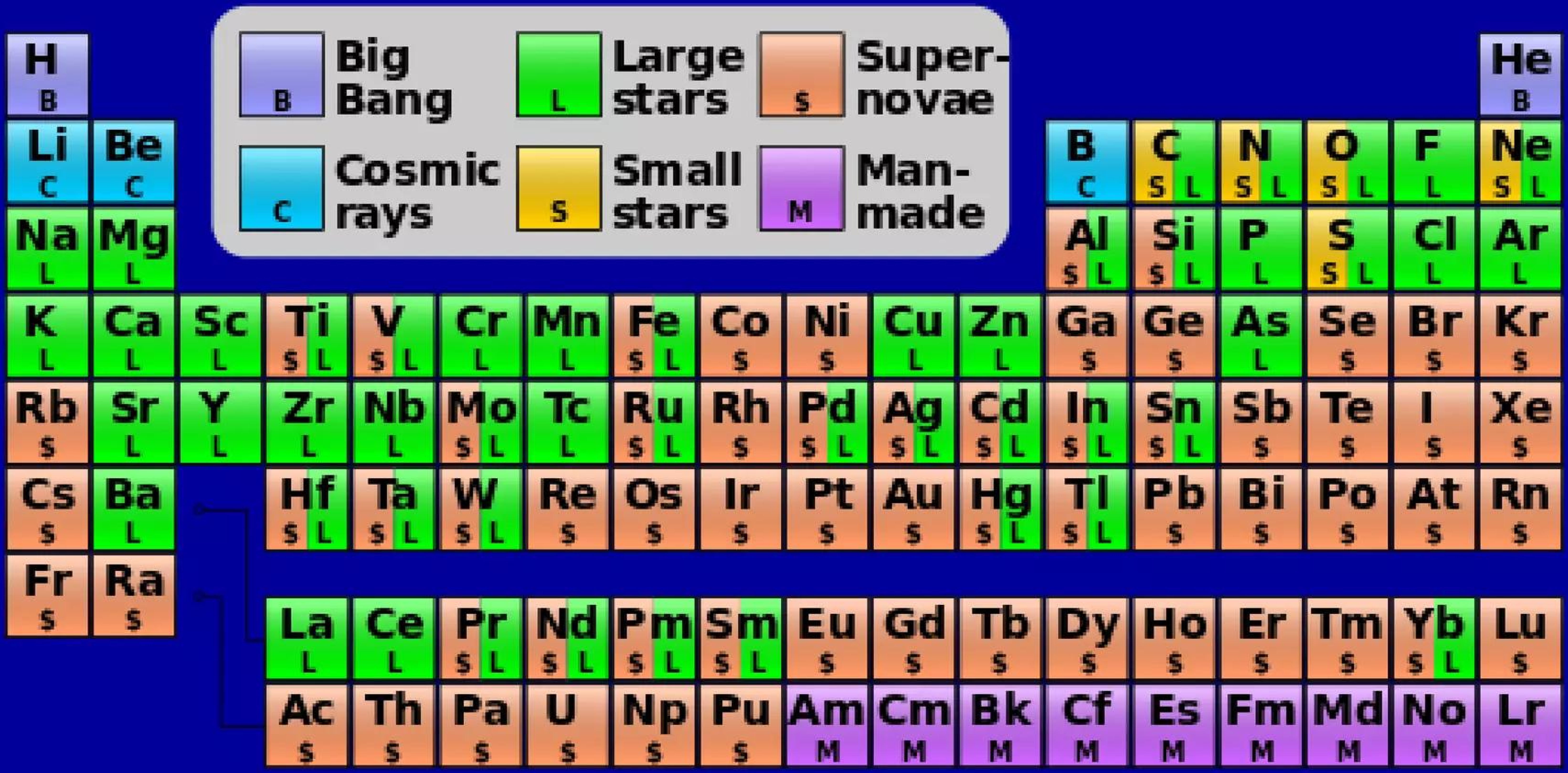
Abstract: "We report here for the first time about the registration of an extraordinary high flux of low-energy neutrons generated during thunderstorms. The measured neutron count rate enhancements are directly connected with thunderstorm discharges. The low-energy neutron flux value obtained in our work is a challenge for the photonuclear channel of neutron generation in thunderstorm: the estimated value of the needed high-energy γ-ray flux is about 3 orders of magnitude higher than that one observed."

Lattice comments: experimental data collected by Gurevich *et al.* and published in *Phys Rev Lett* is the first instance in which: (a) observed neutron fluxes associated with lightning discharges could be accurately counted, well-estimated quantitatively, and temporally correlated with lightning discharges; and (b) better insights were achieved into energy spectra of such lightning-produced neutrons. Importantly, size of low-energy neutron fluxes observed by Gurevich *et al.* are much too large to be explained by photonuclear mechanism (which in recent years was thought by many to explain neutron production in lightning channels). Given that fusion processes had already been decisively ruled-out in years prior to a recent rise in popularity of the photonuclear mechanism (see L. Babich & R. R-Dupre - 2007), the Widom-Larsen-Srivastava many-body, collective magnetic e^- + p^+ weak-interaction mechanism is the only theoretical approach that can successfully explain key features of this new data

Old paradigm: stars create most elements in Periodic Table

Big Bang and cosmic ray spallation produce all the remaining elements

r- & s-processes produce all elements not created by Big Bang, CRs, or spallation

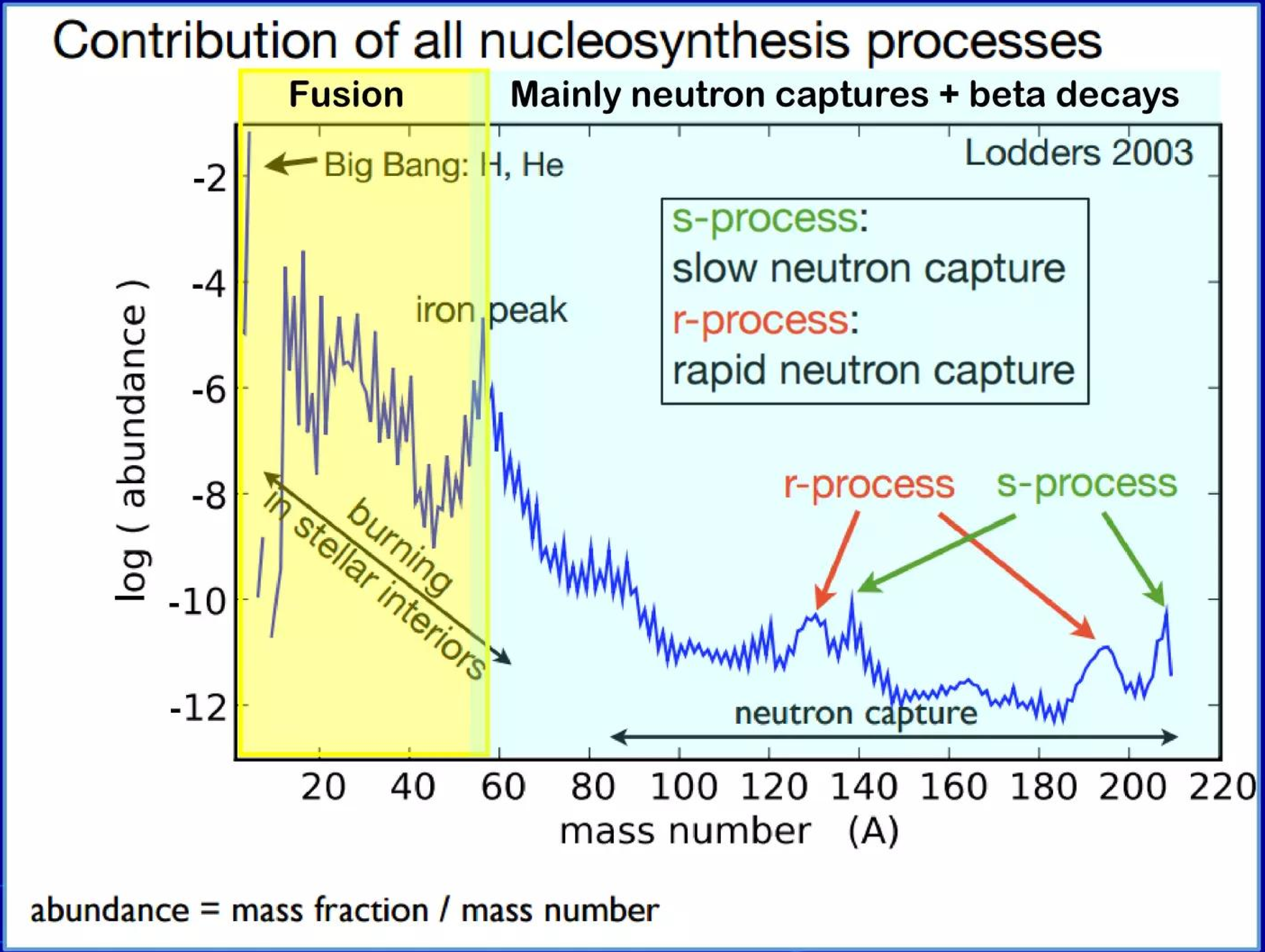


Credit: Cmglee via Wikipedia

Present astrophysical paradigm about nucleosynthesis

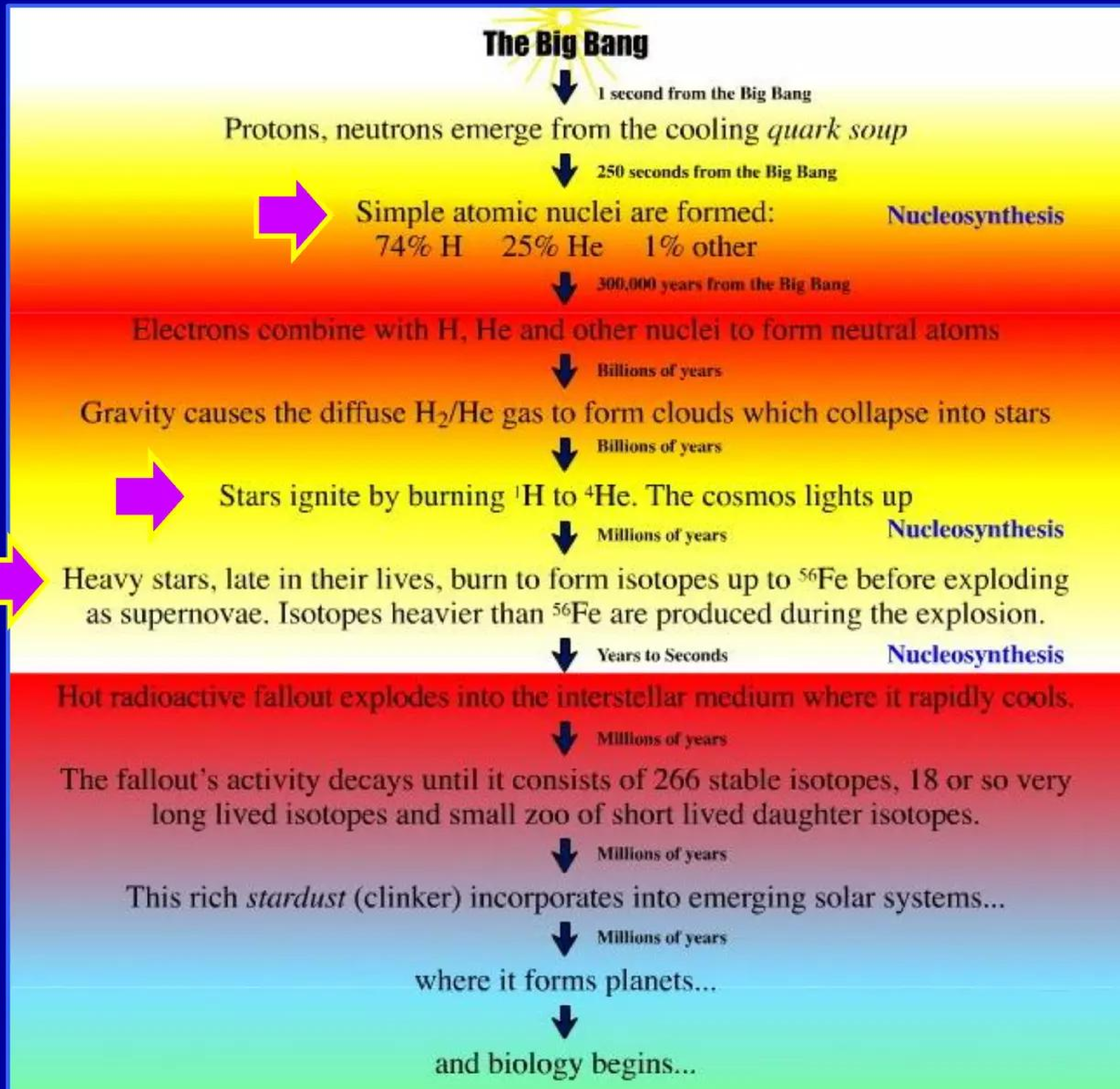
Depending on mass, Big Bang, fusion, s-/r-processes create elements

Fusion, s-/r-processes happen in stars - little nucleosynthesis occurs elsewhere



Adapted after Lodders (2003)

Present astrophysical paradigm about nucleosynthesis



http://www.meta-synthesis.com/webbook/32_n-synth/nucleosynthesis.html

New: nucleosynthesis occurs well-outside of stellar cores

Elemental transmutations go left-to-right across rows of Periodic Table

Neutron-catalyzed transmutations can produce elements heavier than Hydrogen

PRAMANA
journal of
physics

A primer for electroweak induced low-energy nuclear reactions

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Abstract. Under special circumstances, electromagnetic and weak interactions can induce low-energy nuclear reactions to occur with observable rates for a variety of processes. A common element in all these applications is that the electromagnetic energy stored in many relatively slow-moving electrons can – under appropriate circumstances – be collectively transferred into fewer, much faster electrons with energies sufficient for the latter to combine with protons (or deuterons, if present) to produce neutrons via weak interactions. The produced neutrons can then initiate low-energy nuclear reactions through further nuclear transmutations. The aim of this paper is to extend and enlarge upon various examples analysed previously, present order of magnitude estimates for each and to illuminate a common unifying theme amongst all of them.

Keywords. Nuclear transmutations; low-energy nuclear reaction; electroweak.

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W-L-S theory spans vast range of length-scales and energies

E-fields in condensed matter vs. B-field particle acceleration in plasmas

Short-range collective electric field effects dominate

Longer-range collective magnetic field effects begin to dominate

Long-range collective magnetic field effects dominate

local electric fields

Organized magnetic fields with plasmas

Low - medium electric and/or ion currents

Regime: ultralow energy neutron reactions (LENRs) in condensed matter

$e^* + p^+ \rightarrow$ 1 neutron + neutrino or $e^* + d^+ \rightarrow$ 2 neutrons + neutrino

Neutron production, capture, release energy, and transmutation products

- Microorganisms – biological transmutations by certain types of earthly bacteria & fungi
- Pressure gradients across membranes – e.g., Iwamura, Li, & Arata-Zhang - gas phase
- Current-driven P&F-type chemical cells - liquid phase; glow discharge cells - gas phase
- Laser-triggered chemical cells – e.g., Letts, Cravens, Violante, etc. - liquid or gas phase

High currents: electrons and/or ions

- RF-triggered dusty plasmas - gas phase
- Current-driven dusty plasmas - gas phase
- Vacuum diodes – e.g. Proton-21, Kiev, Ukraine, Sandia NL (US) in 1970s - gas phase
- Exploding wires – e.g., Wendt & Irion, Chicago 1922; Z-pinch, Sandia NL - gas phase
- Piezoelectric and pyroelectric processes in solid-state materials – Carpinteri, Naranjo
- Magnetic flux compression generators, e.g. US (LANL), Russia
- Lightning (terrestrial, planetary, nebular), especially in dusty environments – e.g., Dwyer
- ULMN-catalyzed subcritical fission reactors (<<< nuclear waste) - reprocess old wastes

Higher fluxes of neutrons

Scales-up to very large length scales — Huge range of magnetic field strengths

Mega-scale currents

Mixed regime: high energy particle reactions and/or LENRs on dust

Magnetic effects dominate large length-scale plasmas: $e^- + p^+ \rightarrow$ *lepton* + *X*

- Stars - additional nuclear reactions occur in photospheres, flares, and further out in coronas
- Dusty, hydrogen-rich nebular plasma clouds exposed to stellar photon and particle radiation
- Magnetars/active galactic nuclei: W-L mechanism can in theory create UHE TeV cosmic rays

>>>> fluxes

~0 eV Ultra low energy neutrons .... MeV neutrons ...GeV... TeVs ...EeVs

Increasing neutron and charged particle energies

Many-body collective effects span vast range of length-scales

W-L-S theory and its collective effects extend from LENRs in condensed matter regimes to environments found in high-current exploding wires, e.g., large wire inductors, as well as up to large-length-scale, magnetically dominated regimes that occur in astrophysical systems

Length Scale	Type of System	Electromagnetic Regime	Many-body Collective Phenomena	Comment
Submicron	Certain earthly bacteria and some fungi	Very high, short-range electric fields	Transmutations, high level of gamma shielding	Obtain unavailable trace elements; survive deadly gamma or X-ray radiation
Microns	Hydrogen isotopes on metallic surfaces	Very high, short-range electric fields on solid substrates	Transmutations, high level of gamma shielding, heat, some energetic particles	This regime is useful for small-scale commercial power generation
Microns to many meters	Exploding wires, planetary lightning	Dusty plasmas: mixed high-current and high local magnetic fields	Transmutations, 'leakier' gamma shielding, heat; X-rays up to 10 keV, larger energetic particle fluxes	This regime is useful for large-scale commercial power generation
Many meters to kilometers	Outer layers and atmospheres of stars (flux tubes)	Ideal and dusty plasmas: high mega-currents of electrons, protons, and ions inside large-scale, ordered magnetic structures with substantial internal fields	Energetic charged particles and neutrons (MeVs to EeVs), X-rays, gamma-ray bursts, and ultra-high-energy cosmic rays (TeVs to EeVs)	Provides explanation for heating of solar corona and radioactive isotopes in stellar atmospheres
Up to several AU (distance from earth to Sun)	Neutron stars and active galactic nuclei in vicinity of compact, massive objects (black holes)			Provides mechanism for creating extremely high energy particles in plasma-filled magnetic flux tubes with sufficient field strengths

Note: mass renormalization of electrons by high local E-fields not a key factor in magnetically dominated regimes on large length scales

Many-body collective magnetic effects accelerate particles

Magnetic field energy collectively transferred to charged particles & ions

- ✓ Please note that in magnetically ordered astrophysical plasmas (which typically occur on relatively large length-scales, as opposed to nanometers to microns for LENR processes in condensed matter) W-L theory involves many-body collective magnetic effects. Also note that under these conditions, neutrons produced via weak interactions per W-L theory are not necessarily ultralow energy (ULE); in stellar magnetic flux tubes and much more energetic events such as violent flare explosions, neutrons and varying array of particles (e.g., protons, positrons) may be created at energies ranging from GeVs to TeVs and all the way to EeVs (10^{18} eV)
- ✓ With dusty astrophysical plasmas in regions where average temperatures are such that intact embedded dust grains and nanoparticles (which then may be strongly charged locally) can maintain integrity for a time therein, W-L condensed matter LENRs producing ~ULE neutrons may also occur on surfaces of such particles
- ✓ Quoting from conclusions in our *Pramana* paper: "Three seemingly diverse physical phenomena, viz., metallic hydride cells, exploding wires and the solar corona, do have a unifying theme. Under appropriate conditions which we have now well delineated, in all these processes electromagnetic energy gets collectively harnessed to provide enough kinetic energy to a certain fraction of the electrons to combine with protons (or any other ions present) and produce neutrons through weak interactions. The produced neutrons then combine with other nuclei to induce low-energy nuclear reactions and transmutations."

Quotation from 2010 “Primer” paper published in *Pramana*

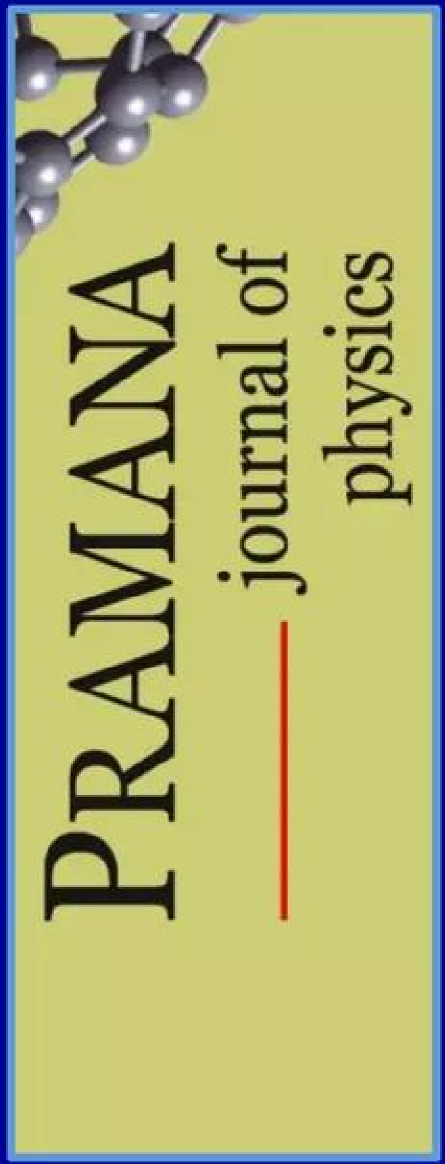
W-L-S mechanism explains production of GeV protons in big Solar flares

Explosion or disintegration of solar flux tube also called “magnetic reconnection”

“Quite recently [5], another application of the magnetic mode inducing LENR has been made to unravel the mystery surrounding the observed particle production and nuclear transmutations in the solar corona and the solar flares [15 - 23]. Spectacular pictures of flux tubes are now available [24] showing giant magnetic flux tubes exiting out of one sunspot and entering into another. We showed theoretically [5] how these could lead to steady LENR. In fierce solar flares, we found that as a flux tube disintegrates it generated electric fields strong enough to accelerate electrons and protons toward each other with the centre of mass energy of 300 GeV, equivalent to the highest energy electron-proton colliding beam (HERA) built on Earth. For a strong solar flare which occurred on 14 July 2000, we computed the flux of muons which reached Earth. Our theoretical flux agrees quite nicely with the experimental data from the L3+C Collaboration at LEP through their observation of high-energy muons produced in coincidence with this huge flare [23].”

Exploding magnetic flux tubes accelerate charged particles

Eq. 20 calculates the mean acceleration energy for a flux tube explosion



On the other hand, for a spectacular solar flare which lasts for a time Δt, the loss of magnetic flux tube would yield a mean Faraday law acceleration voltage $\bar{V}$ around the walls given by

$$\bar{V} = \frac{\Delta\Phi}{c\Delta t}. \tag{18}$$

Inserting $\Delta\Phi = B\Delta S$ as before, where B denotes the mean magnetic field before the explosion and ΔS is the inner cross-sectional area of the flux tube, we have for the mean acceleration energy

$$e\bar{V} = (eB)\frac{\Delta S}{\Lambda}, \quad \text{where } \Lambda = c\Delta t. \tag{19}$$

For a cylindrical geometry, we can again rewrite it in a useful form

$$e\bar{V} \approx (30\ \text{GeV})\left(\frac{B}{\text{kG}}\right)\left(\frac{\pi R^2}{\Lambda - \text{km}}\right). \tag{20}$$

For a coronal mass ejecting coil exploding in a time $\Delta t \approx 10^2$ s, we may estimate

$$R \approx 10^4\ \text{km}$$

$$B \approx 1\ \text{kG}$$

$$\Lambda \approx 3 \times 10^7\ \text{km}$$

$$e\bar{V} \approx 300\ \text{GeV}. \tag{21}$$

Physically, it corresponds to a colliding beam of electrons and protons with a centre of mass energy of 300 GeV. More on these matters can be seen in §5.

"A primer for electro-weak induced low energy nuclear reactions", Y. Srivastava, A. Widom, and L. Larsen, *Pramana - Journal of Physics* 75 pp. 617 - 637 (2010)

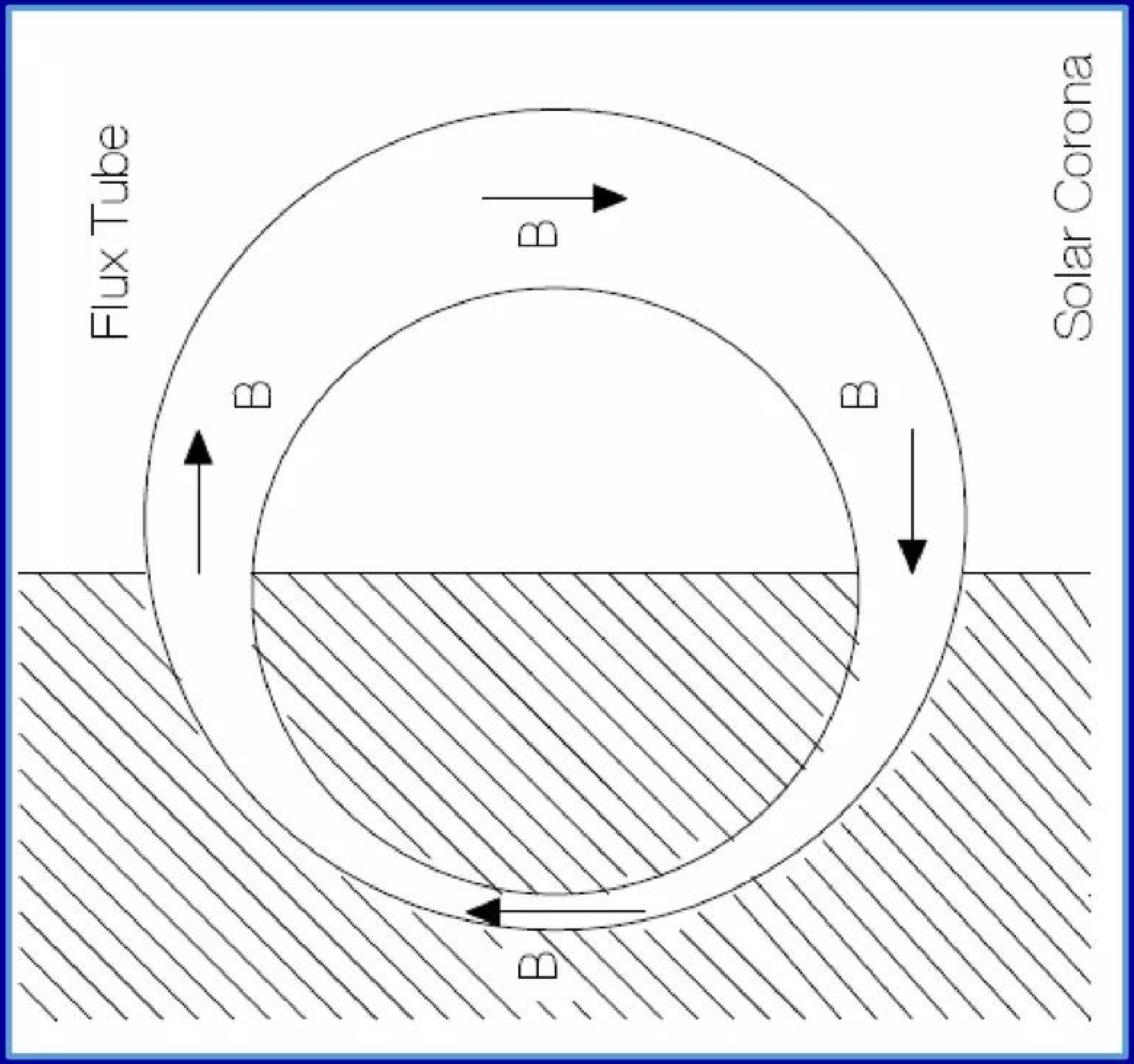
W-L-S posits electroweak $e^- + p^+$ reactions in coronal loops

Mechanism will accelerate protons and electrons in magnetic flux tubes

Neutron production and nucleosynthesis can occur outside dense cores of stars

Widom, Srivastava & Larsen (2008)

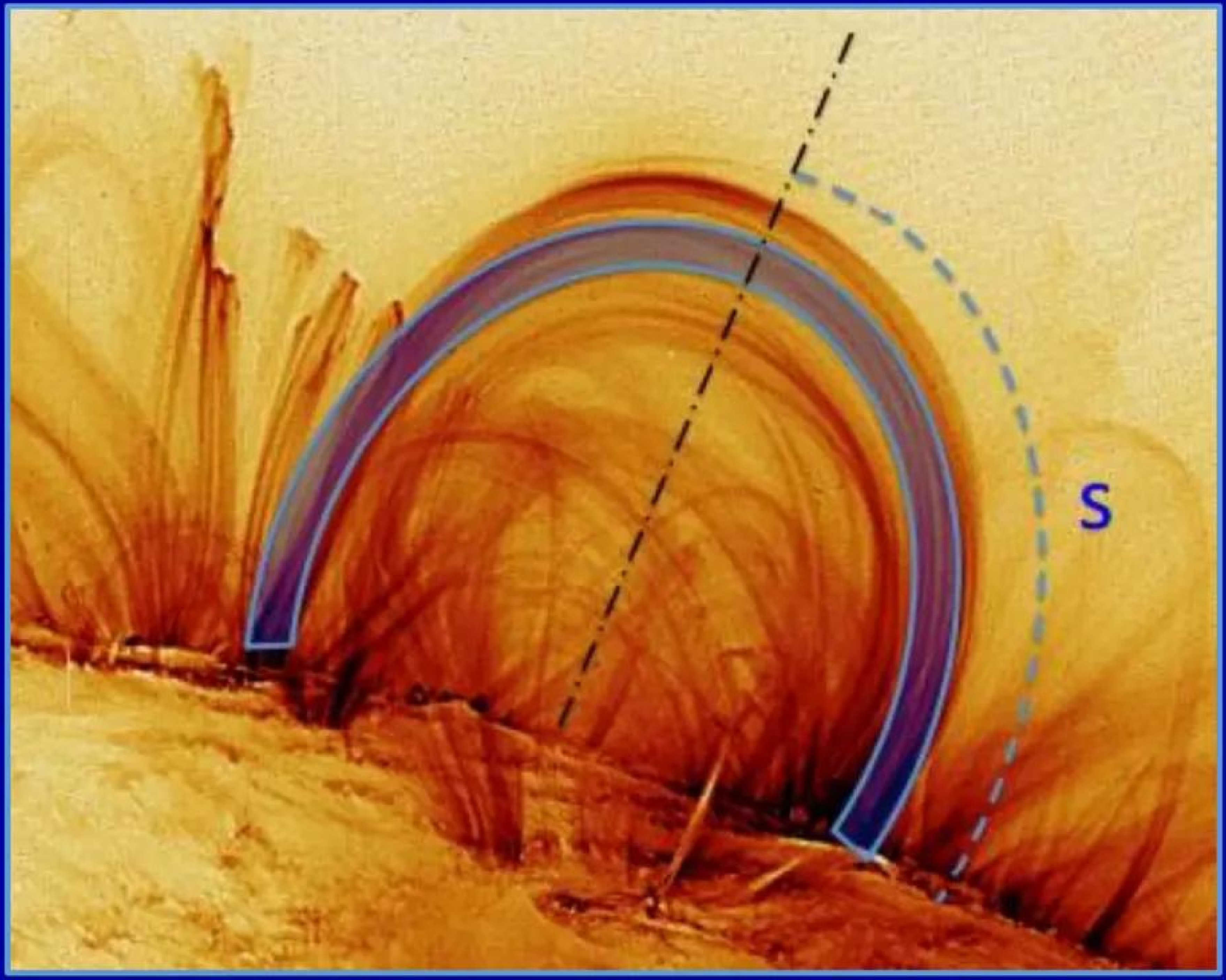
Fig. 1 - Magnetic flux tube



http://arxiv.org/pdf/0804.2647.pdf

F. Reale (2014)

Fig. 12 - Plasma confined in a loop

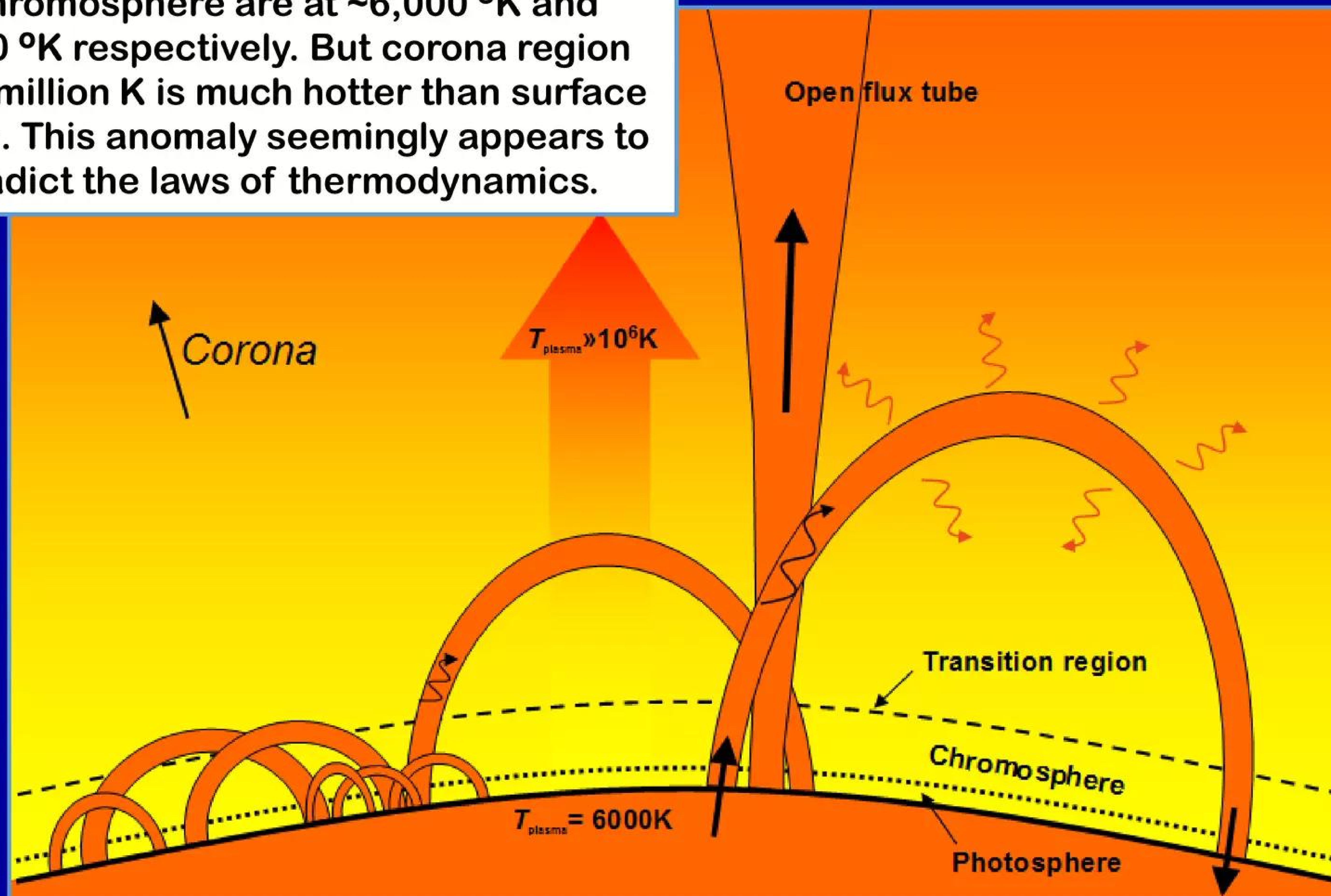


http://solarphysics.livingreviews.org/Articles/lrsp-2014-4/download/lrsp-2014-4Color.pdf

W-L-S theory explains anomalous heating of solar corona

Sun's corona is 2 million ºK but surface temperature only 6,000 ºK - Why?

Sun's core is at temperature of ~15 million degrees K; surface of star's photosphere and chromosphere are at ~6,000 ºK and 10,000 ºK respectively. But corona region at ~ 2 million K is much hotter than surface of sun. This anomaly seemingly appears to contradict the laws of thermodynamics.

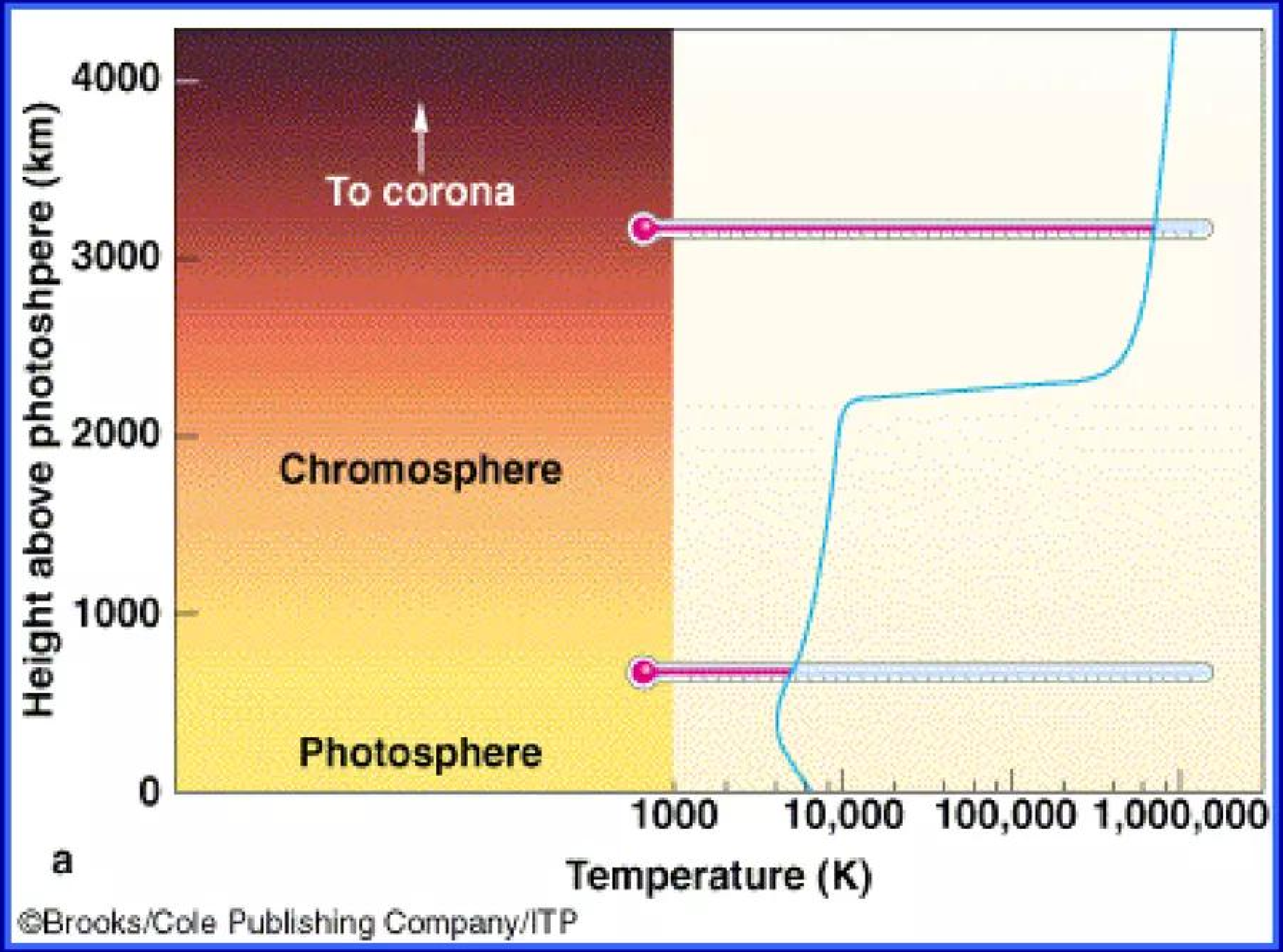


Credit: Ian O'Neill in his thesis titled "Quiescent coronal loops heated by turbulence"

W-L-S theory explains anomalous heating of solar corona

Step-up electrical transformer is analogue of our explanation for heating

Magnetic flux tubes collectively transfer energy from photosphere up to corona



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arXiv:nucl-th/0804.2647v1 4 pages (2008)

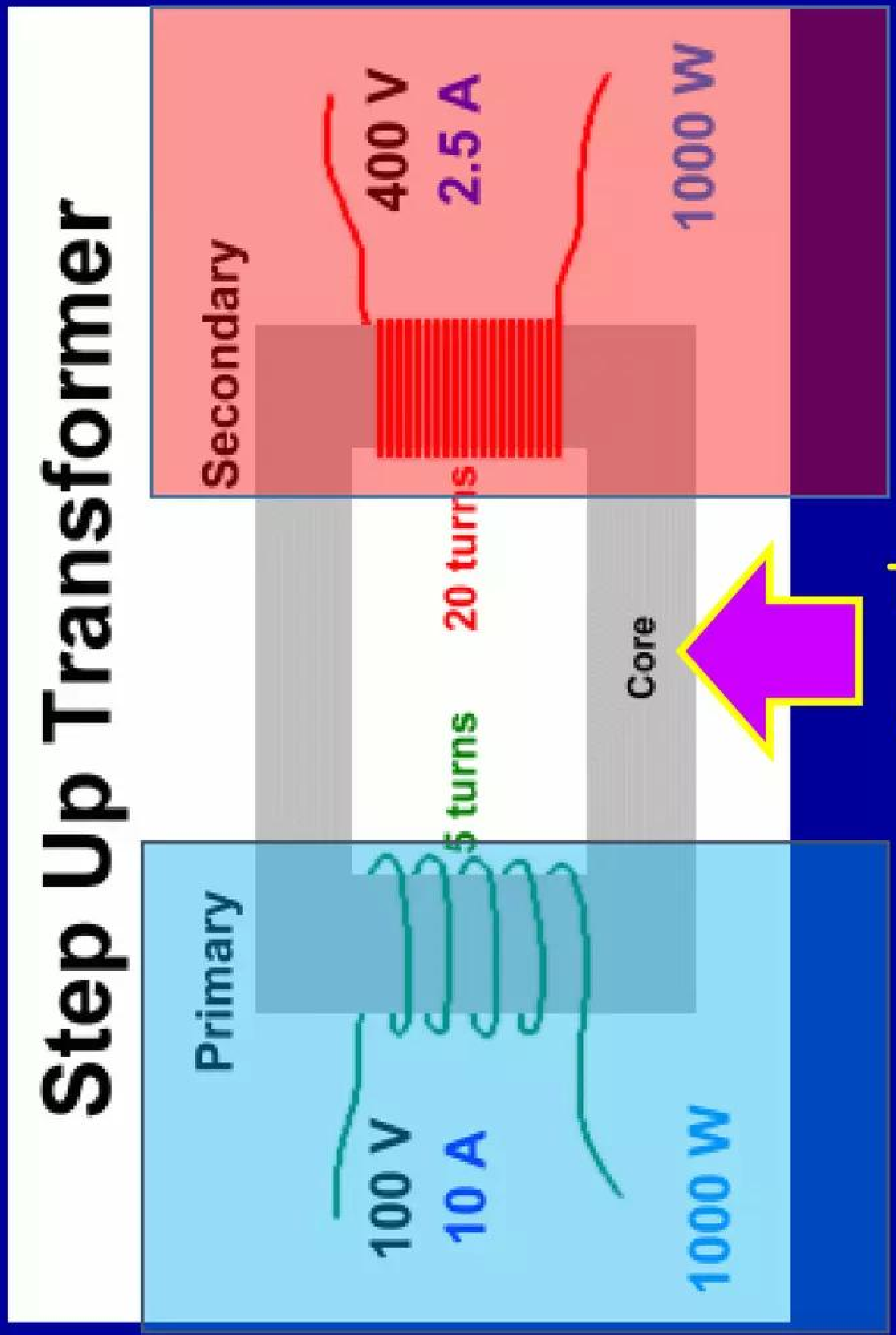
http://arxiv.org/pdf/0804.2647.pdf

Quoting: "The essence of the step up transformer mechanism is that the kinetic energy distributed among a very large number of charged particles in the photosphere can be transferred via the magnetic flux tube to a distributed kinetic energy shared among a distant much smaller number of charged particles located in the corona, i.e. a small accelerating voltage in the primary coil produces a large accelerating voltage in the secondary coil. The resulting transfer of kinetic energy is collective from a large group of charged particles to a smaller group of charged particles. The kinetic energy per charged particle of the dilute gas in the corona may then become much higher than the kinetic energy per charged particle of the more dense fluid in the photosphere."

W-L-S theory explains anomalous heating of solar corona

Step-up electrical transformer is analogue of our explanation for heating

Magnetic flux tubes collectively transfer energy from the photosphere to corona



Secondary coil

Transformer equivalent of solar coronal region

Transformer core is analogue of solar magnetic flux tube

Primary coil

Transformer equivalent of solar photosphere

Step-up transformer equation

$$V_p I_p = V_s I_s$$

Electric utility transformers

Below see J. Klimchuk "Key aspects of coronal heating" (2015) at URL:

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4410549/pdf/rsta20140256.pdf

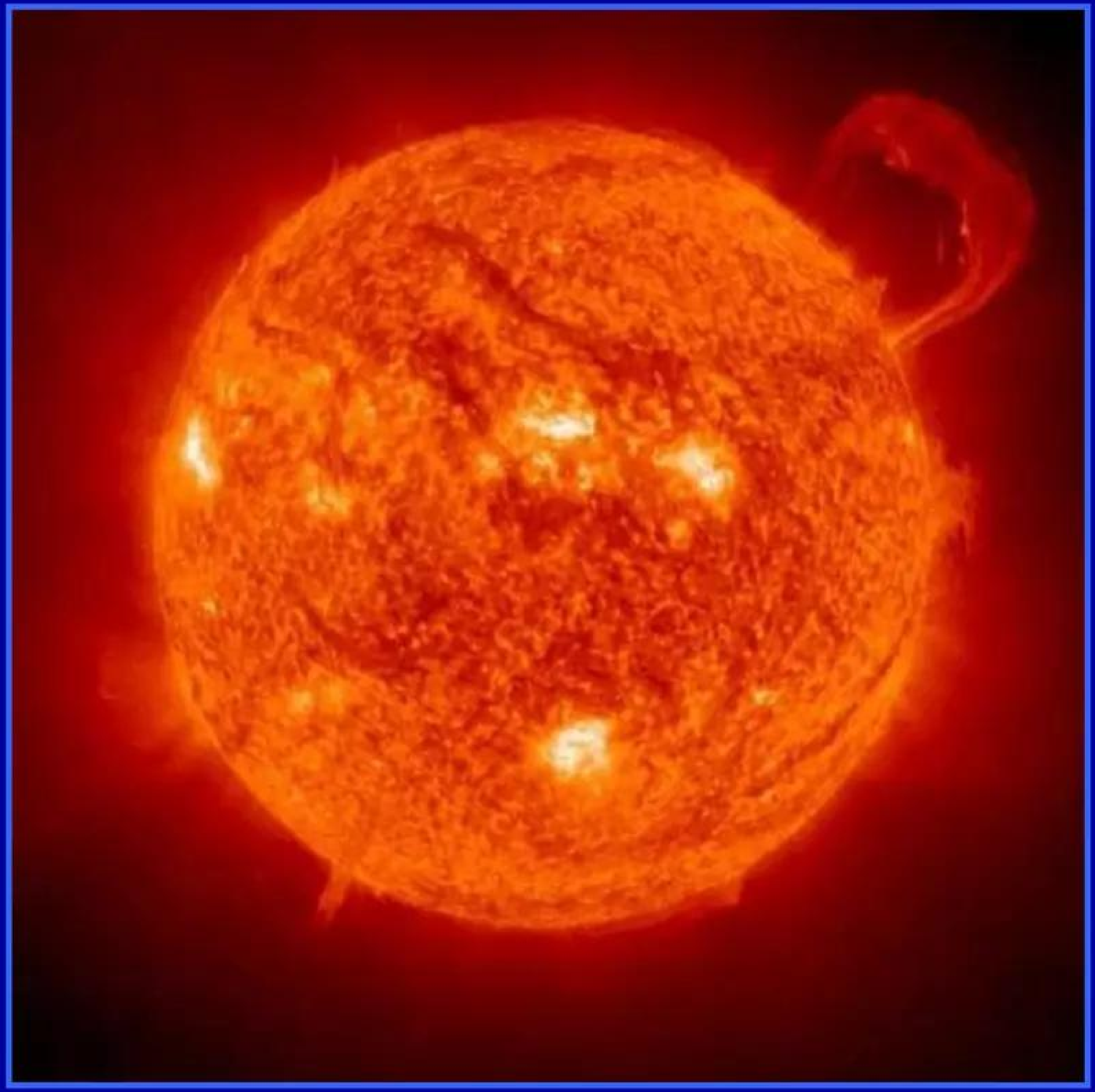
Plasma-filled magnetic flux tubes occur on the Sun

Also called coronal loops; have been observed on other types of stars

These large length-scale ordered magnetic structures quite common in Universe

Idealized graphic of magnetic flux tubes anchored in Sun's surface

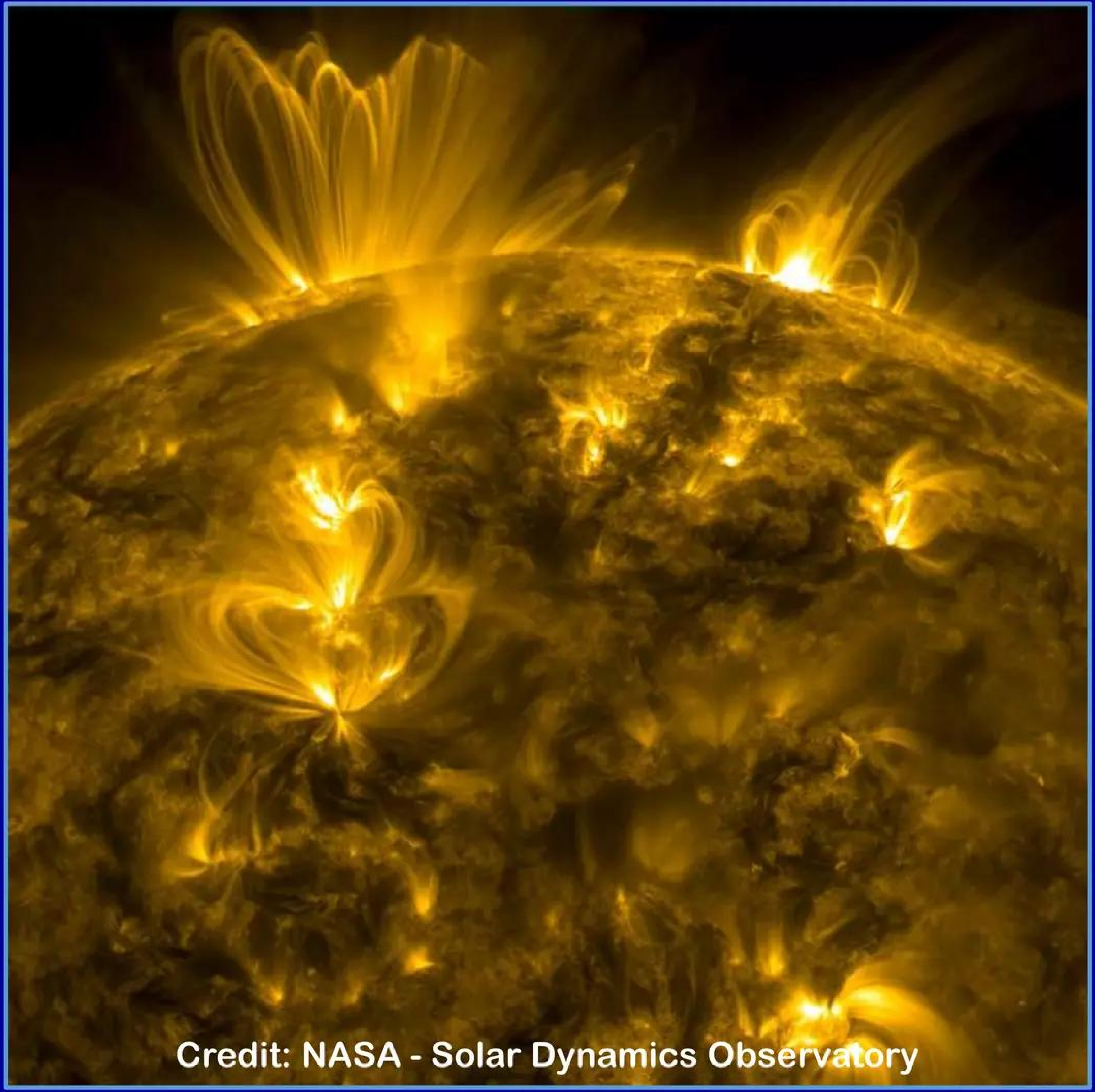
Credit: NASA SOHO - false-color image of Sun in extreme ultraviolet



Plasma-filled magnetic flux tubes imaged on solar surface

Large amounts of stored energy are contained in loops' magnetic fields

Coronal loops (magnetic flux tubes) from Sun's surface on October 14 - 15, 2014

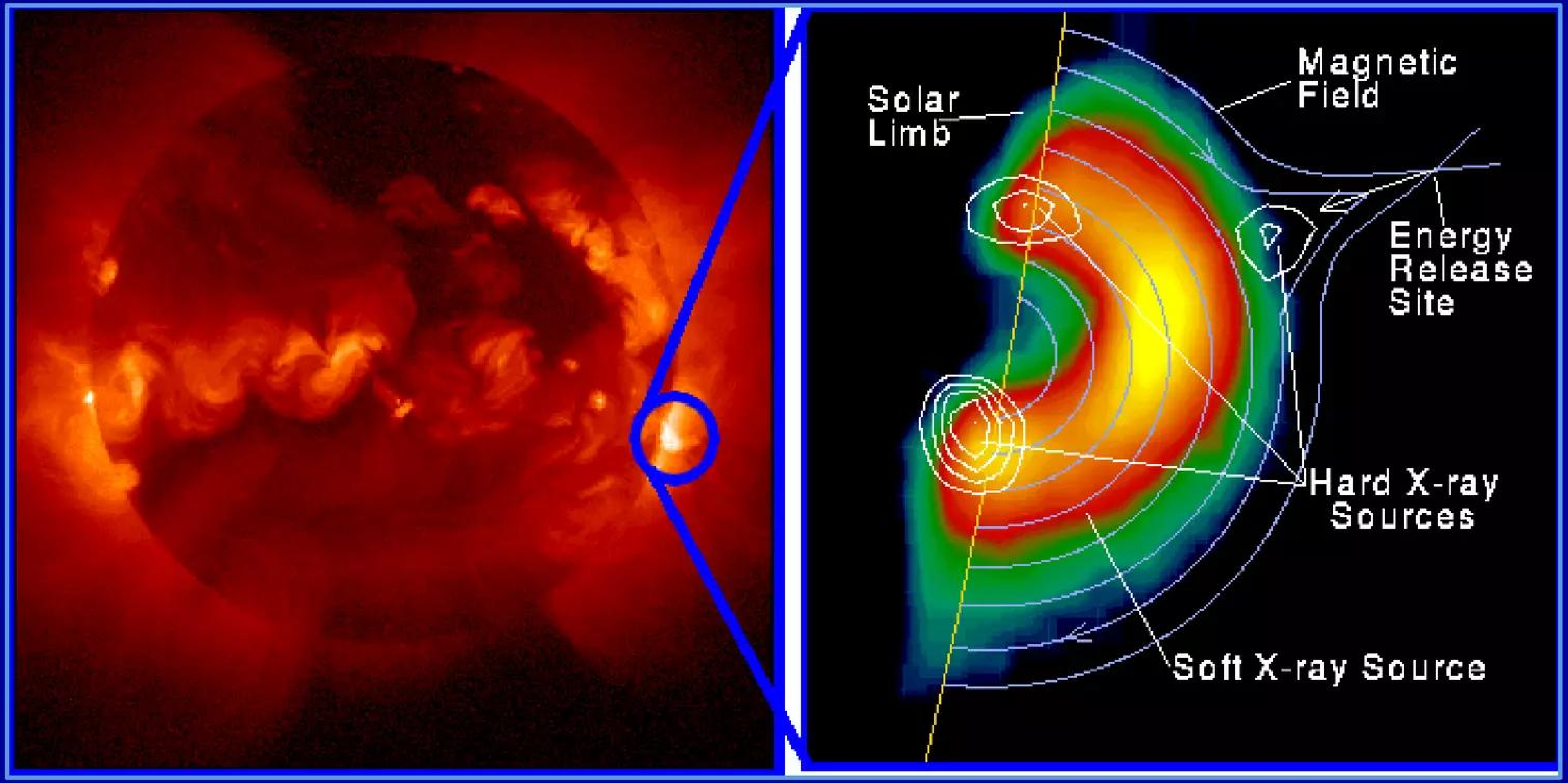


X-rays are emitted from magnetic flux tubes in solar flares

Radiation produced by electrons accelerated inside such coronal loops

Gamma radiation is produced when electrons accelerated to even higher energies

Details of X-ray image of solar flare observed by Yohkoh Soft X-ray Telescope



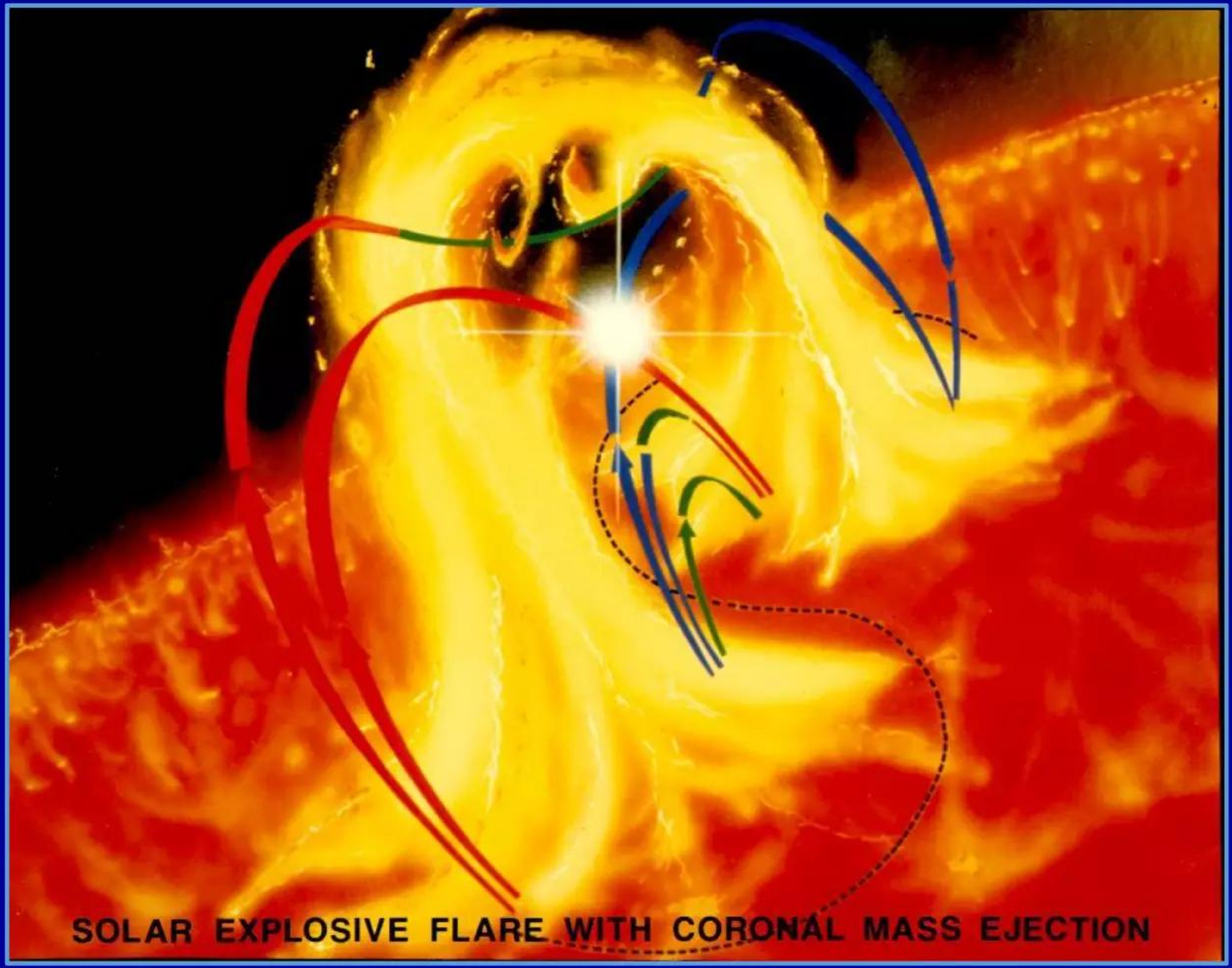
Credit: Yohkoh imaging team and NASA/Goddard – event occurred January 13, 1992

http://science.nasa.gov/science-news/science-at-nasa/1999/ast02jun99_1/

Explosion of magnetic flux tubes occurs in solar flares

Released magnetic energy increases kinetic energy of particles in loops

Artist's concept shows explosive solar flare evolving into a coronal mass ejection



Credit: NASA/Marshall Space Flight Center

Many-body collective $e + p$ reactions occur on Sun

Quoted from: "A primer for electro-weak energy nuclear reactions"

Nucleosynthesis and energetic particle production occurs in magnetic flux tubes

- ✓ "If and when the kinetic energy of the circulating currents in a part of the floating flux tube becomes sufficiently high, the flux tube would become unstable and explode into a solar flare which may be accompanied by a coronal mass ejection. There is a rapid conversion of the magnetic energy into charged particle kinetic energy. These high-energy products from the explosion initiate nuclear as well as elementary particle interactions, some of which have been detected in laboratories."
- ✓ "Recent NASA and ESA pictures show that the surface of the Sun is covered by a carpet-like interwoven mesh of magnetic flux tubes of smaller dimensions.* Some of these smaller structures possess enough magnetic energy to lead to LENRs through a continual conversion of their energy into particle kinetic energy. Occurrence of such nuclear processes in a roughly steady state would account for the solar corona remaining much hotter than the photosphere."
- ✓ "... our picture belies the notion that all nuclear reactions are contained within the core of the Sun."
- ✓ "On the contrary, it provides strong theoretical support for experimental anomalies such as short-lived isotopes that have been observed in the spectra of stars having unusually high average magnetic fields."

* - idea of small loops in 'carpet' is supported by experimental data of H. Peter *et al.*, *A&A* (2013)

Tantalizing results in high-current discharge experiments

Metallic target exploded by current pulse exhibits LENR transmutations

Photon spectrum emitted from target similar to astrophysical gamma ray sources

"Controlled nucleosynthesis, breakthroughs in experiment and theory," S. Adamenko (Ed.), F. Selleri (Ed.), A. van der Merwe (Ed.), Springer Verlag, Dordrecht, The Netherlands ISBN-13: 978-1402058738 (2007)

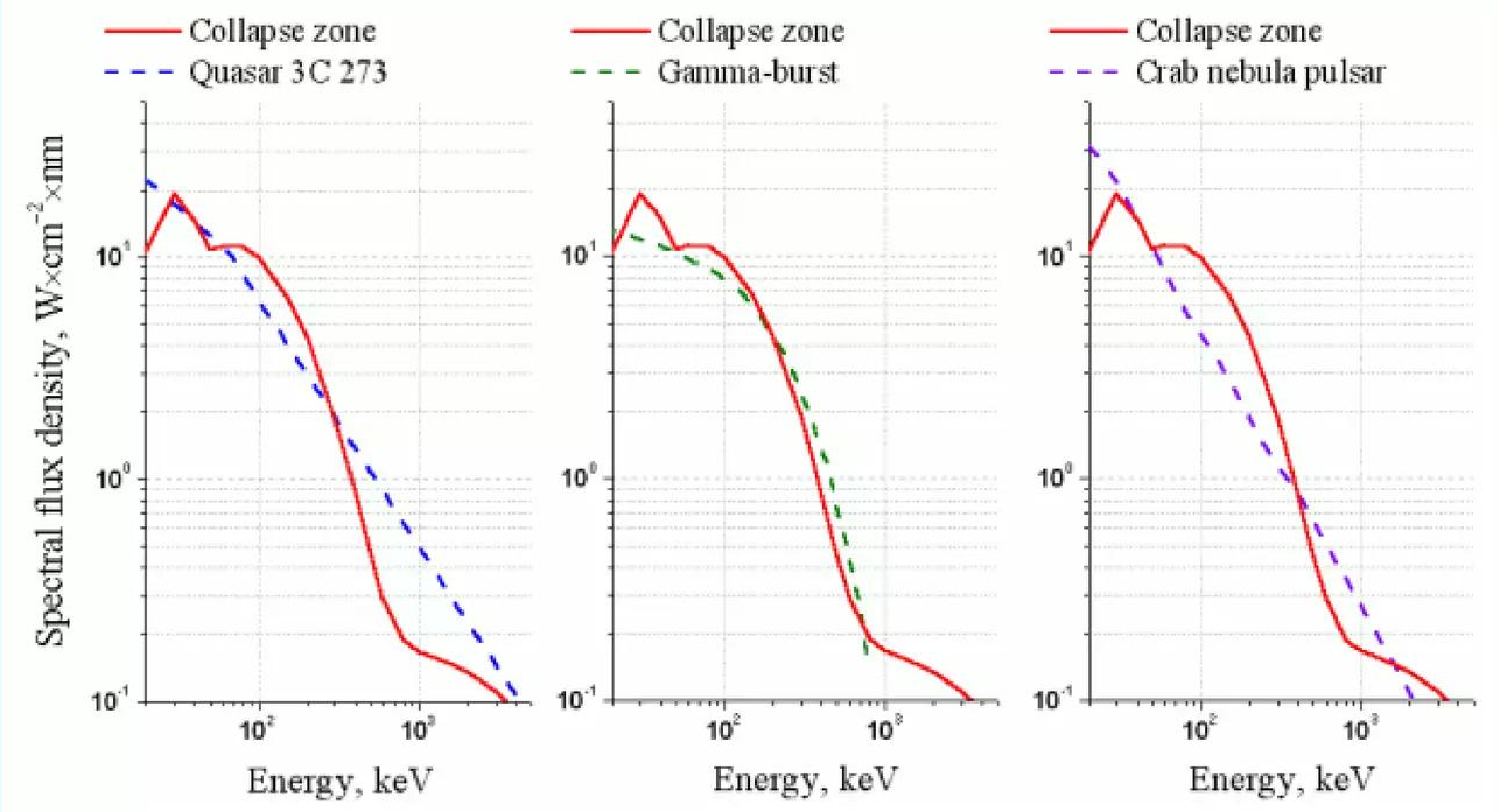


Fig. 6: Comparison of the emission spectra of the exploded target to those of quasars, pulsars, and gamma-bursts in the energy range from 10 keV to 10 MeV.

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.561.4239&rep=rep1&type=pdf

Neutron stars have highest-known average magnetic fields

Typical magnetic field is ~4 x 10^{12} Gauss - magnetars go up to 10^{15} Gauss

Thin atmospheres appear to be comprised of partially ionized Hydrogen or Helium

Neutron-star cross section

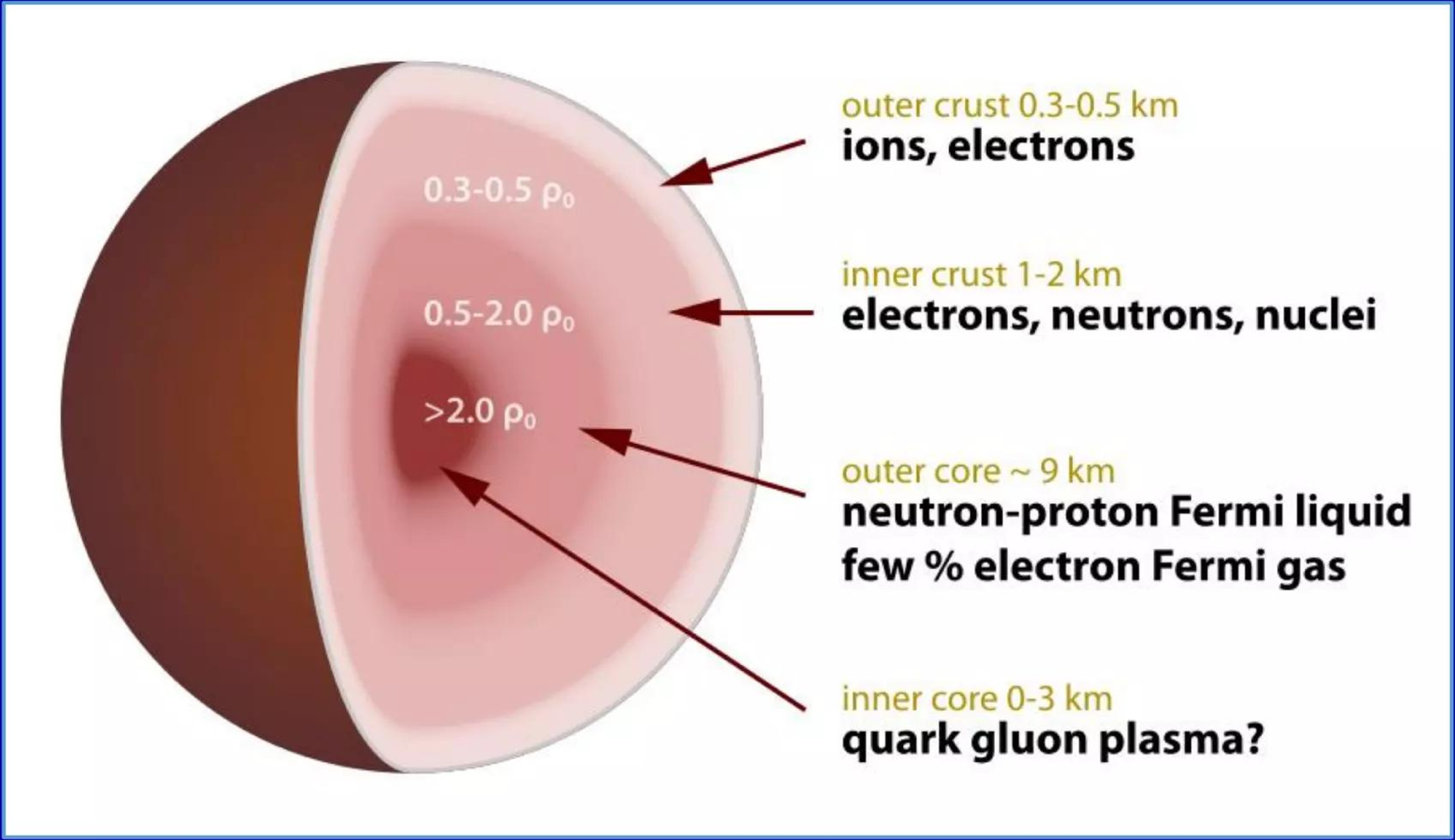


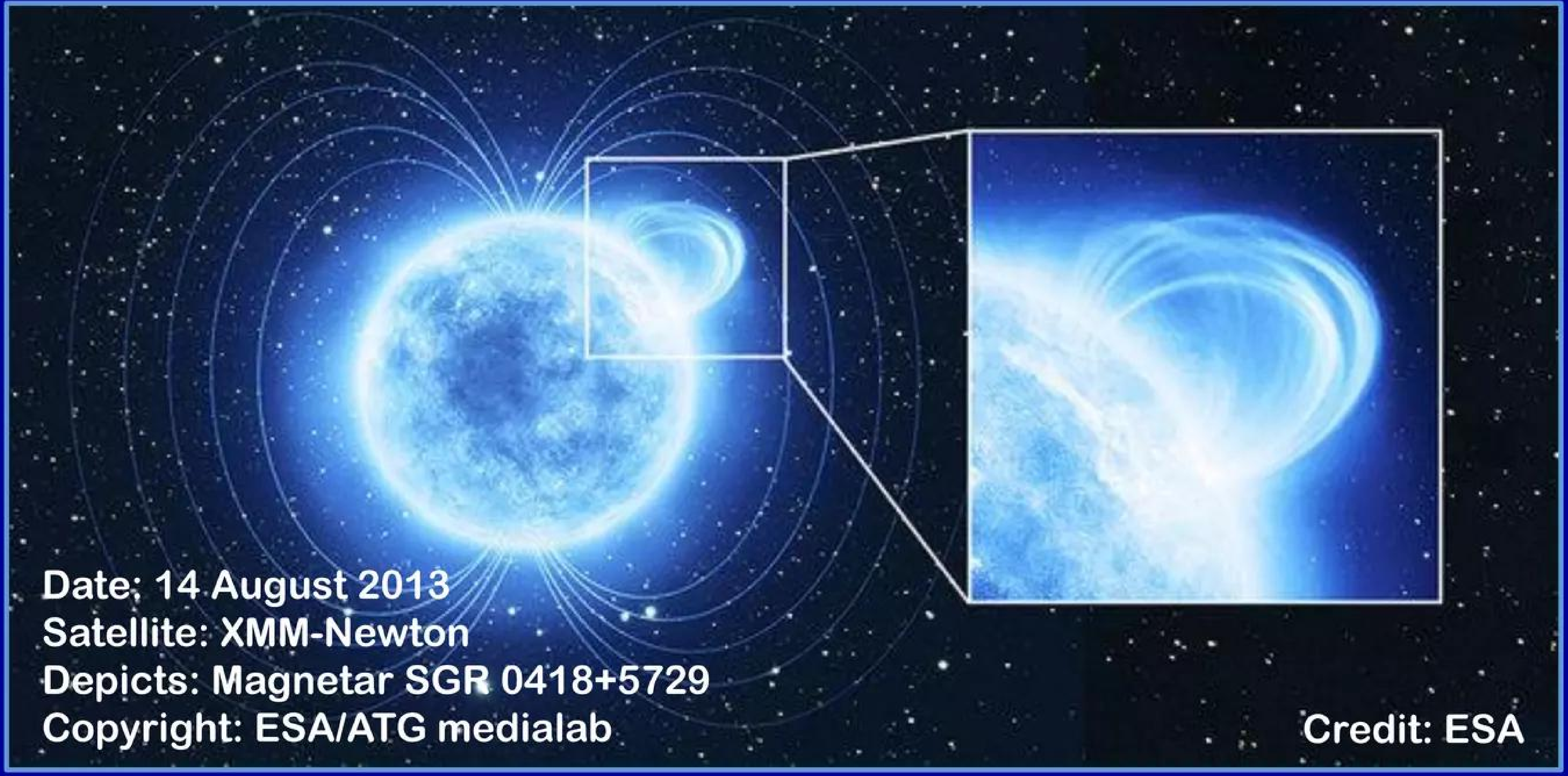
Image credit: Robert Schulze

Data supports assumption that flux tubes contain protons

Plasma-filled magnetic flux tubes on neutron stars are like coronal loops

Widom-Larsen-Srivastava acceleration physics creates UHE cosmic rays therein

Magnetic loops on magnetar SGR 0418 has been hypothesized by ESA scientists



"The strong internal magnetic field of this magnetar reveals itself only in a small feature emerging from its surface, where protons absorb some of the X-rays emitted by the magnetar. The protons are confined in this region by a strong and localised magnetic field, with lines that are probably shaped like a series of adjacent arcs, resembling the appearance of loops on the surface of the Sun."

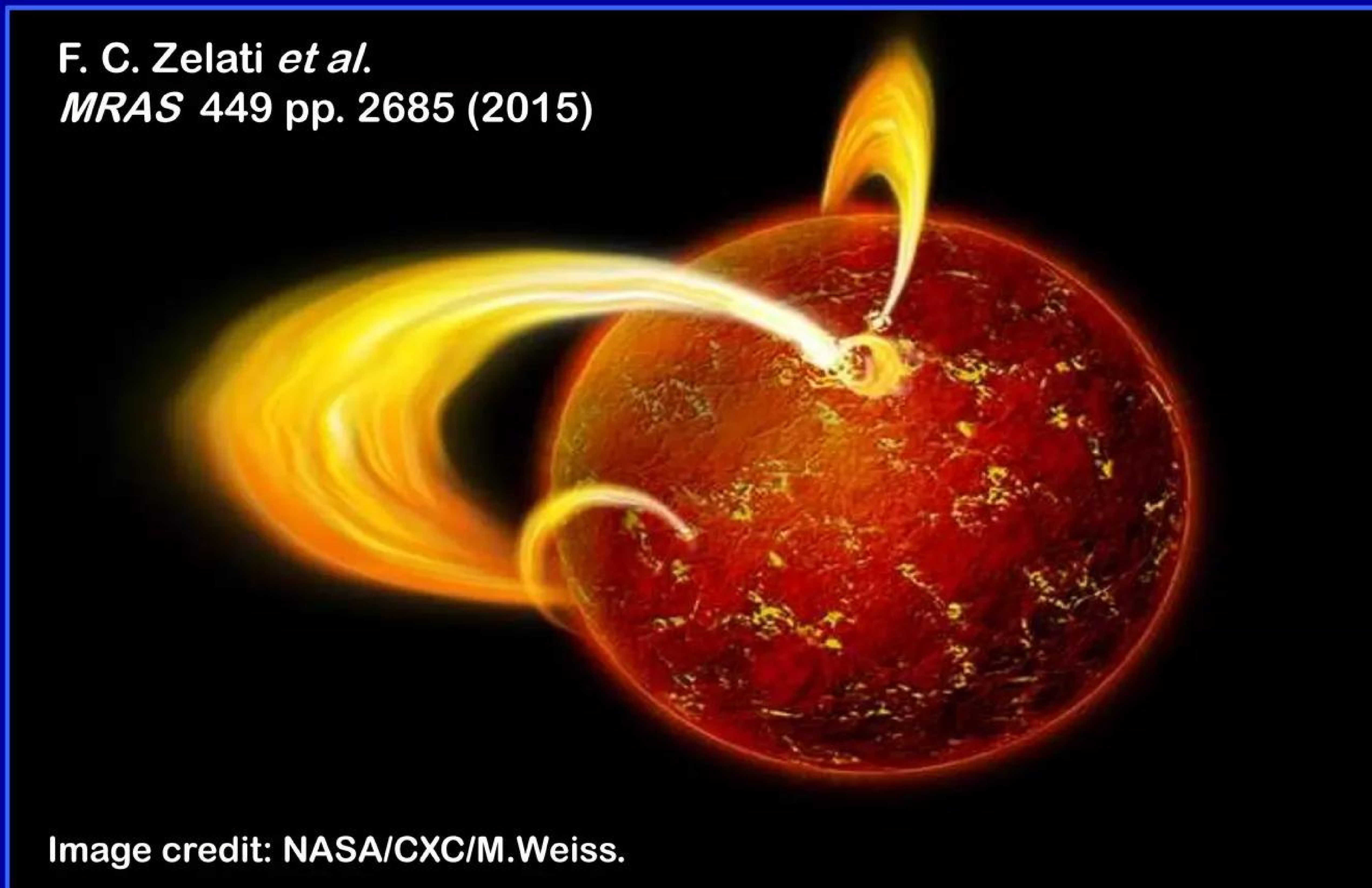
http://sci.esa.int/xmm-newton/52775-magnetar-sgr-04185729-with-a-magnetic-loop/

Plasma-filled coronal loops observed on a magnetar?

Magnetar SGR J1745-2900 shows evidence for magnetic flux tubes

"Additional heating of star surface from currents flowing in twisted magnetic bundle"

"Shows how an extremely rapidly rotating neutron star, which has formed from the collapse of a very massive star, can produce incredibly powerful magnetic fields."



"Magnetar near supermassive black hole delivers surprises" May 14, 2015
http://phys.org/news/2015-05-magnetar-supermassive-black-hole.html

http://mnras.oxfordjournals.org/content/449/3/2685.abstract

Plasma-filled coronal loops observed on a magnetar?

Magnetar SGR J1745-2900 shows evidence for magnetic flux tubes

"Corresponds to a charge-separated flow … current is carried by electrons (and ions)"

On the other hand, we can estimate the density of the particles responsible for the resonant Compton scattering which produces the X-ray tail as

$$n_{\rm rcs} \simeq \frac{J_B \mathcal{M}}{ve} \simeq \frac{\mathcal{M}B}{4\pi\beta e r} \sim 1.7\times10^{16}\,\frac{\mathcal{M}B_{14}}{\beta}\left(\frac{r}{R_*}\right)^{-1}\,{\rm cm}^{-3}\,, \quad (3)$$

where $\vec{J_B} = (c/4\pi)\vec{\nabla}\times\vec{B}$ is the conduction current, B is the local magnetic field, and r is the length-scale over which B varies ($R_* \sim 10^6$ cm is the star radius). In the magnetosphere of a magnetar the real current is always very close to J_B and it is mostly conducted by $e^{\pm}$ pairs (Beloborodov 2007). The abundance of pairs is accounted for by the multiplicity factor $\mathcal{M}$ which is the ratio between the actual charge density (including pairs) and the minimum density needed to sustain J_B; the latter corresponds to a charge–separated flow in which the current is carried only by electrons (and ions). If the same charge population is responsible for both resonant Compton scattering and surface heating, the densities given by eqs. (2) and (3) should be equal. This implies

$$B_{14}\left(\frac{r}{R_*}\right)^{-1}\mathcal{M}\Gamma = 2.5\times10^{6}\left(\frac{kT}{1\ {\rm keV}}\right)^{4}. \quad (4)$$

"The X-ray outburst of the Galactic Centre magnetar SGR J1745–2900 during the first 1.5 year" F. C. Zelati *et al.* *MRAS* 449 pp. 2685 (2015)

http://mnras.oxfordjournals.org/content/449/3/2685.abstract nature International weekly journal of science

"A large-scale dynamo and magnetoturbulence in rapidly rotating core-collapse supernovae"
P. Mösta, C. Ott, D. Radice, L. Roberts, E. Schnetter & R. Haas, *Nature* **528** pp. 376 - 379 (2015)

Abstract: "Magnetohydrodynamic turbulence is important in many high-energy astrophysical systems, where instabilities can amplify the local magnetic field over very short timescales. Specifically, the magnetorotational instability and dynamo action have been suggested as a mechanism for the growth of magnetar-strength magnetic fields (of 10^{15} gauss and above) and for powering the explosion of a rotating massive star. Such stars are candidate progenitors of type Ic-bl hypernovae, which make up all supernovae that are connected to long γ-ray bursts. The magnetorotational instability has been studied with local high-resolution shearing-box simulations in three dimensions, and with global two-dimensional simulations, but it is not known whether turbulence driven by this instability can result in the creation of a large-scale, ordered and dynamically relevant field. Here we report results from global, three-dimensional, general-relativistic magnetohydrodynamic turbulence simulations. We show that hydromagnetic turbulence in rapidly rotating protoneutron stars produces an inverse cascade of energy. We find a large-scale, ordered toroidal field that is consistent with the formation of bipolar magnetorotationally driven outflows. Our results demonstrate that rapidly rotating massive stars are plausible progenitors for both type Ic-bl supernovae and long γ-ray bursts, and provide a viable mechanism for the formation of magnetars. Moreover, our findings suggest that rapidly rotating massive stars might lie behind potentially magnetar-powered superluminous supernovae."

Magnetic flux tubes form in rotating massive star collapse

Mösta et al.'s simulation shows huge magnetic field of ~7.0 x 10^{14} Gauss

W-L-S mechanism accelerates protons to center-of-mass energies ≈ 5.5 x 10^{18} eV

Accelerated particles center-of-mass energy for exploding flux tube

$$e\overline{V} \approx (30\ \text{GeV}) \left(\frac{B}{\text{kG}}\right) \left(\frac{\pi R^2}{\Lambda - \text{km}}\right)$$

Eq. (20) in *Pramana* paper (2010)

Assumptions: magnetic flux tube formed on rapidly rotating protoneutron star initially contains protons, electrons, some neutrons, and traces of other elemental ions if any infalling matter also happens to be present; flux tube predicted by their simulation = 1.0 km in diameter* and has a time Δt = 10 milliseconds* and the magnetic field inside = 7.0 x 10^{14} Gauss (7.0 x 10^{11} kilogauss)

Calculation based on Eq. 20 presuming that flux tube destabilizes and explodes:

$\Lambda = c\,\Delta t = (2.998 \times 10^5) \times (10 \times 10^{-3}\ \text{sec}) = 29.98 \times 10^2\ \text{km} \approx 3.0 \times 10^3\ \text{km}$

$B = 7.0 \times 10^{11}\ kG$

$\pi r^2 = 3.1416 \times (0.5)^2 = 3.1416 \times 0.25 = 0.7854\ \text{km}^2$

$e\overline{V} \approx [\,(30.0) \times (7.0 \times 10^{11})\,] \times (0.7854 / 3.0 \times 10^3) \approx [\,2.1 \times 10^{13}\,]\,(2.6 \times 10^{-4})$

$e\overline{V} \approx 54.6 \times 10^8\ \text{GeV} \approx 5.46 \times 10^9\ \text{GeV} \approx 5.46 \times 10^{18}\ \text{eV} \approx 5.5 \times 10^{18}\ \text{eV}$

* Private communication with an author of Mösta *et al.*

Magnetic flux tubes predicted to occur on accretion disks

Some probably filled with Hydrogen plasma just like solar coronal loops

Magnetic bridges connecting disk to black hole provide enormous energy source

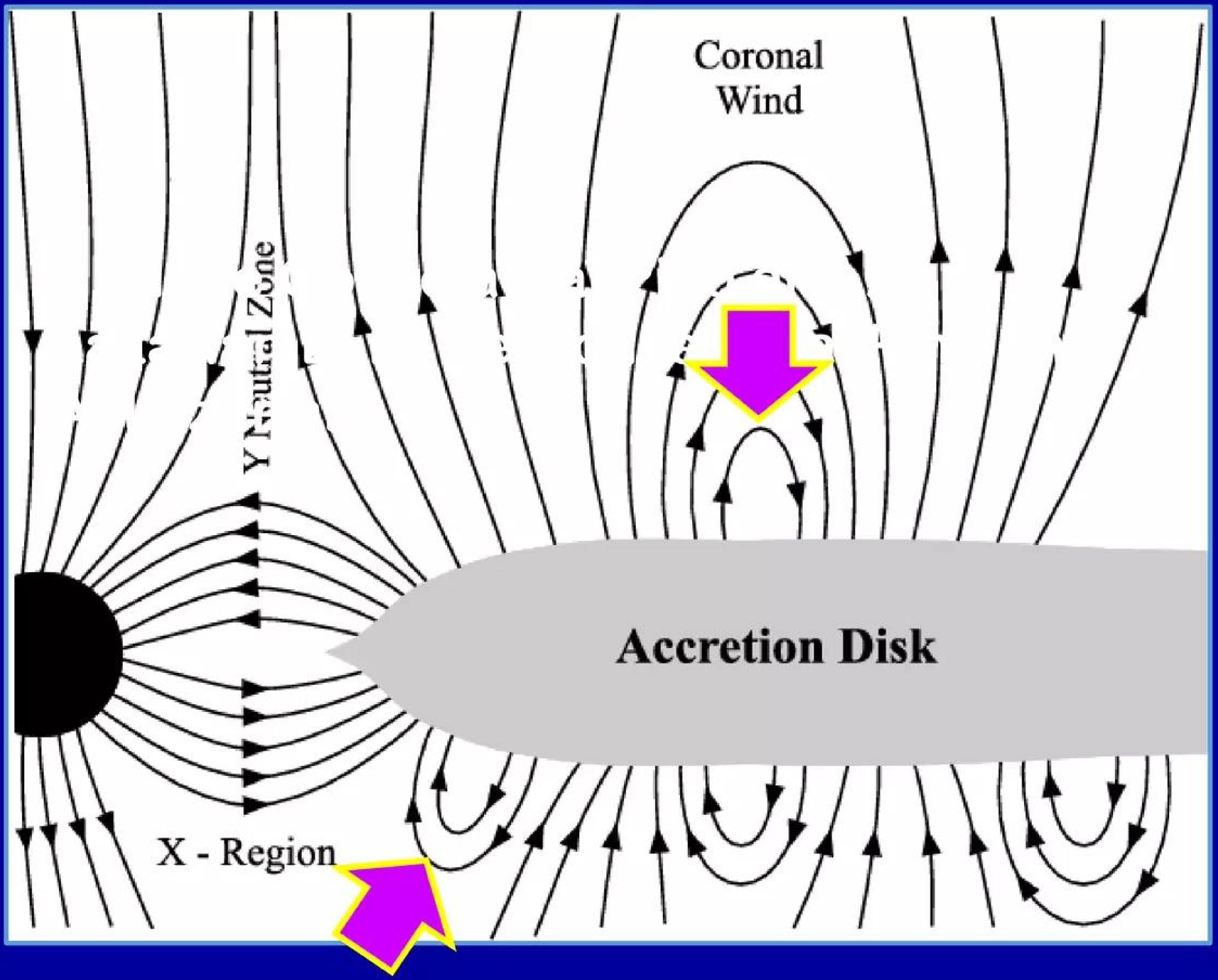
Artist's concept of very hot, luminous Hydrogen-rich accretion disk surrounding a supermassive black hole with twin plasma jets

http://tinyurl.com/psqy25e

Coronal loop analogues could likely occur on accretion disks

"Above inner edge of accretion disk … a magnetic field intensity of 7×10^8 G"

"Production of the large scale superluminal ejections of the microquasar GRS 1915+105 by violent magnetic reconnection"
E. M. de Gouveia Dal Pino and A. Lazarian
Astronomy & Astrophysics **441** pp. 845 - 853 (2005)



http://www.aanda.org/articles/aa/full/2005/39/aa2590-04/aa2590-04.right.html

Concept: magnetic bridges connect disks to black holes

Bridges are unstable and will expand explosively to form powerful jets

Gigantic proton and electron currents circulate inside the loop much akin to Sun

Schematic picture of the magnetic configuration of the current loop around the rotating black hole. The magnetic flux tubes (called magnetic bridges) bridge the region between the ergosphere and the disk.

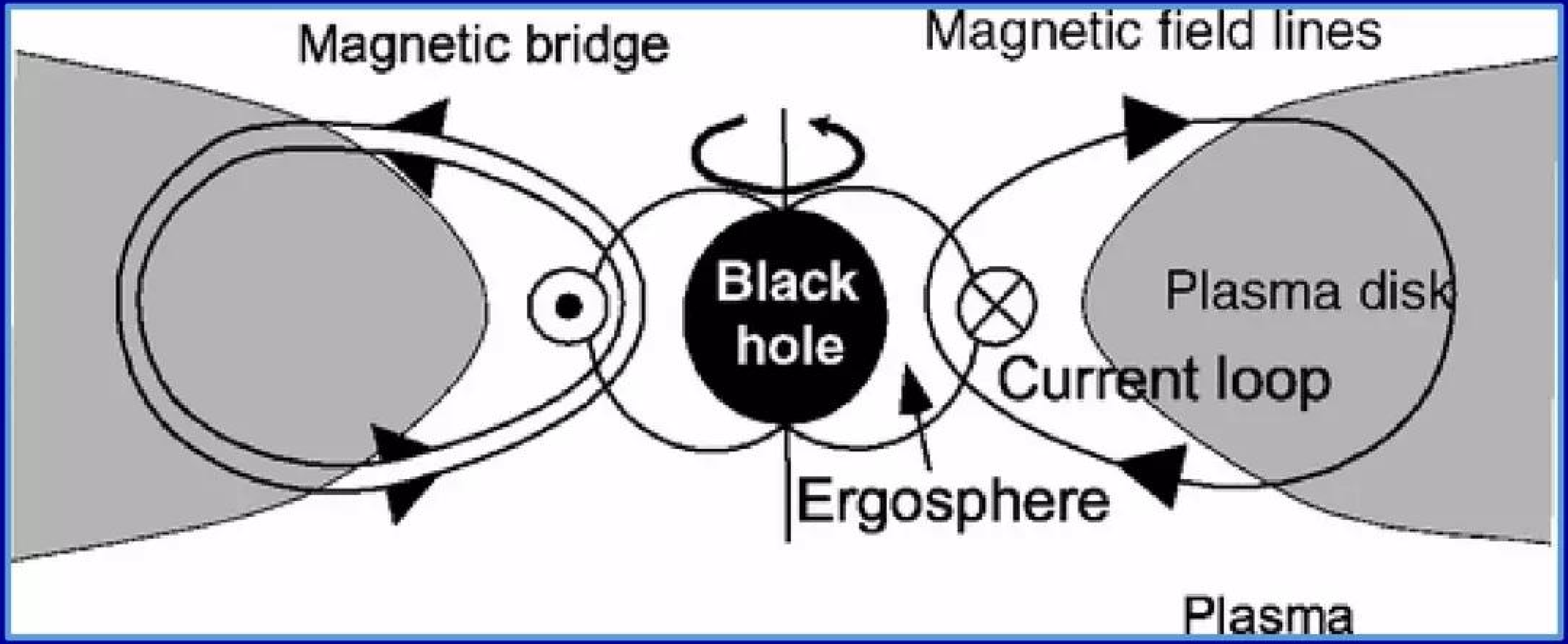


Figure 1.

"Jet formation driven by the expansion of magnetic bridges between the ergosphere and the disk around a rapidly rotating black hole"
S. Koide, T. Kudoh, and K. Shibata
***Physical Review D* 74 pp. 044005 (2006)**

Structures near black hole conducive to W-L-S mechanism

Magnetic B-field strengths could be very high and structures quite large

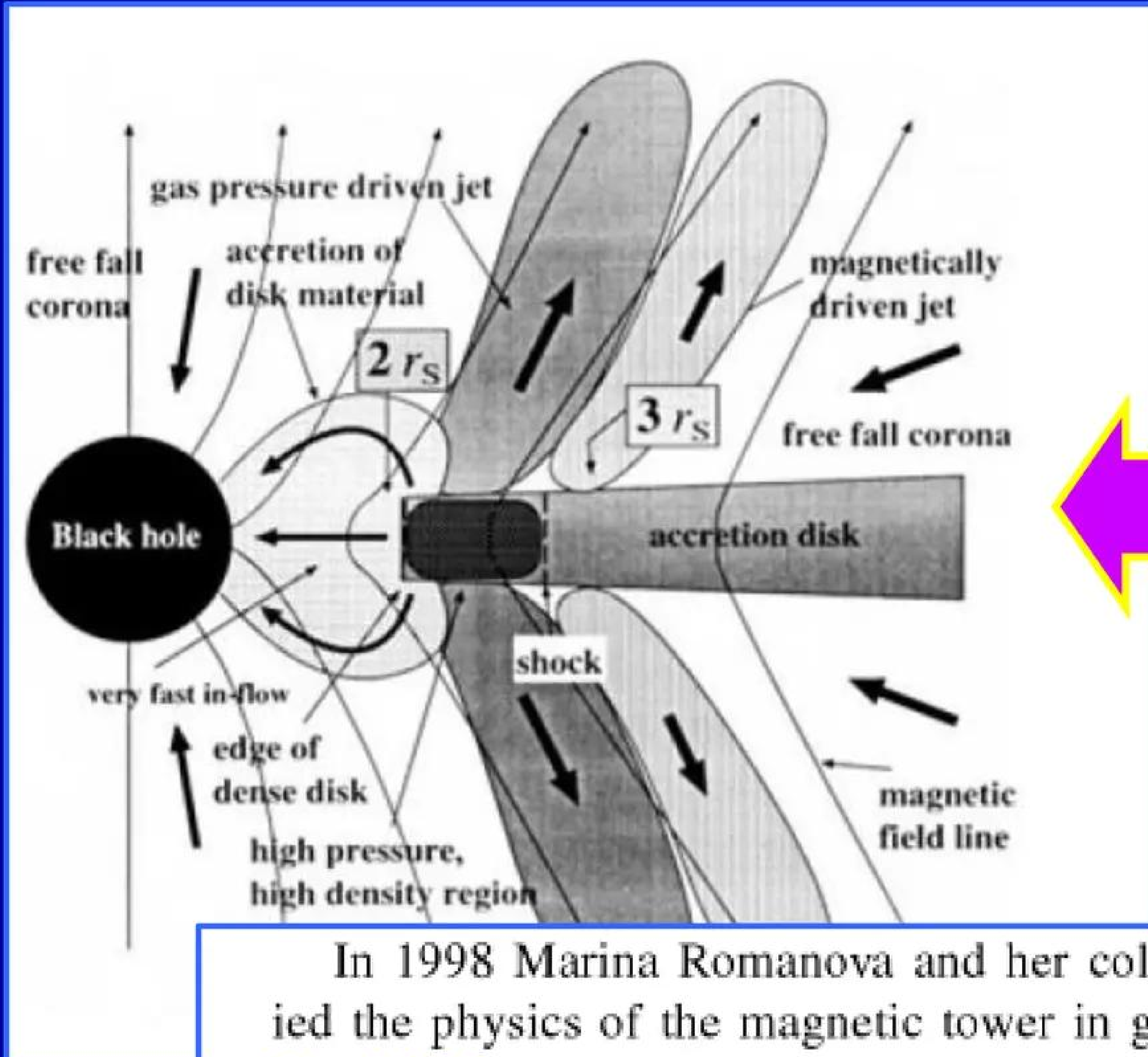


Fig. 14.22 in "Black hole astrophysics: the engine paradigm" David L. Meier, 897 pp. Springer-Verlag Heidelberg (2012)

In 1998 Marina Romanova and her colleagues in Russia and at Cornell studied the physics of the magnetic tower in great detail [515]. Particularly telling is Fig. 14.37 from their paper, which shows the opening of a single closed coronal field loop in one of their simulations. The dominant force causing the field line to inflate is, of course, the $J \times B$ magnetic force. In fact, it acts in a largely force-free manner here, unlike in our earlier magnetic switch simulations. As predicted by Lynden-Bell, magnetic towers can have most of their output energy in the form of magnetic Poynting flux – at least initially and close to the black hole. In the year 2000 this was demonstrated numerically by the same group, this time led by Galina Ustyugova and now joined by colleagues at Los Alamos National Laboratory, Hui Li and Stirling Colgate [516].

Structures near black hole conducive to W-L-S mechanism

Like coronal loop formation on Sun but >>> larger size & magnetic fields

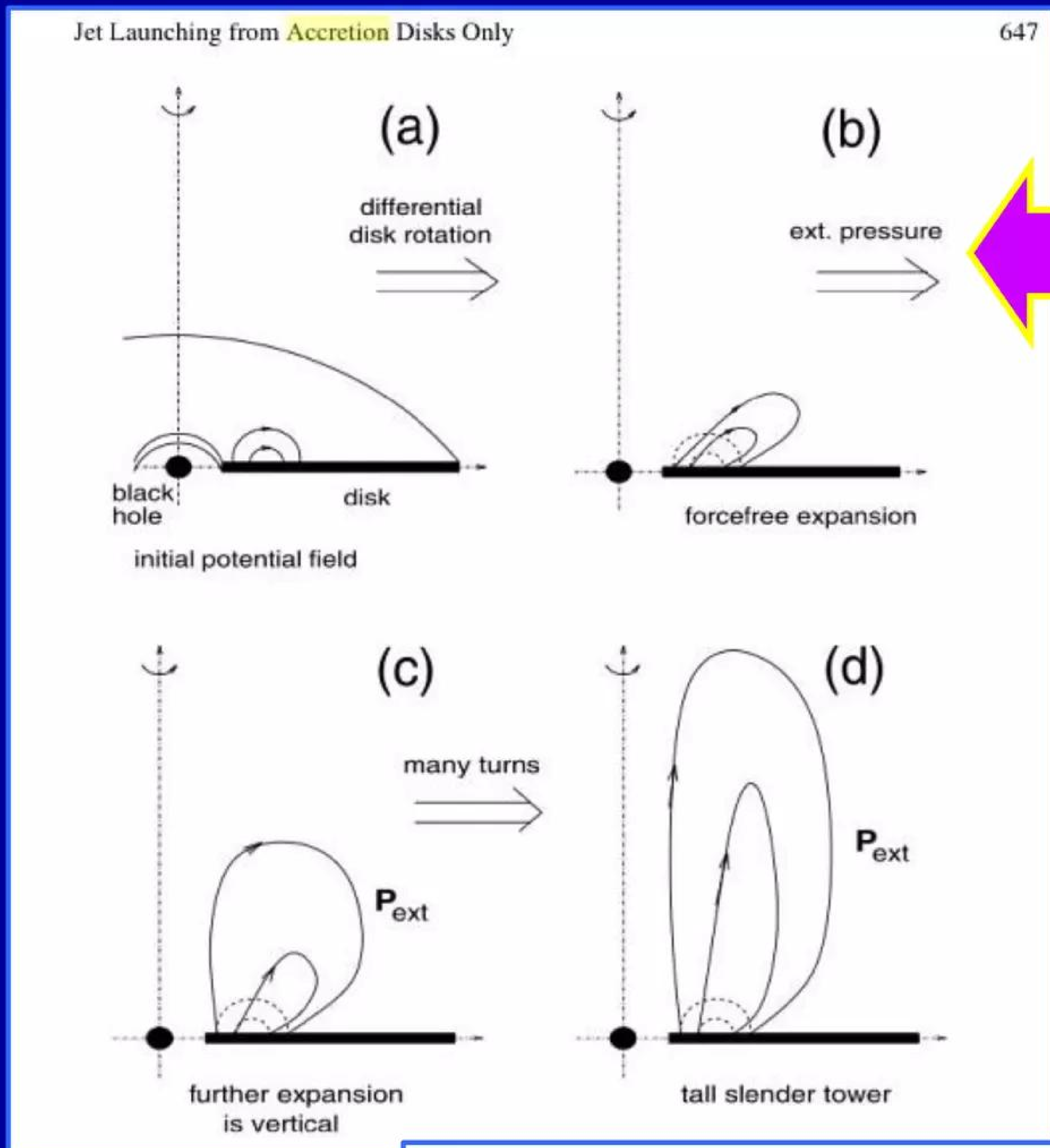


Fig. 14.35: Development of a magnetic tower jet. (a) Initial conditions in the disk (tilted here for easy viewing); a magnetic flux tube connects two different radii in the disk. (b) Early inflation of the flux loop, showing before (dotted) and after (solid) magnetic states. (c) Eventual confinement of the tower in R by external gas pressure; (d) After many disk rotations the initial loops have evolved into a rising magnetic tower. Adapted from Fig. 1 of [513], by permission of the AAS.

Fig. 14.35 in "Black hole astrophysics: the engine paradigm" David L. Meier, 897 pp. Springer-Verlag Heidelberg (2012)

Also see:

"Fast radio bursts and radio transients from black hole batteries"
C. Mingarelli *et al.*
arXiv:1511.02870v1 [astro-ph.HE]
November 9, 2015

http://arxiv.org/pdf/1511.02870v1.pdf

Structures near black hole conducive to W-L-S mechanism

Plasma-filled magnetic flux tubes emerge from torus surrounding the BH

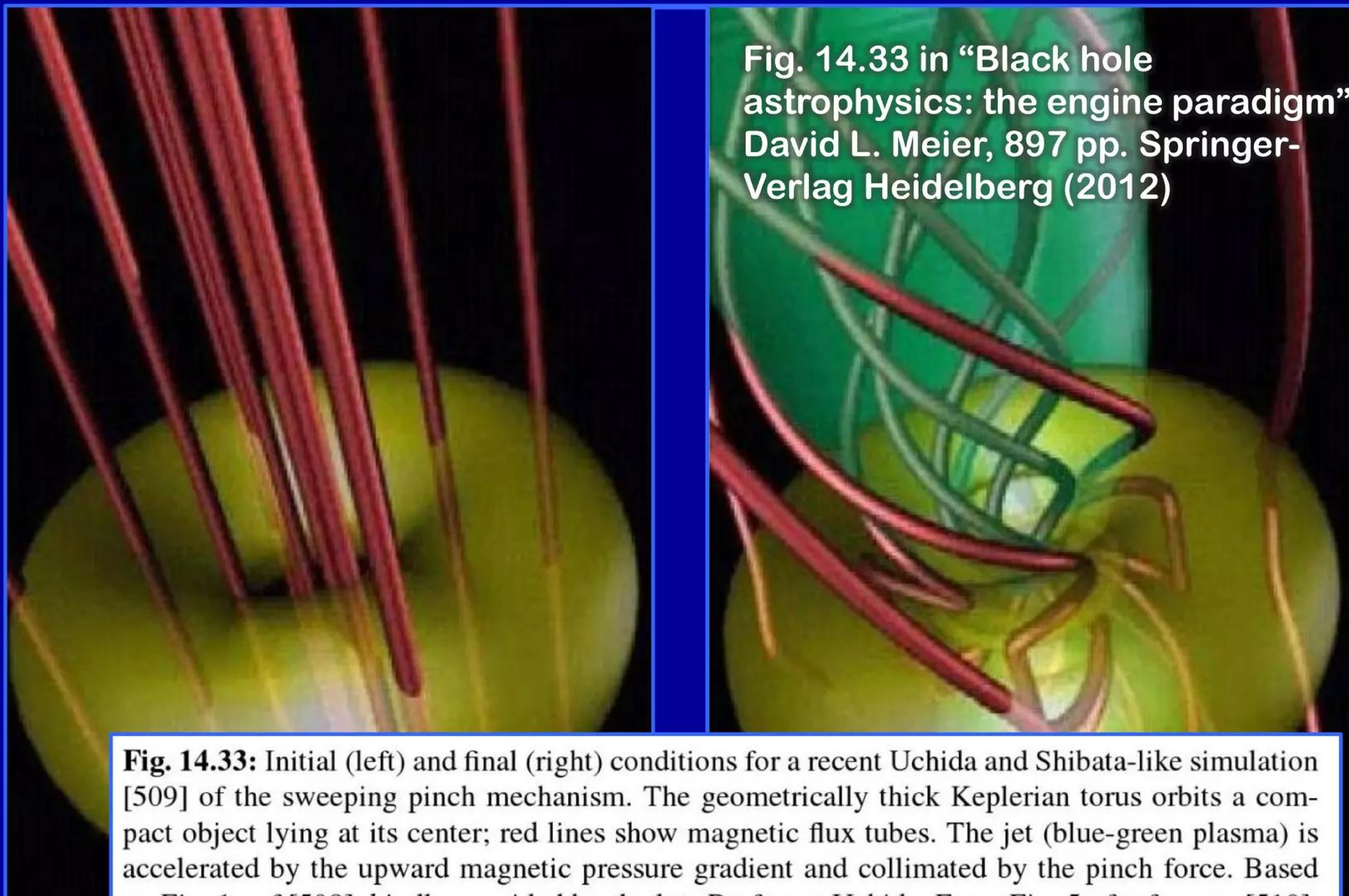


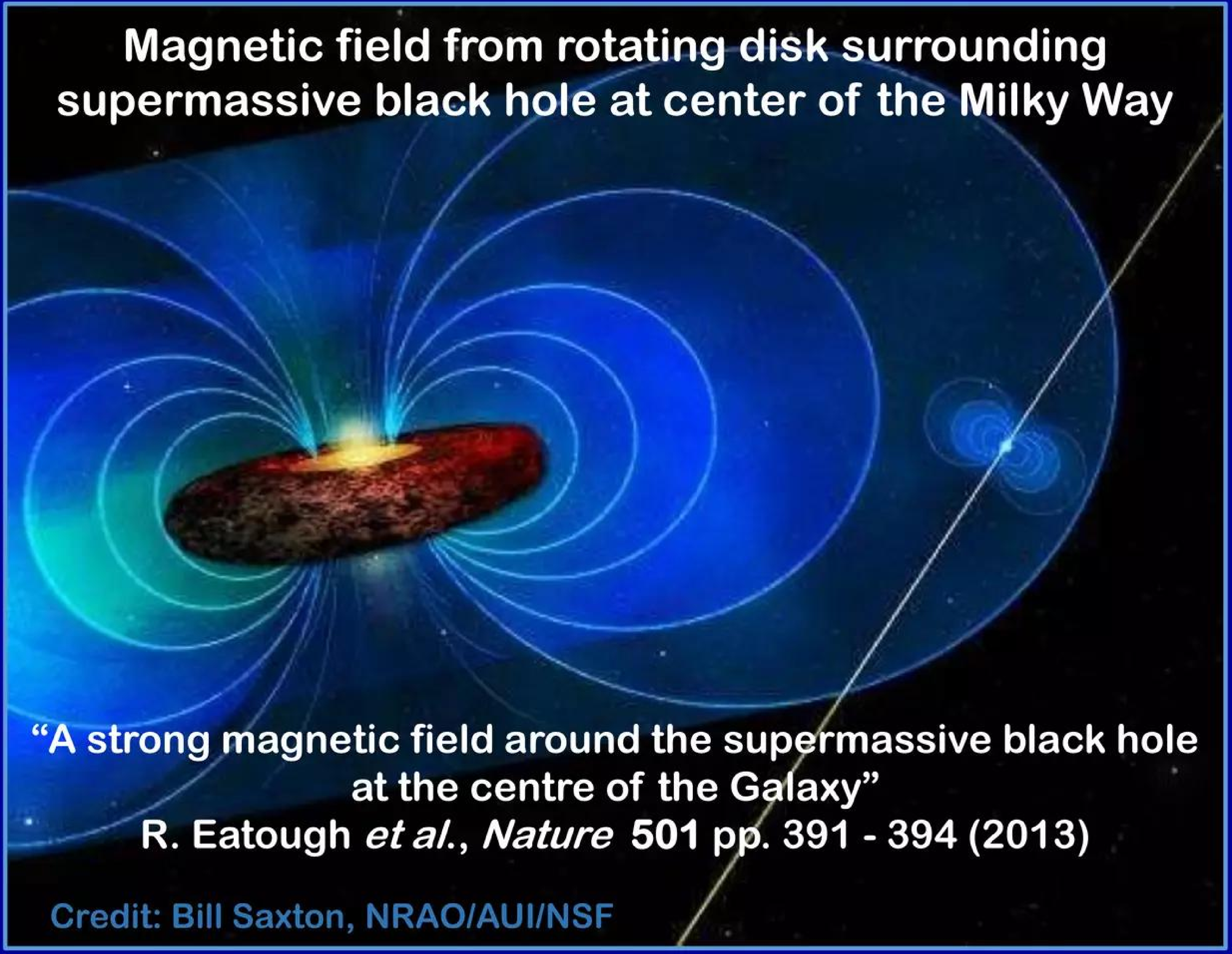
Fig. 14.33: Initial (left) and final (right) conditions for a recent Uchida and Shibata-like simulation [509] of the sweeping pinch mechanism. The geometrically thick Keplerian torus orbits a compact object lying at its center; red lines show magnetic flux tubes. The jet (blue-green plasma) is accelerated by the upward magnetic pressure gradient and collimated by the pinch force. Based on Fig. 1a of [508], kindly provided by the late Professor Uchida. From Fig. 5 of reference [510]. Reprinted with permission from AAAS.

Many data suggest strong magnetic fields near black holes

W-L-S: 100s of Gauss in *very* large flux tube provides huge acceleration

"Simple $B \propto r^{-1}$ scaling would … provide several hundred Gauss magnetic fields"

http://www.nature.com/nature/journal/v501/n7467/full/nature12499.html



http://arxiv.org/pdf/1308.3147v1.pdf

Many data suggest strong magnetic fields near black holes

New measurements suggest ordered magnetic fields near event horizons

“Resolved magnetic-field structure and variability near the event horizon of Sagittarius A* ”
M. Johnson *et al.*, *Science* 350 pp. 1242 - 1245 (Dec. 4, 2015)

http://www.sciencemag.org/content/350/6265/1242

http://arxiv.org/pdf/1512.01220v1.pdf

Black hole classifications

Class	Mass	Size
Supermassive black hole	~10^5–10^{10} M_{Sun}	~0.001–400 AU
Intermediate-mass black hole	~10^3 M_{Sun}	~10^3 km ≈ R_{Earth}
Stellar black hole	~10 M_{Sun}	~30 km
Micro black hole	up to ~M_{Moon}	up to ~0.1 mm

Source: Wikipedia

Credit: CFA / M. Weiss

http://www.astro.phys.s.chiba-u.ac.jp/mhd2005/presentation/y_kato.pdf

Magnetic flux tubes may form on black hole accretion disks

Magnetic fields of ~7.0 x 10^8 Gauss develop on upper edge of such disks

Case #1: mechanism accelerates protons to center-of-mass energies ≈2 x 10^{17} eV

Accelerated particles center-of-mass energy for exploding flux tube

$$e\bar{V} \approx (30\ \text{GeV}) \left(\frac{B}{\text{kG}}\right) \left(\frac{\pi R^2}{\Lambda - \text{km}}\right).$$

Eq. (20) in *Pramana* paper (2010)

Assumptions: magnetic flux tube formed on *supermassive* black hole accretion disk initially contains protons, electrons, some neutrons, and traces of other elemental ions if any infalling matter is present; assume flux tube dimensions are comparable to those of a similar structure on the Sun, namely that its radius = 10^4 km and time Δ t = 10^2 seconds and magnetic field inside = 7.0 x 10^8 Gauss (7.0 x 10^5 kilogauss) per paper by de Gouveia Dal Pino and Lazarian in *A&A* (2005)

Calculation based on Eq. 20 presuming that flux tube destabilizes and explodes:

$\Lambda = c\,\Delta t = (2.998 \times 10^5) \times (1 \times 10^2\ \text{sec}) = 2.998 \times 10^7\ \text{km} \approx 3.0 \times 10^7\ \text{km}$

$B = 7.0 \times 10^5\ kG$

$\pi r^2 = 3.1416 \times (1 \times 10^4)^2 = 3.1416 \times (1 \times 10^8) \approx 3.1 \times 10^8\ \text{km}^2$

$e\overline{V} \approx [\,(30.0) \times (7.0 \times 10^5)\,] \times (3.1 \times 10^8 / 3.0 \times 10^7) \approx [\,2.1 \times 10^7\,] \times (1.03 \times 10^1)$

$e\overline{V} \approx 2.16 \times 10^8\ \text{GeV} \approx 2.16 \times 10^{17}\ \text{eV} \approx 2.2 \times 10^{17}\ \text{eV}$

Magnetic flux tubes may form on black hole accretion disks

Magnetic fields of ~7.0 x 10^8 Gauss develop on upper edge of such disks

Case #2: mechanism accelerates protons to center-of-mass energies ≈ .9 x 10^{19} eV

Accelerated particles center-of-mass energy for exploding flux tube

$$eV \approx (30\text{ GeV})\left(\frac{B}{\text{kG}}\right)\left(\frac{\pi R^2}{\Lambda - \text{km}}\right)$$

Eq. (20) in *Pramana* paper (2010)

Assumptions: magnetic flux tube formed on *supermassive* black hole accretion disk initially contains protons, electrons, some neutrons, and traces of other elemental ions if any infalling matter is present; now assume flux tube dimensions as follows: radius = 6.4 x 10^3 km (radius of the earth) and time $\Delta t = 10^2$ seconds and magnetic field inside averages = 7.0 x 10^{10} G while the flux tube exists

Calculation based on Eq. 20 presuming that flux tube destabilizes and explodes:

$$\Lambda = c\,\Delta t = (2.998 \times 10^5) \times (1 \times 10^2 \text{ sec}) = 2.998 \times 10^7 \text{ km} \approx 3.0 \times 10^7 \text{ km}$$

$$B = 7.0 \times 10^7\ kG$$

$$\pi r^2 = 3.1416 \times (6.4 \times 10^3)^2 = 3.1416 \times (41.0 \times 10^6) \approx 128.8 \times 10^6 \approx 1.288 \times 10^8 \text{ km}^2$$

$$e\overline{V} \approx [\,(30.0) \times (7.0 \times 10^7)\,] \times (1.288 \times 10^8 / 3.0 \times 10^7) \approx [\,2.1 \times 10^9\,] \times (0.43 \times 10^1)$$

$$e\overline{V} \approx 0.90 \times 10^{10} \text{ GeV} \approx 0.9 \times 10^{19} \text{ eV}$$

“Magnetic tower” flux tubes may form near black hole jets

Large tube: radius = 10^6 cm, magnetic field = 7 x 10^8 Gauss, time = 10^2 s

Widom-Larsen mechanism accelerates protons to mean energies of ~2.0 x 10^{21} eV

Accelerated particles center-of-mass energy for exploding flux tube

$$e\bar{V} \approx (30\ \mathrm{GeV}) \left(\frac{B}{\mathrm{kG}}\right) \left(\frac{\pi R^2}{\Lambda - \mathrm{km}}\right).$$

Eq. (20) in *Pramana* paper (2010)

Assumptions: magnetic flux tube develops near base of relativistic jet as it is forming on a supermassive black hole; tube initially contains mixture of protons, electrons, some neutrons, and traces of other elemental ions if any infalling matter is present; assume flux tube dimensions are as follows: radius = 1 x 10^6 km and time $\Delta t = 10^2$ seconds and magnetic field inside = 7.0 x 10^8 Gauss (7.0 x 10^5 kilogauss); these parameters represent transient values before tube violently destroyed by explosion

Calculation based on Eq. 20 presuming that this flux tube destabilizes and explodes:

$\Lambda = c\,\Delta t = (2.998 \times 10^5) \times (1 \times 10^2\ \mathrm{sec}) = 2.998 \times 10^7\ \mathrm{km} \approx 3.0 \times 10^7\ \mathrm{km}$

$B = 7.0 \times 10^5\ kG$

$\pi r^2 = 3.1416 \times (1.0 \times 10^6)^2 = 3.1416 \times (1 \times 10^{12}) \approx 3.14 \times 10^{12}\ \mathrm{km}^2$

$e\bar{V} \approx [\,(30.0) \times (7.0 \times 10^5)\,] \times (3.14 \times 10^{12} / 3.0 \times 10^7) \approx [\,21.0 \times 10^6\,] \times (1.05 \times 10^5)$

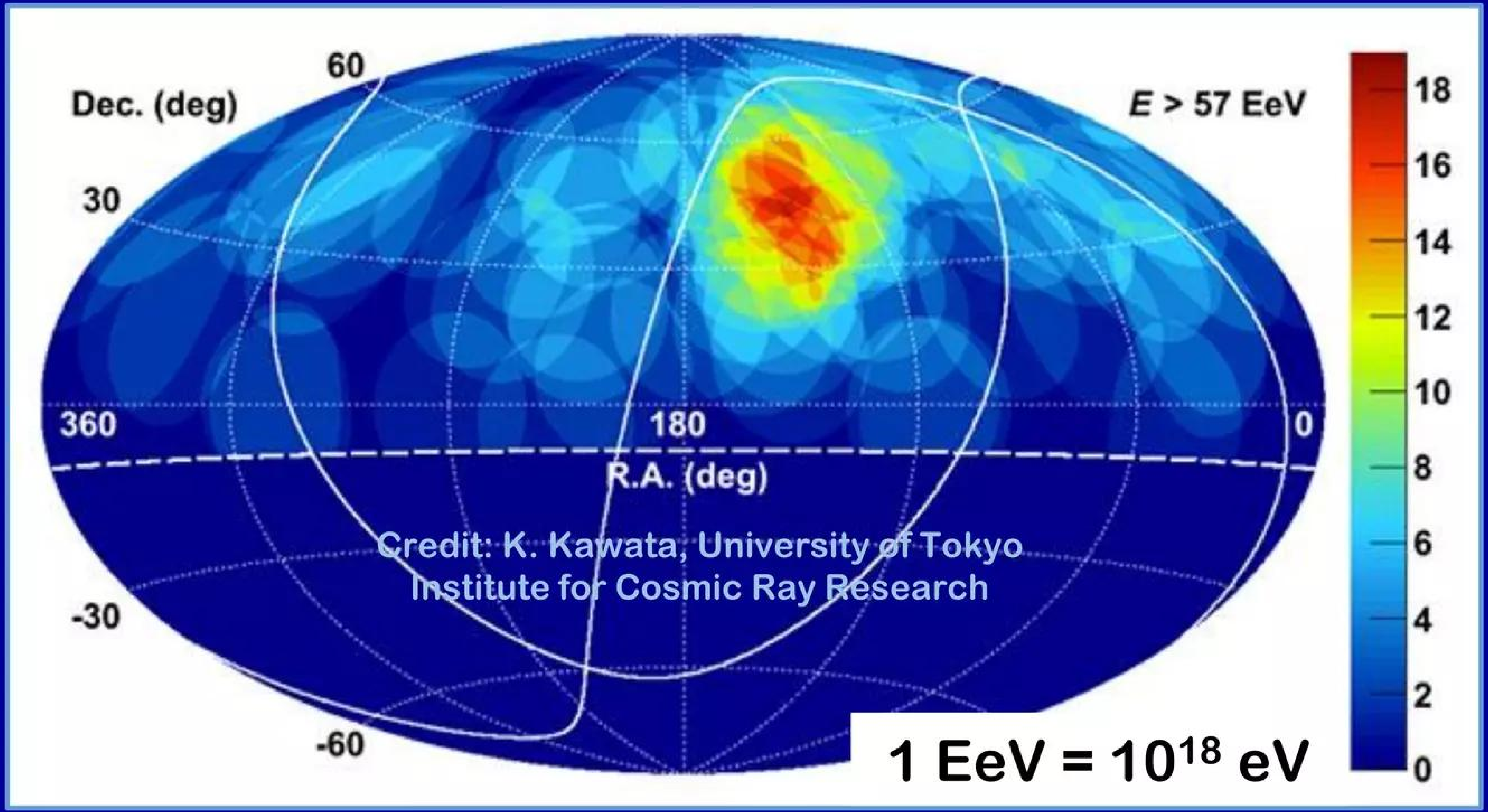
$e\bar{V} \approx 22.05 \times 10^{11}\ \mathrm{GeV} \approx 2.205 \times 10^{12}\ \mathrm{GeV} \approx 2.21 \times 10^{21}\ \mathrm{eV} \approx$ **2.2 x 10^{21} eV**

Some data shows hot spot for ultrahigh energy cosmic rays

About 27% of 87 UHE CRs >57 EeV come from 6% of sky near Ursa Major

Are compact objects with ionized H and *very* high magnetic fields found therein ?

- ✓ Recent data suggests there may be a hotspot for UHE CRs in direction of Ursa Major
- ✓ Our calculations suggest large plasma-filled flux tube structures with extremely high transient magnetic fields near black holes would be source candidates if data correct
- ✓ Thus and per He *et al.* (2014) might look near hotspot for objects like M82 and Mrk 180



1 EeV = 10^{18} eV

"Ultra-high-energy-cosmic-ray hot spots from tidal disruption events" D. Pfeffer *et al.* arXiv:1512.04959v1 [astro-ph.HE] 15 Dec 2015

http://arxiv.org/pdf/1512.04959v1.pdf

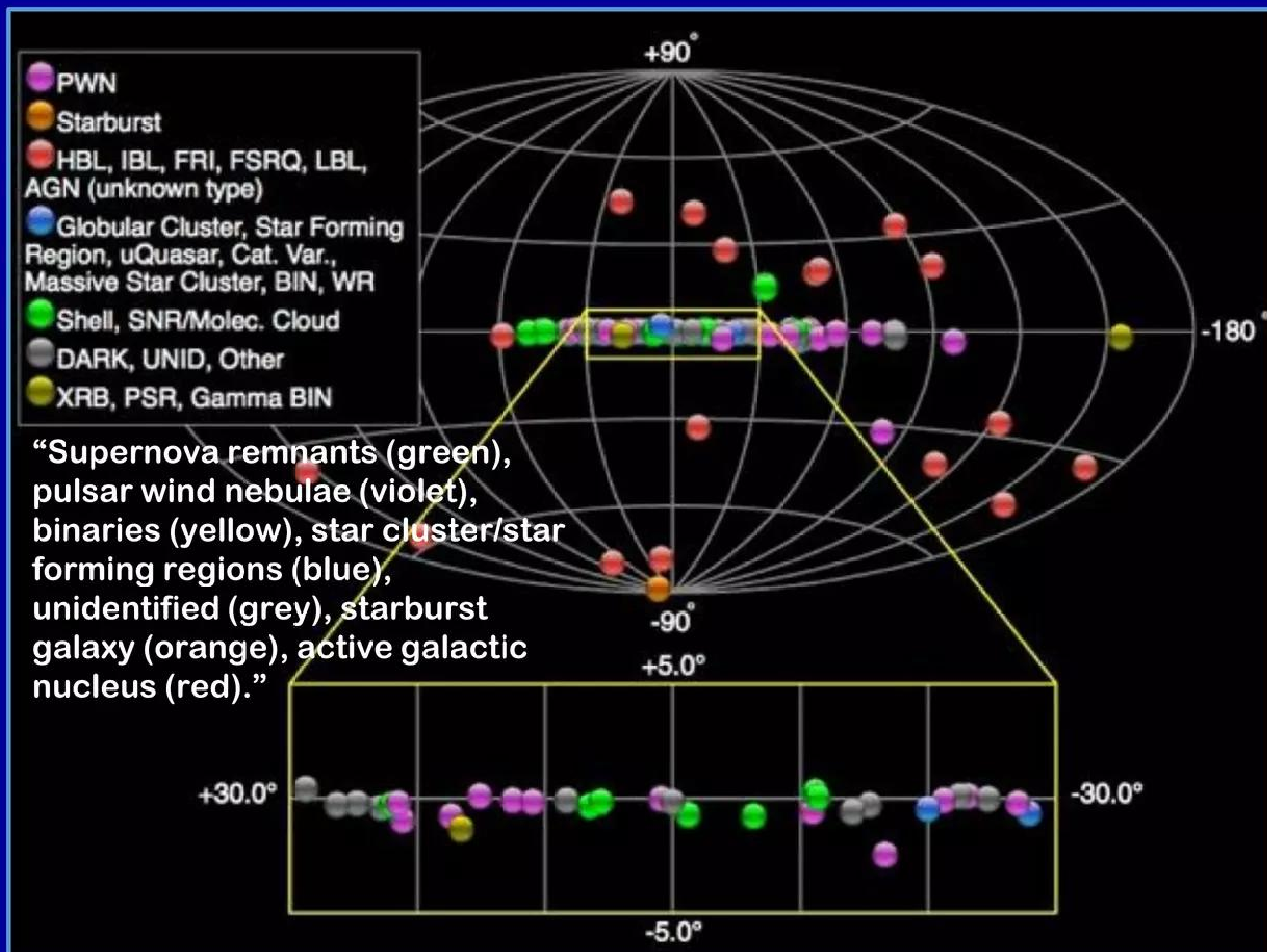
Cosmic ray gamma sources frequent in plane of our galaxy

Very high energy gamma photons are those with energies > 10s of GeVs

Data indicates wide variety of different types of sources for VHE gamma emission

TeVCat sky map of H.E.S.S.-discovered gamma ray sources as of July 2012
Colors indicates likely nature of each source

High Energy Stereoscopic System
H.E.S.S.

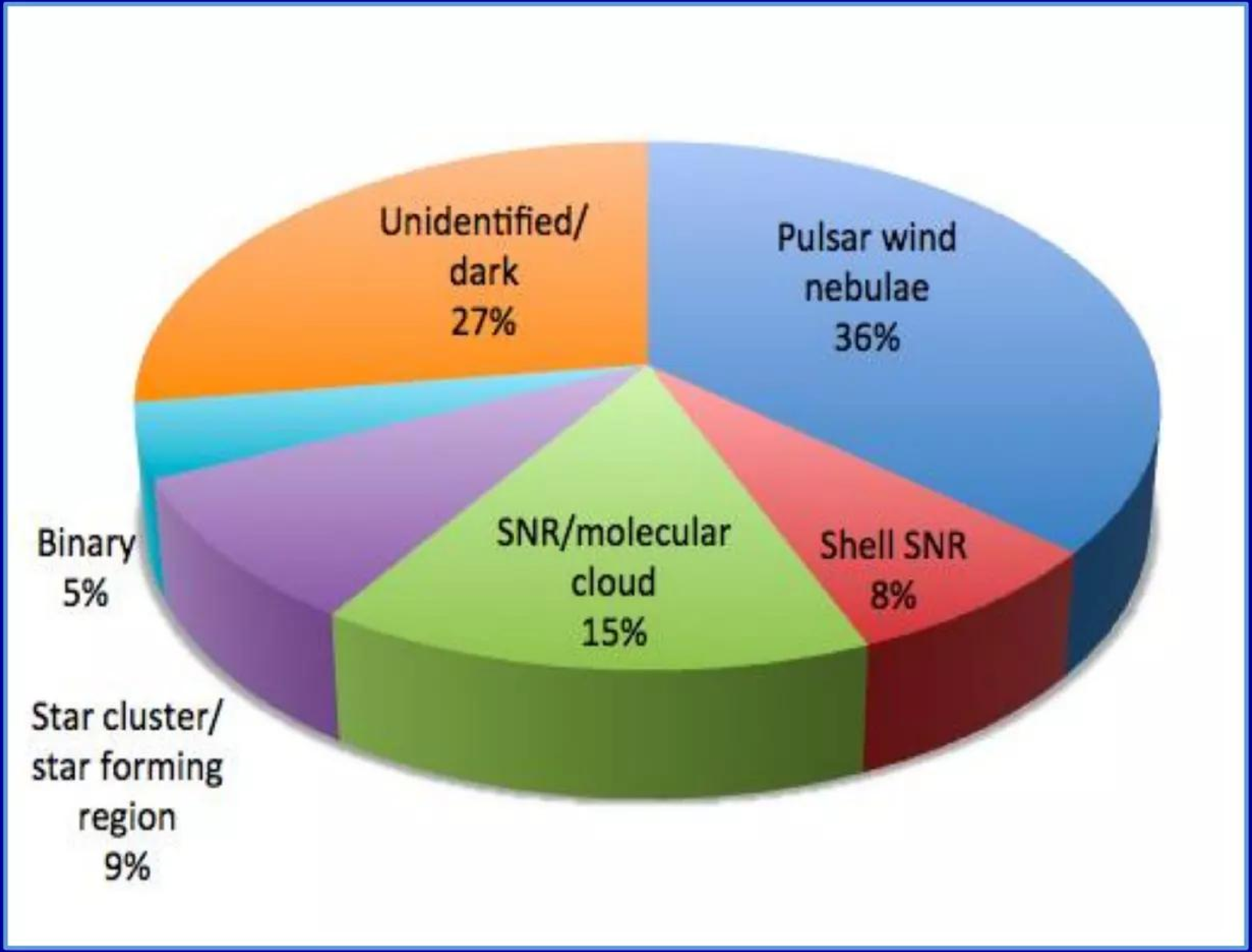


https://www.mpi-hd.mpg.de/hfm/HESS/pages/about/physics/

Pulsar wind nebulae + unidentified (probably pulsars) = 63%

W-L-S many-body collective mechanism can create gammas >10s of TeVs

"It is now recognized that acceleration of particles to very high energies and the resulting emission of very high energy gamma rays is not a rare phenomenon, but rather a frequent byproduct of stellar evolution."



https://www.mpi-hd.mpg.de/hfm/HESS/pages/about/physics/

Nucleosynthesis via W-L-S electroweak neutron production

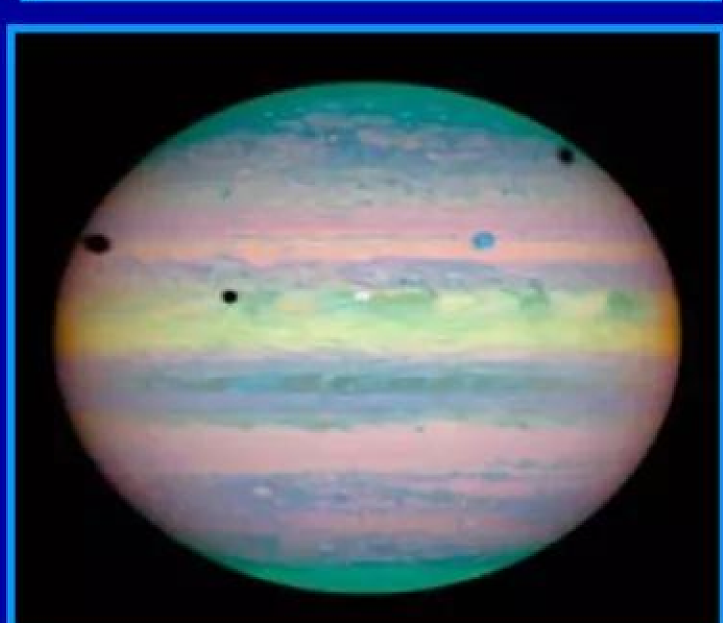
Not limited to superhot stellar interiors --- very low rates may be common

Collective W-L-S $e + p$ reactions occur on many types of stars, nebulae & planets

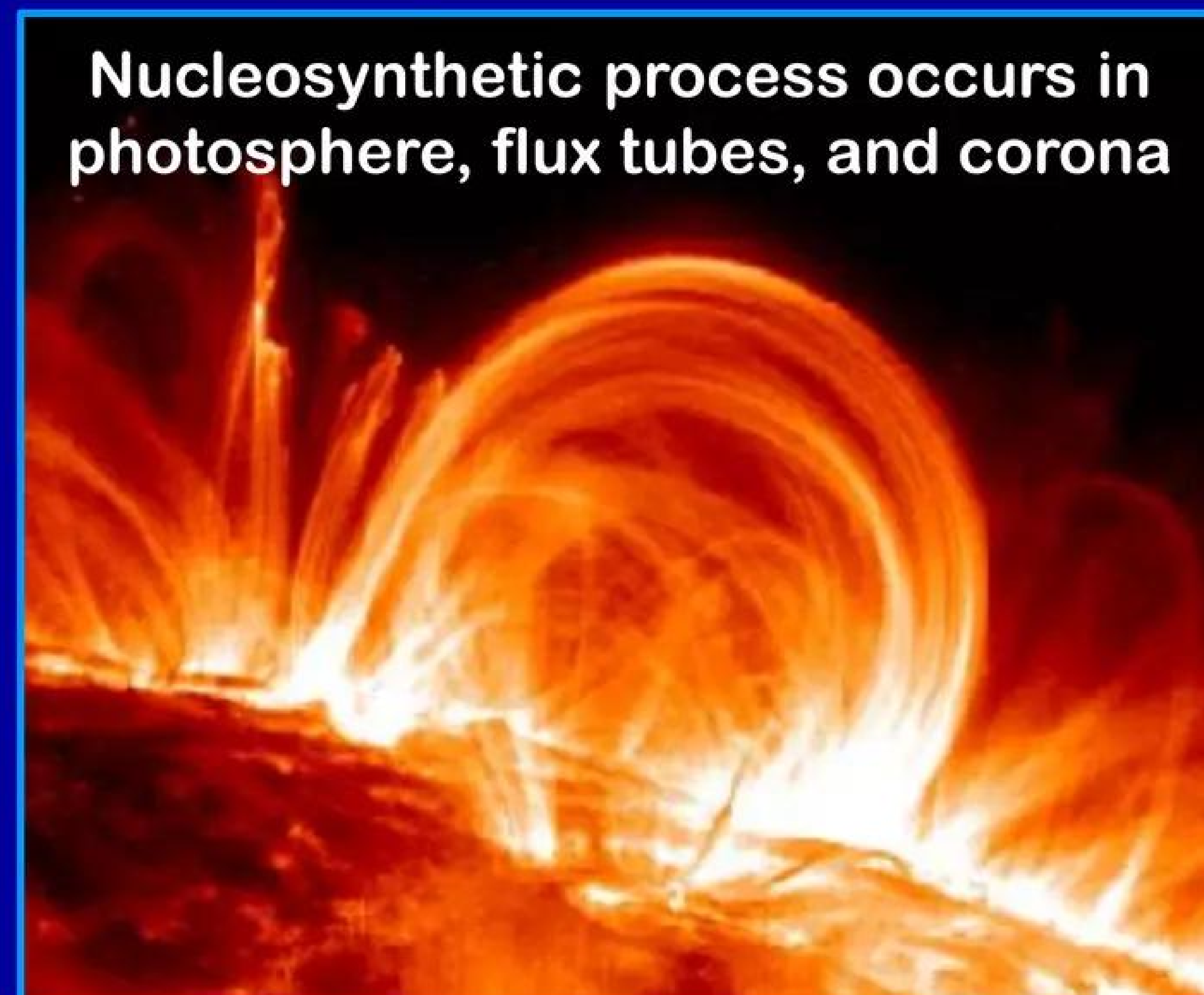
Planetary lightning produces neutrons

Earth: LENRs occur in many places

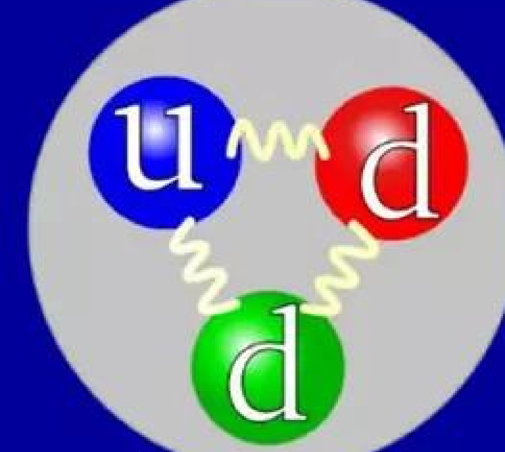
Gas-ant planets: Jupiter not failed star



W-L-S operates on the Sun

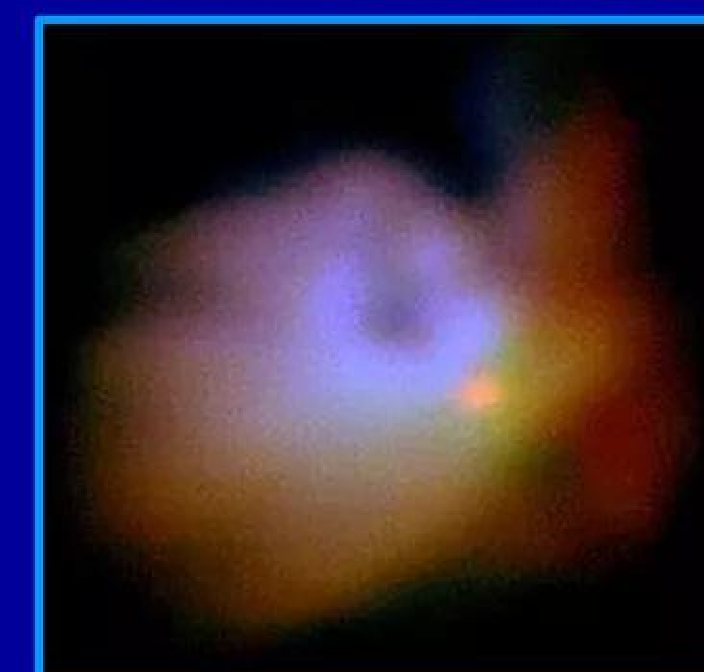


Credit: TRACE image of coronal loops in UV



Quark structure of the neutron - credit: Wikipedia

Very dusty Eagle Nebula



T-Tauri star embedded In nebulosity

White dwarf stars – don't support fusion

Miley et al. LENR experiments show 5-peak mass spectrum

Is unique signature of ultralow energy neutron capture and beta$^-$ decays

Widom & Larsen predict 5-peak mass spectrum with a simple 2-parameter model

Product mass-spectrum predicted by W-L model vs. raw data

"Nuclear abundances in metallic hydride electrodes of electrolytic chemical cells"
A. Widom and L. Larsen
arXiv:cond-mat/0602472 (Feb 2006)

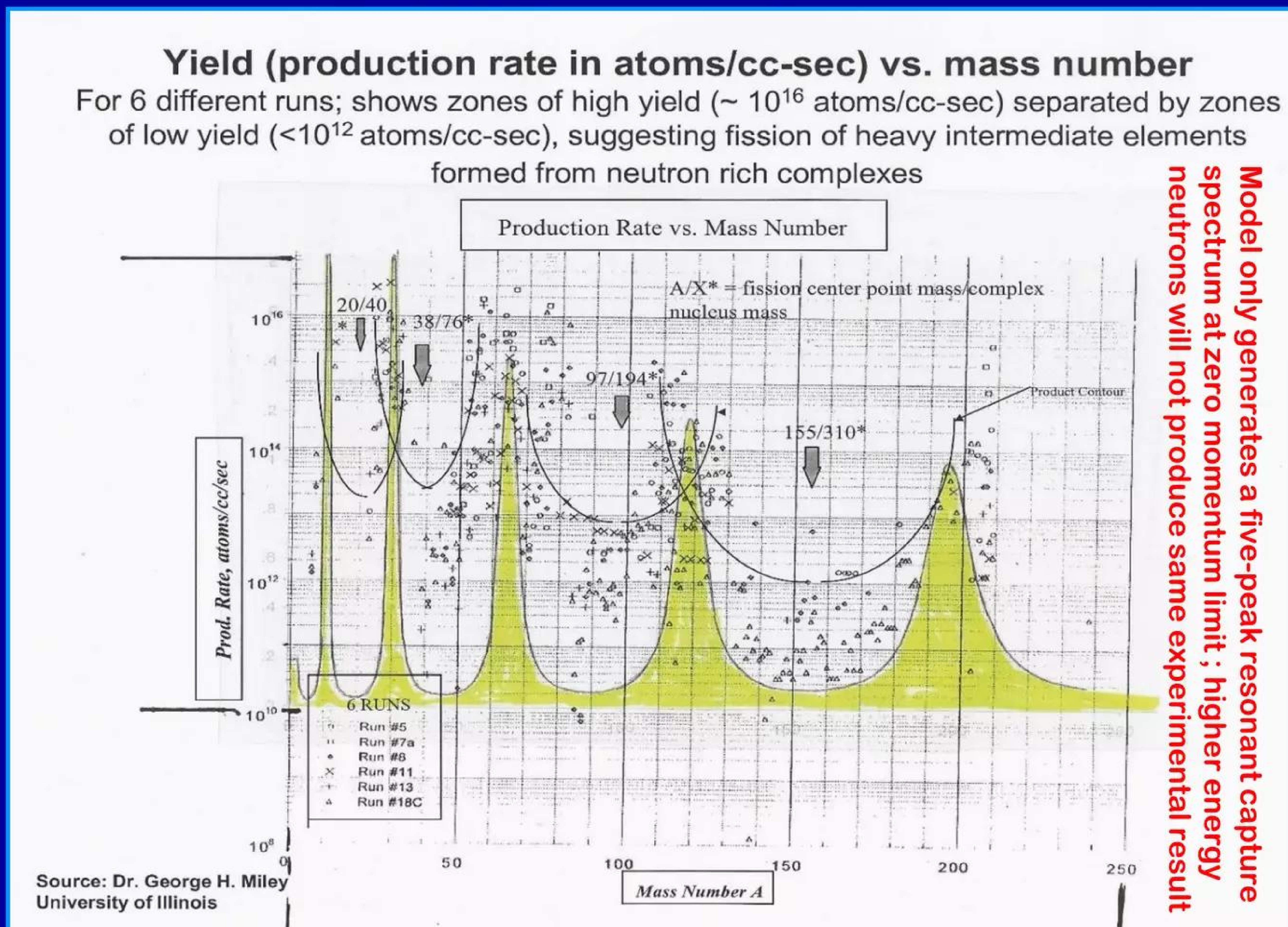


Chart presents Miley's raw data; yellow peaks and valleys show results of W-L neutron optical potential model superimposed onto Miley data

http://arxiv.org/pdf/cond-mat/0602472v1.pdf

Fowler et al. suggested ex-core nucleosynthesis in 1965

In spite of their huge professional stature the paper was and is ignored

Astrophysical community believed nucleosynthesis only occurs in stellar cores

"The synthesis and destruction of elements in peculiar stars of Types A and B," W. Fowler, E. Burbidge, G. Burbidge, and F. Hoyle *The Astrophysical Journal* 142 pp. 423 - 450 (1965) http://adsabs.harvard.edu/full/1965ApJ...142..423F

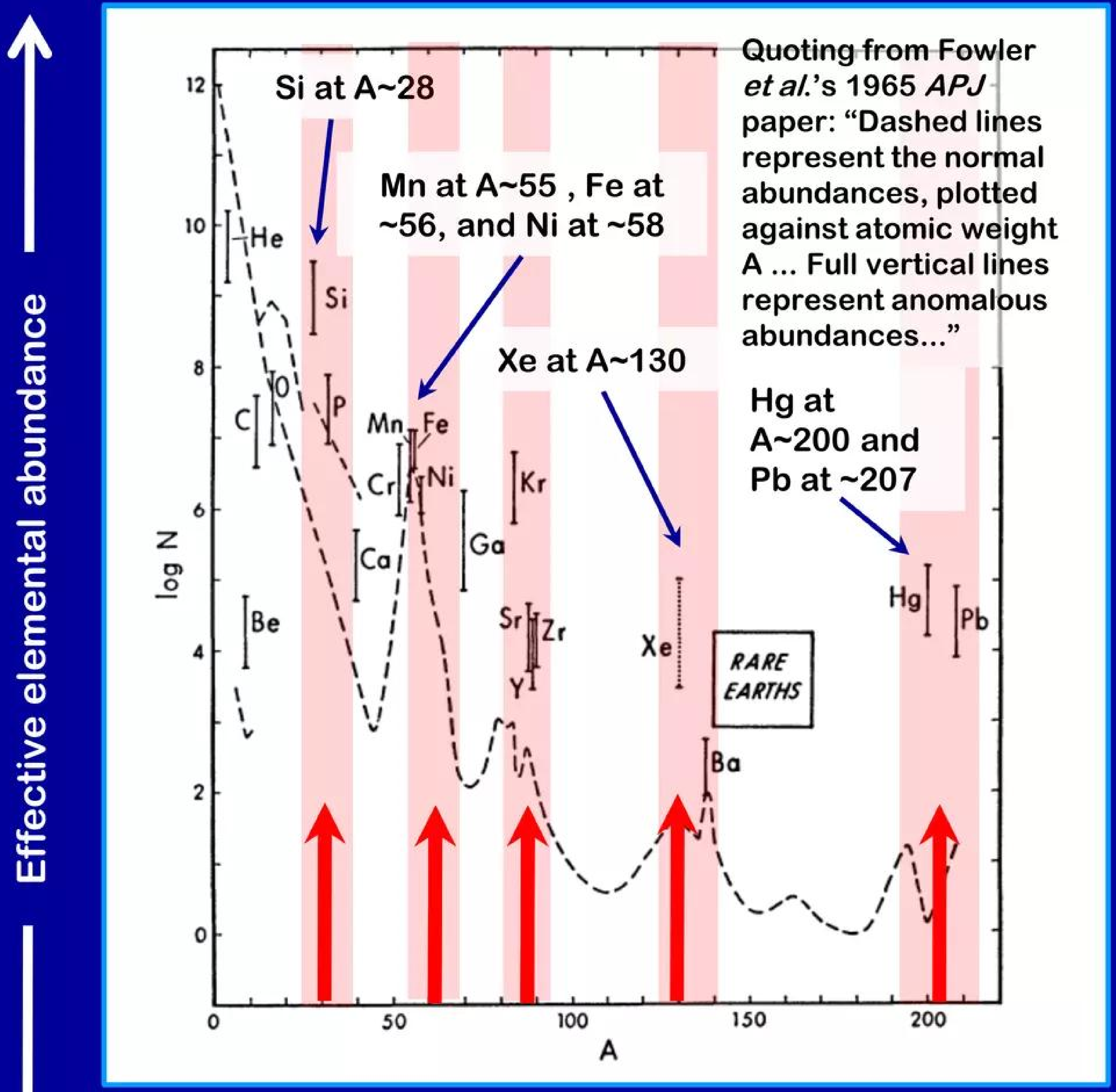
- ✓ After publishing B^2FH in 1957 (which still overshadows astrophysics today, 58 years later), Fowler, both Burbidges, and Hoyle went even further with their thinking in attempting to better explain anomalous elemental overabundances spectroscopically measured in the atmospheres of certain "chemically peculiar" (CP) A and B stars having much-higher-than-normal atmospheric magnetic fields
- ✓ Summarizing: to explain anomalous atmospheric abundances in CP stars that appeared to be inconsistent with 'core-only' nucleosynthesis, they proposed several alternative mechanisms. While no final conclusion was reached, they did note one (then heretical) possibility (quoting p.430): "We then developed a theory for the production of anomalous abundances in a thin atmospheric layer by surface nuclear reactions, the energy for which came from the star's magnetic field. We postulated that large fluxes of protons were accelerated in spot regions in the surface and gave rise both to spallation in the highest levels and to a neutron flux through (*p*, *n*)-reactions lower in the atmosphere, and that these neutrons were captured to produce the overabundances of the heavy elements."

Peaks and valleys in Fowler et al. data compared to LENRs

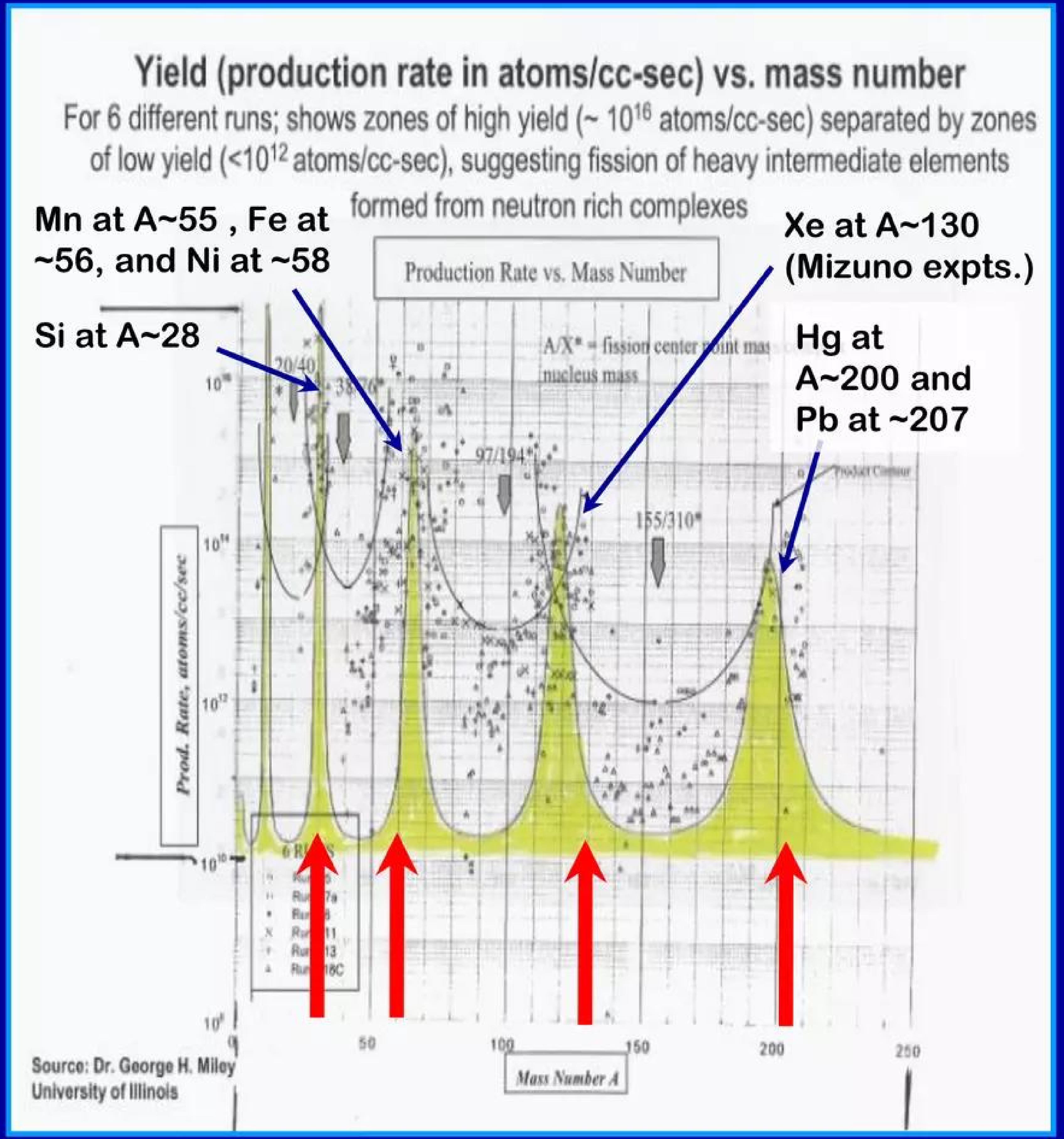
Tantalizing similarity between Fowler, Miley datasets and output of model

Overabundances observed in CP stars could have some contribution from LENRs

Fowler Fig. 2: Dashed lines = normal abundances; vertical lines = anomalous abundances



Adapted Fig. 2 – Fowler et al. (1965)



Miley data (1996) with superimposed W-L model

Atomic weight A goes from 0 to 200+ on each chart

Chemically peculiar (CP) stars with strong magnetic fields

Goriely proposed that nuclear reactions occur on surface of HD 101065

"Nucleosynthesis by accelerated particles to account for the surface composition of HD 101065" S. Goriely, *Astronomy & Astrophysics* 466 pp. 619 - 626 (2007)
http://www.aanda.org/articles/aa/pdf/2007/17/aa6583-06.pdf

- ✓ HD 101065 is another name for very chemically peculiar (CP) Przybylski's Star (Ap class), first discovered by the astronomer Antoni Przybylski in 1961 and discussed by Fowler *et al.* (*APJ* 1965). It has since drawn widespread attention because its spectra indicate the presence of highly anomalous array of different elements in its atmosphere, including rare earth elements (REEs) and Actinides; for an older review article, "HD 101065:Przybylski's Star," E. Munoz, J. Crepp, and A. Narayanan see: http://www2.astro.psu.edu/~ealicea/research/gradschool/przyreport.pdf

- ✓ Quoting Goriely: "The mechanisms responsible for exciting roAp stars and other physical parameters that distinguish them from non pulsating CP stars remain an open question. The CP stars exhibit a remarkable variety of elemental enhancements and depletions in their photospheres, sometimes 5 to 6 orders of magnitudes different than found in the sun (Cowley & Bord 2004) … Various scenarios have been suggested to account for the origin of CP stars, including contact binaries that transfer mass to each other and eventually merge into a single star. However, quantitatively, the CP-star abundance peculiarities have been explained almost uniquely on the basis of diffusion processes, i.e. the diffusive segregation of ionic and isotopic species resulting from the balance between radiative and gravitational forces within the atmosphere and sub atmospheric regions (Michaud 1970, 2004)."

Anomalous elements are found in HD 101065's atmosphere

Neutron-catalyzed nucleosynthesis of elements can explain this data

Need charged particle acceleration mechanism that creates neutron fluxes

- ✓ "Recent observations suggest the presence of short-lived radioactive elements, such as Tc, Pm, and 84 ≤ Z ≤ 99 elements, at the surface of the CP roAp star HD 101065, also known as Przybylski's star … if confirmed, it can in no way be explained by diffusion processes. Only nuclear reactions could possibly be responsible for the synthesis of such short-lived radioelements (in particular, Pm's longest isotopic half-life is 17.7 yr) … large magnetic fields observed in Ap stars (in the case of HD 101065, the magnetic field amounts to B = 2300 G) could be at the origin of a significant acceleration of charged particles, mainly protons and α-particles, that in turn can modify the surface content by interaction with the stellar material."
- ✓ Goriely hypothesized that charged particles locally accelerated to high energies by some unknown mechanism(s) produce neutrons via collision-driven spallation reactions that can occur with particle irradiation of solar-like materials; these produced neutrons then capture on elements present in or around HD 101065
- ✓ "Due to the exploratory nature of the present study, no effort has been made to understand the possible mechanisms that could be held responsible for accelerating the energetic particles. As already discussed, these particles could be locally accelerated, but they could also come from an external source. A purely parametric approach is followed by taking the properties of the accelerated proton and α-particle fluxes as free parameters." [W-L-S theory provides acceleration mechanism]

W-L-S e^- + p^+ reactions can produce neutrons on HD 10165

Theory provides acceleration mechanism and creates fluxes of neutrons

- ✓ "In this specific scenario, if fluences of [spallation neutrons] the order 10^{26-27} cm^{-2} can be achieved, the abundances of the elements heavier than iron can not only be increased by 5 orders of magnitude, but also the neutron flux becomes strong enough to bridge the $N > 126$ α-unstable region between Po and Fr and produce actinides with a charge as high as $Z \sim 100$ in large amounts. This is essentially due to the high neutron densities of $N_n \sim 10^{15}$ cm^{-3} reached under these specific conditions ... nuclear flow at an irradiation time greater than some 1000 *s* is shifted to the neutron-rich side of the valley of stability. This property has the decisive effect of enabling a significant production of actinides."
- ✓ "From the general study of Sect. 3, the present nucleosynthesis turns out to be attractive in many respects to explain the abundance estimated at the surface of the CP star HD 101065. First of all, it can be held responsible for a significant production of elements heavier than iron by a few orders of magnitude, without having to call for additional diffusive processes. This nucleosynthesis can be accompanied by a significant production of radioelements, not only Tc or Pm, but also Actinides ranging from Po to Fm, at least for the extreme conditions discussed in Sect. 3.2. ... if we assume that Pm in particular is still present in the atmosphere of HD 101065, the time elapsed between the nucleosynthesis and the observation cannot be much longer than a few years … In summary, many spectroscopic observations of HD 101065 can be met if we assume that extremely high proton and α-particle fluences have irradiated solar-like material."

Tatischeff et al. proposed nucleosynthesis in stellar flares

"Nucleosynthesis in stellar flares"
V. Tatischeff, J-P. Thibaud, and I. Ribas   arXiv preprint (2008)
http://arxiv.org/PS_cache/arxiv/pdf/0801/0801.1777v1.pdf\

- ✓ "The solar-flare gamma-ray line emission testifies that fresh nuclei are synthesized in abundance in energetic solar events ... Solar-type activity is believed to be a phenomenon inherent to the vast majority if not all main-sequence stars. The Sun is not an active star in comparison with numerous stellar objects in the solar neighbourhood that show much higher luminosities in emissions associated with coronal and chromospheric activities. Although gamma-ray line emission from other flaring stars cannot be observed with the current sensitivity of the gamma-ray space instruments, it is more than likely that the Sun is not the only star producing surface nucleosynthesis in flares."
- ✓ "Enormous enhancements of accelerated ^{3}He are measured in impulsive solar flares: the ^{3}He/α ratios found in these events are frequently three to four orders of magnitude larger than the corresponding value in the solar corona and solar wind, where ^{3}He/^{4}He $\sim$5 x 10^{-4}."
- ✓ "Asplund et al. have recently reported the detection of ^{6}Li at $\geq 2\sigma$ confidence level in nine halo stars of low metallicity, [Fe/H] < -1, situated in the turnoff region of the Hertzsprung-Russel diagram. The ^{6}Li abundances measured in these objects are far above the value predicted by Big Bang nucleosynthesis and cannot be explained by galactic cosmic-ray interactions in the interstellar medium either."

Tatischeff et al. proposed Lithium production in stellar flares

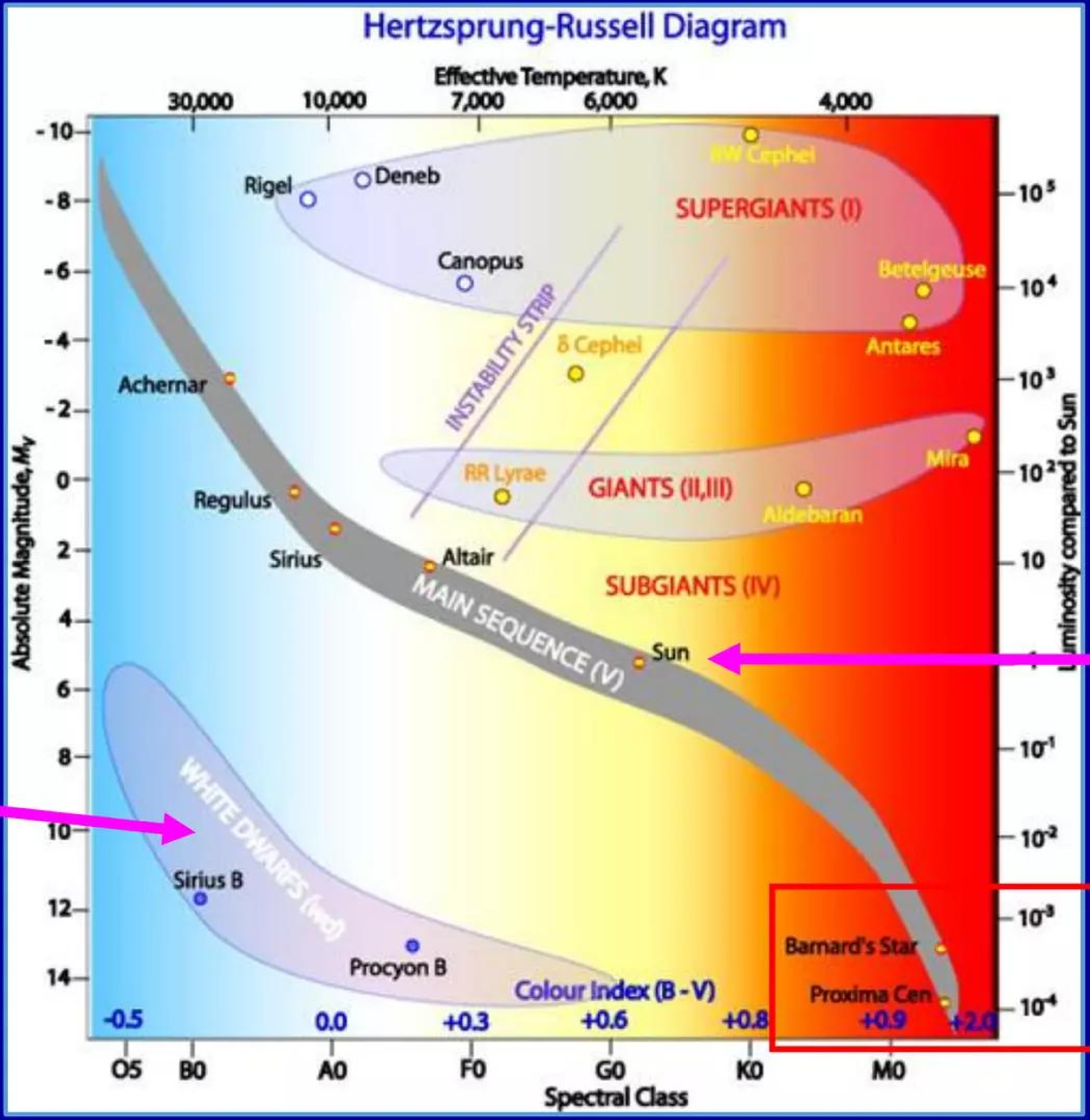
Implies that Big Bang nucleosynthesis is not the only source of Lithium

- ✓ "Tatischeff & Thibaud have shown that a significant amount of ^{6}Li can be produced in the atmospheres of metal-poor halo stars from repeated solar-like flares during their main-sequence evolution ... The Li/H ratios measured in these clusters were found to depend on stellar rotation and activity: the most rapid rotators, which are also the most active stars in chromospheric and coronal emissions, appear to be the most Li rich... Li-activity correlation is not well understood."
- ✓ "We assess the possibility that the observed Li-rotation correlation is due to a significant *in situ* production of Li by stellar flares in the most active main sequence stars [and] assume that the Li atoms produced by nonthermal reactions in the atmosphere of a given star are mainly evacuated by the stellar wind on a relatively short timescale, rather than being mixed into the bulk of the star convection zone. Comparison of the solar wind ^{6}Li abundance with calculations of the production of this isotope in solar flares has shown that this assumption is reasonable for the ... Sun."
- ✓ "We see that the flare contribution to the total Li abundance can be significant for active stars [and] can explain the non-negligible amounts of Li detected in Pleiades stars [and] Li abundances in very active stars ... [and] dispersion in Li abundances observed in young open clusters like the Pleiades and α Persei ... we have shown that stellar flares could account for significant ^{6}Li production in these objects, thus avoiding the need for a new pre-galactic source of this isotope, such as non-standard Big Bang nucleosynthesis and cosmological cosmic rays."

http://confs.obspm.fr/Blois2007/PresentationsPDF/Tatischeff.pdf

Ex-core nucleosynthesis at very low rates maybe common

Plasma-filled magnetic flux tubes occur on many different types of stars

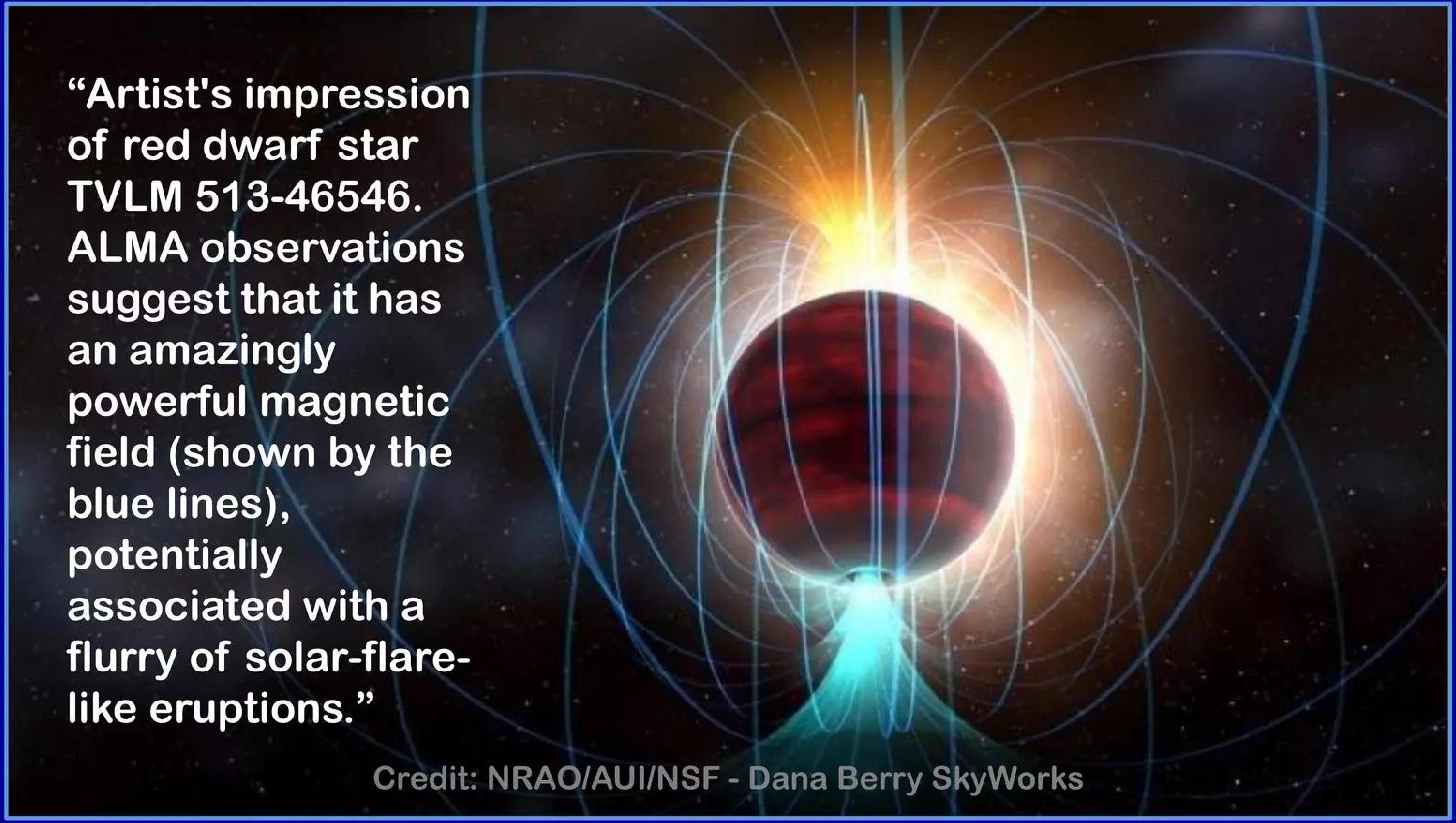


Credit: CSIRO - Australia Telescope National Facility

Plasma-filled magnetic flux tubes exist on red dwarf stars

Red dwarfs are longest-lived and comprise 75 - 80% of stars in galaxy

Energetic particle production and LENR nucleosynthesis occur in atmospheres



https://public.nrao.edu/news/pressreleases/alma-dwarf-star-2015

http://www.almaobservatory.org/images/newsreleases/151119-the-first-millimeter-detection-of-a-non-accreting-ultracool-dwarfpaper.pdf

Plasma-filled magnetic flux tubes exist on red dwarf stars

Red dwarfs are most common and longest-lived stars in the Milky Way

Energetic particle acceleration and LENR nucleosynthesis occurs in atmospheres

THE FIRST MILLIMETER DETECTION OF A NON-ACCRETING ULTRACOOL DWARF

P. K. G. Williams[1], S. L. Casewell[2], C. R. Stark[3], S. P. Littlefair[4], Ch. Helling[5], E. Berger[1]

Rev. 1, 2015 Sep 21

ABSTRACT

The well-studied M9 dwarf TVLM 513–46546 is a rapid rotator ($P_{\rm rot} \sim 2$ hr) hosting a stable, dipolar magnetic field of ~3 kG strength. Here we report its detection with ALMA at 95 GHz at a mean flux density of 56 ± 12 μJy, making it the first ultracool dwarf detected in the millimeter band, excluding young, disk-bearing objects. We also report flux density measurements from unpublished archival VLA data and new optical monitoring data from the Liverpool Telescope. The ALMA data are consistent with a power-law radio spectrum that extends continuously between centimeter and millimeter wavelengths. We argue that the emission is due to the synchrotron process, excluding thermal, free-free, and electron cyclotron maser emission as possible sources. While the ALMA data are consistent with non-time-variable emission, the interval of the observation phased with the optical maximum has an elevated flux density. These early results show how ALMA opens a new window for studying the magnetic activity of ultracool dwarfs, particularly shedding light on the particle acceleration mechanism operating in their immediate surroundings.

Keywords: brown dwarfs — radio continuum: stars — stars: individual: TVLM 513-46546

https://public.nrao.edu/news/pressreleases/alma-dwarf-star-2015

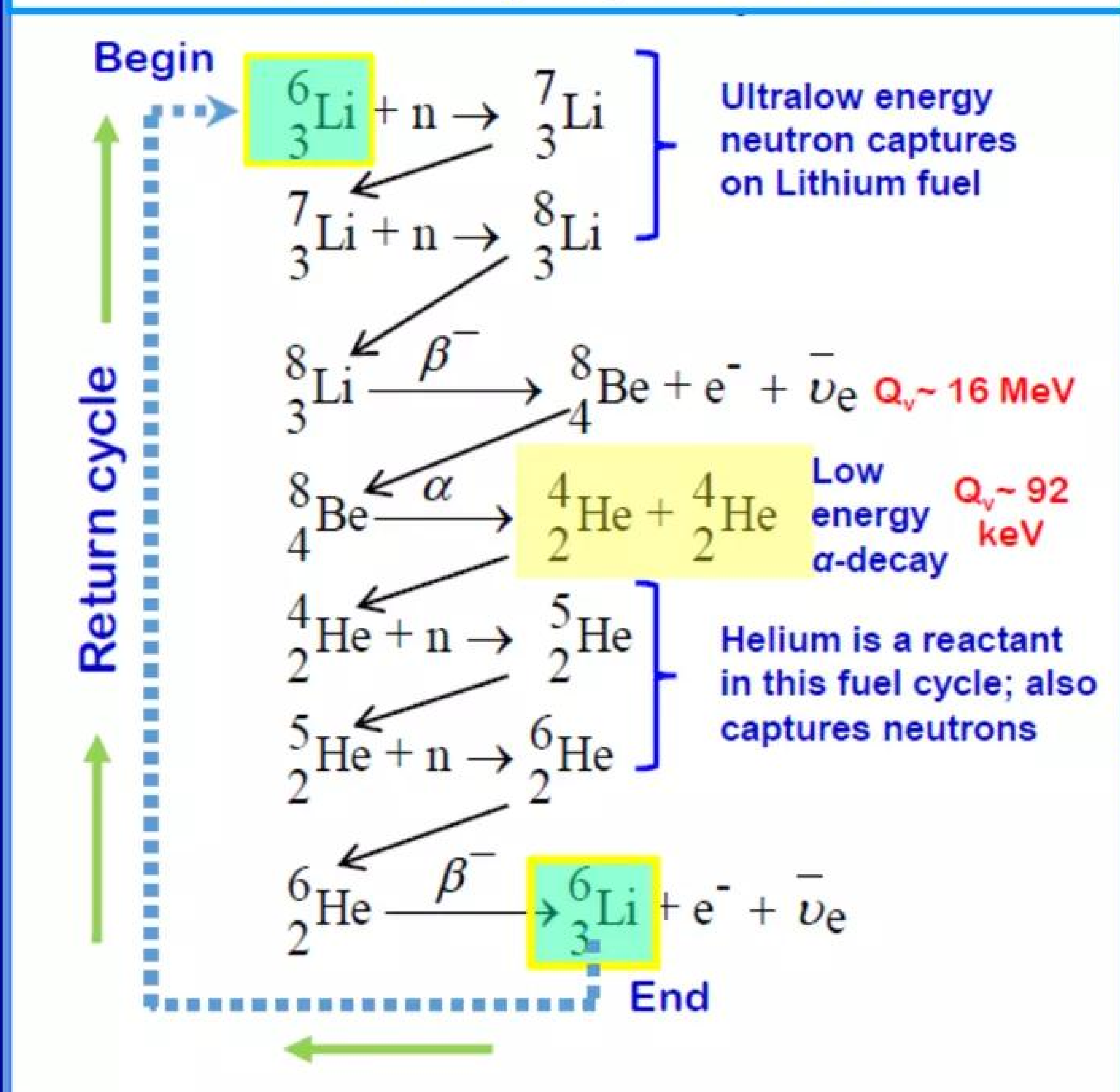
http://www.almaobservatory.org/images/newsreleases/151119-the-first-millimeter-detection-of-a-non-accreting-ultracool-dwarfpaper.pdf

Several types of younger, smaller stars may burn Lithium

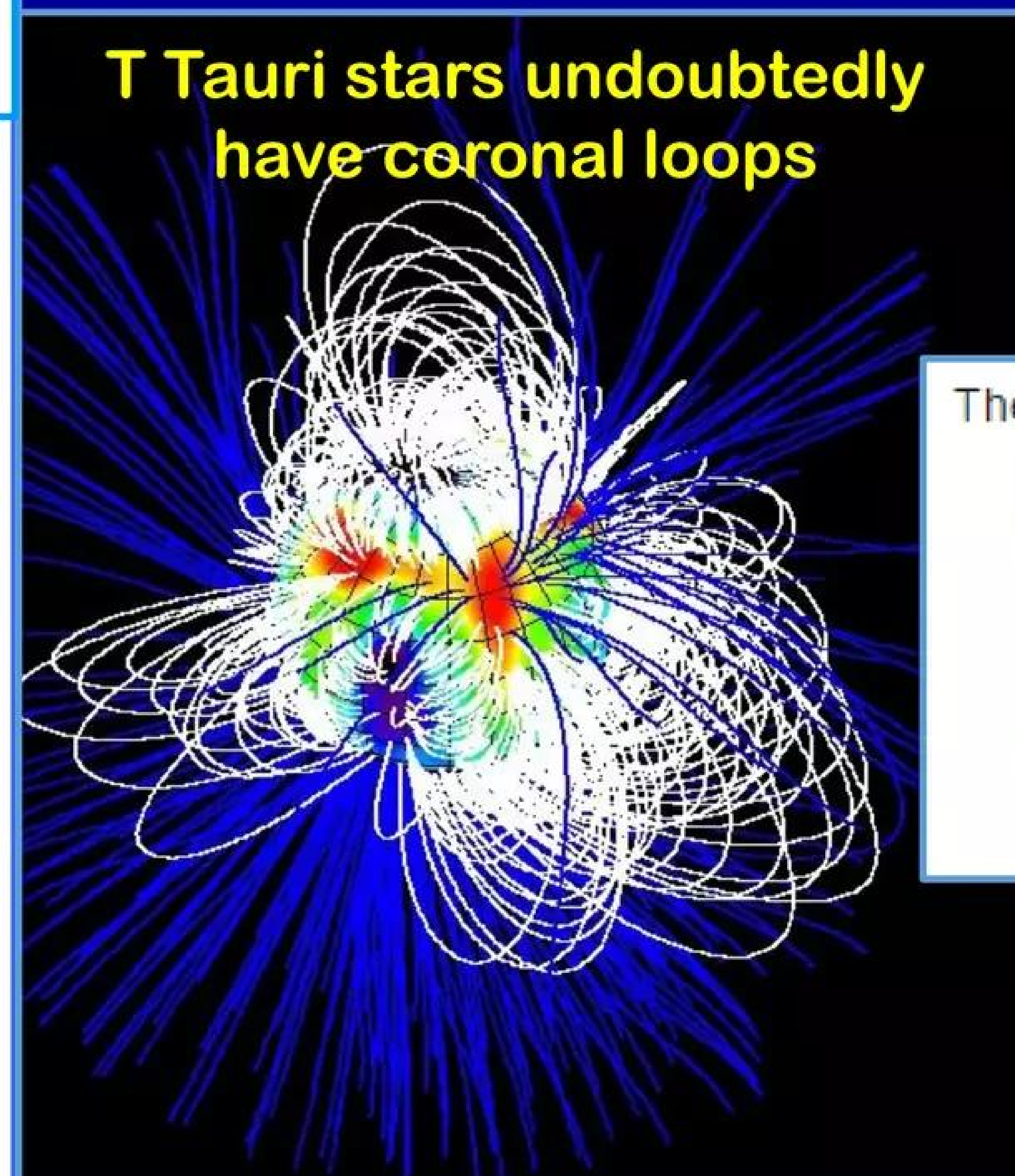
LENR Lithium cycle produces ~ same products as P-P Lithium burning

LENRs

Reactions have been demonstrated in laboratory experiments



Surface magnetic field of young T Tauri-type star named SU Aur



Credit: Pascalou Petit

Fusion reactions

The P-P chain for Lithium burning is as follows

$$p + ^{6}_{3}Li \rightarrow ^{7}_{4}Be$$
$$^{7}_{4}Be + e^- \rightarrow ^{7}_{3}Li + \nu$$
$$p + ^{7}_{3}Li \rightarrow ^{8}_{4}Be \quad \text{(unstable)}$$
$$^{8}_{4}Be \rightarrow 2\, ^{4}_{2}He + \text{energy}$$

"Tauri star is a type of pre–main sequence star that is being heated through gravitational contraction and has not yet begun to burn hydrogen at its core. They are variable stars that are magnetically active. The magnetic field of these stars is thought to interact with its strong stellar wind, transferring angular momentum to the surrounding protoplanetary disk." Source: Wikipedia

W-L-S theory can explain Lithium anomalies in certain stars

U.S. government observed equivalent anomalies in LENR experiments

"Wide spread of Lithium abundances for physically similar stars is one of the enigmas of modern astrophysics" - Polosukhina *et al*. (2011)

Slide #19: data reported through Edward Teller of Lawrence Livermore National Laboratory at a 1989 EPRI-NSF workshop described LLNL experiments in which significant depletion of Lithium-6 was observed on cathodes in electrochemical cells

http://www.slideshare.net/lewisglarsen/lattice-energy-llc-us-government-labs-reported-clearcut-neutron-capture-data-from-pf-cells-in-oct-1989-may-13-2015

"Lithium and isotopic ratio $^6Li/^7Li$ in magnetic roAp stars as an indicator of active processes" N. Polosukhina *et al.*, *Magnetic Stars* pp. 382 - 389 (2011)

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N. Polosukhina *et al.*, *Mem. S.A.It. Suppl.* **22** pp. 129 - 136 (2012)

http://adsabs.harvard.edu/full/2012MSAIS..22..129P

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A. Shavrina *et al.*, a*rXiv: 1304.4175v1 [astro-ph.SR]* (15 Apr 2013)

http://arxiv.org/pdf/1304.4175v1.pdf

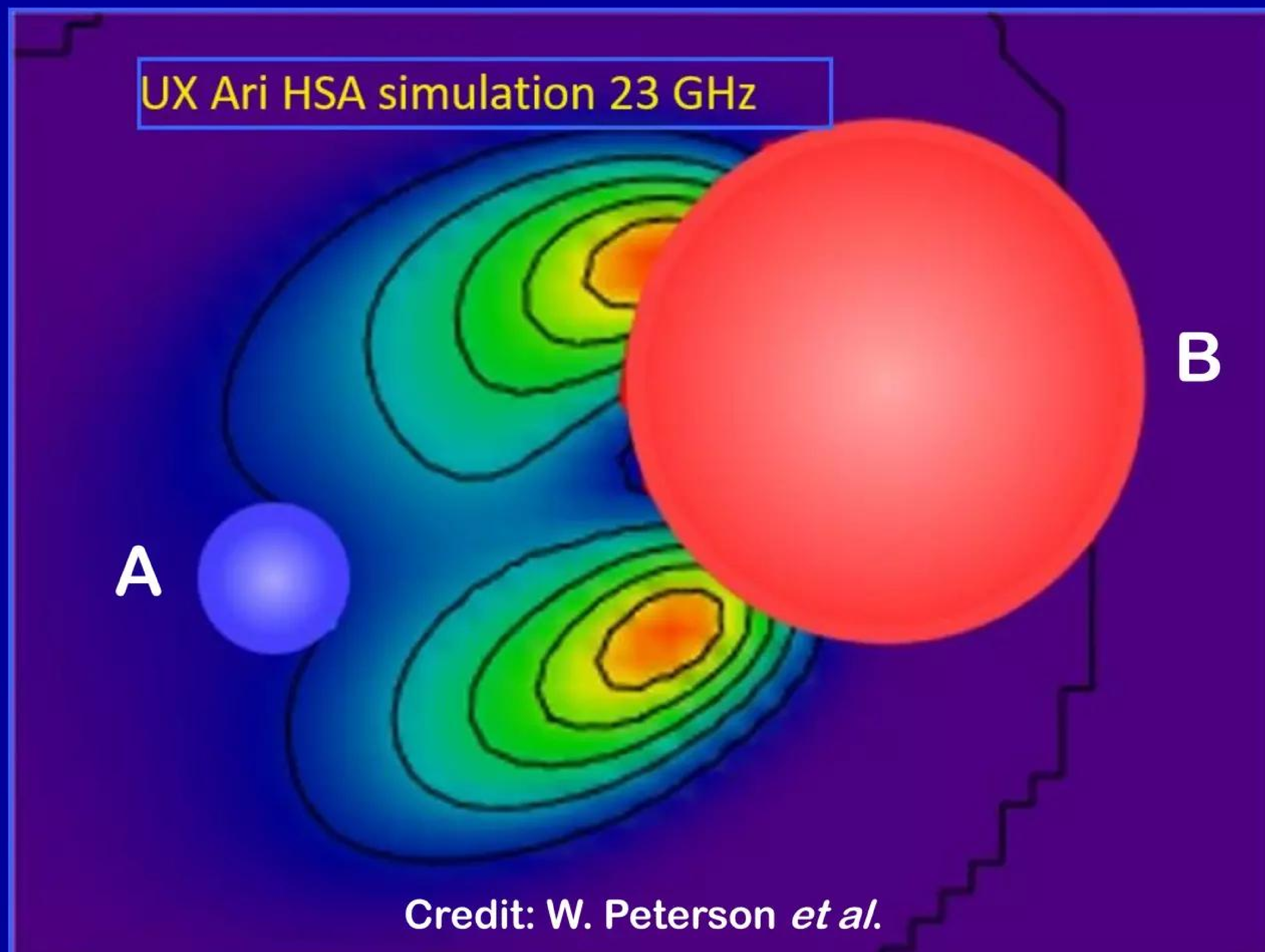
Algol B has plasma-filled coronal loop magnetic structures

"Are Algol's coronal loop structures common to active binaries?"

Three-star system: Algol B is yellow G8IV subgiant star close to Algol A

Direct imaging of a coronal loop on Algol B

"Sub-millisecond astrometry of the Algol system"

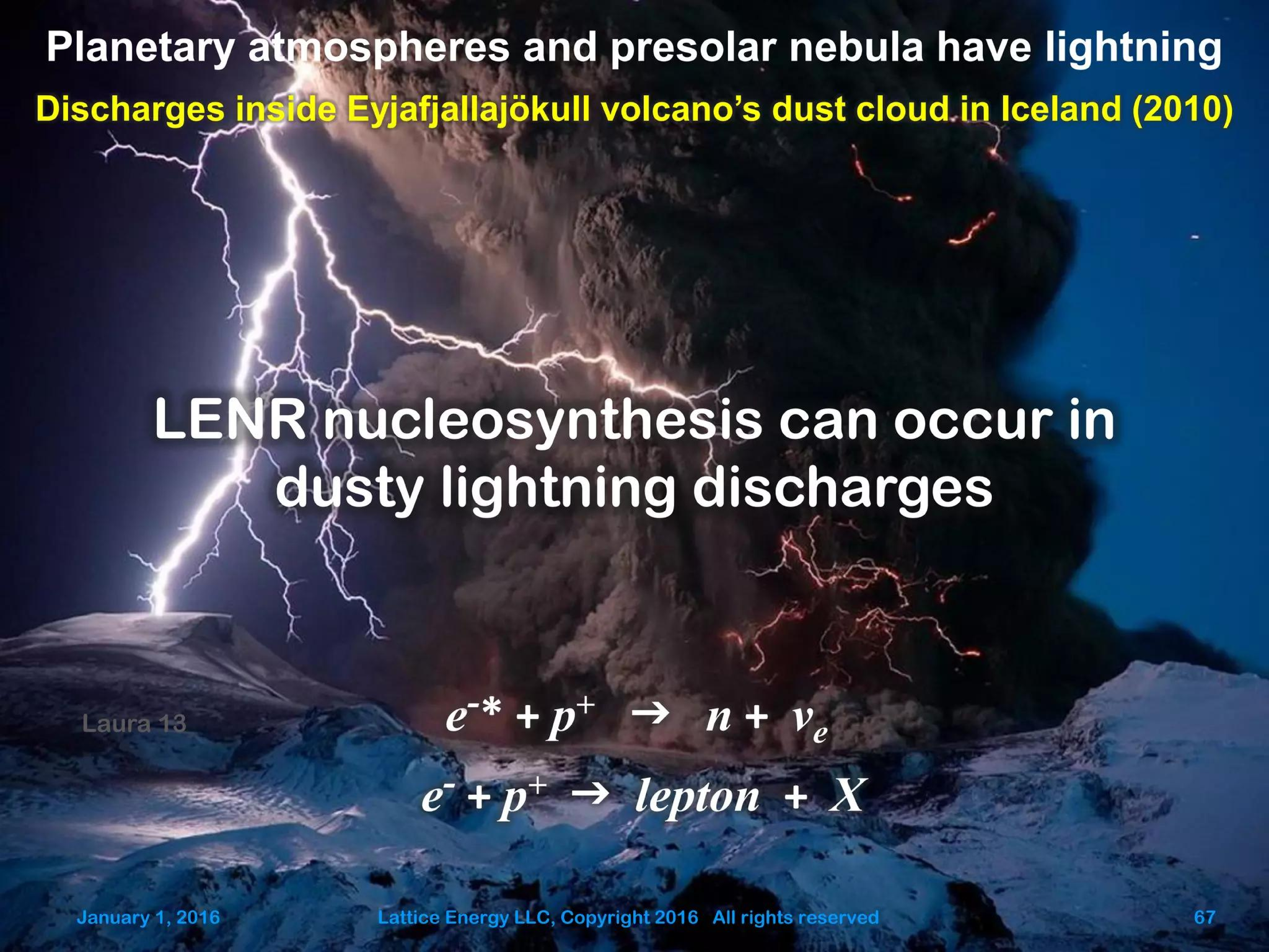


W. Peterson and R. Mutel (Univ. of Iowa, M. Goss (NRAO), and M. Gudel (ETH, Zurich)

http://www.slideserve.com/robbin/sub-milliarcsecond-astrometry-of-the-algol-system

Planetary atmospheres and presolar nebula have lightning

Discharges inside Eyjafjallajökull volcano’s dust cloud in Iceland (2010)



LENR nucleosynthesis can occur in dusty lightning discharges

$$e^{-*} + p^{+} \rightarrow n + \nu_e$$

$$e^{-} + p^{+} \rightarrow lepton + X$$

LENRs occur in lightning with embedded dust & aerosols

Intense lightning activity observed in gas giant planetary atmospheres

Could lightning-driven nucleosynthesis produce heat and isotopic anomalies ?

- ✓ Lattice's speculative conjecture: thanks to various interplanetary probes, it is now well known that substantial violent lighting activity occurs in the atmospheres of Jupiter, Saturn, Neptune, and to a much lesser degree, Uranus. It is also well-known that their atmospheres are all rich in Hydrogen in various forms and contain variable quantities of dust --- thus, they possess all the necessary ingredients for the LENR nucleosynthetic mechanism. It is also well known that Jupiter radiates ~2.7 times as much energy as it receives from the Sun; Saturn ~3.0x; Neptune ~2.7x; and Uranus ~1.0x. Are LENR processes contributing to such excess thermal energy production?
- ✓ Up until now, most of us (Lattice included) have thought in terms of there being a sharp line of demarcation between "stars" and "planets," stars being where fusion-driven nucleosynthesis takes place and planets where almost entirely chemical processes occur. Given the possibility of LENRs, that old idea may require revision
- ✓ Viewed through that long-standing conceptual paradigm, Jupiter and like gas-giant planets were regarded by many as "failed stars." Perhaps there exists a continuum of heat-producing objects between radiologically dead rocky planets and stars that are hot enough to support nuclear fusion processes --- the middle-ground being occupied by nucleosynthetically dynamic objects with increasing amounts of LENRs taking place in them. Maybe Jupiter, Saturn, and "brown dwarfs" really didn't fail?

Chemical fractionation cannot explain Genesis Mission data

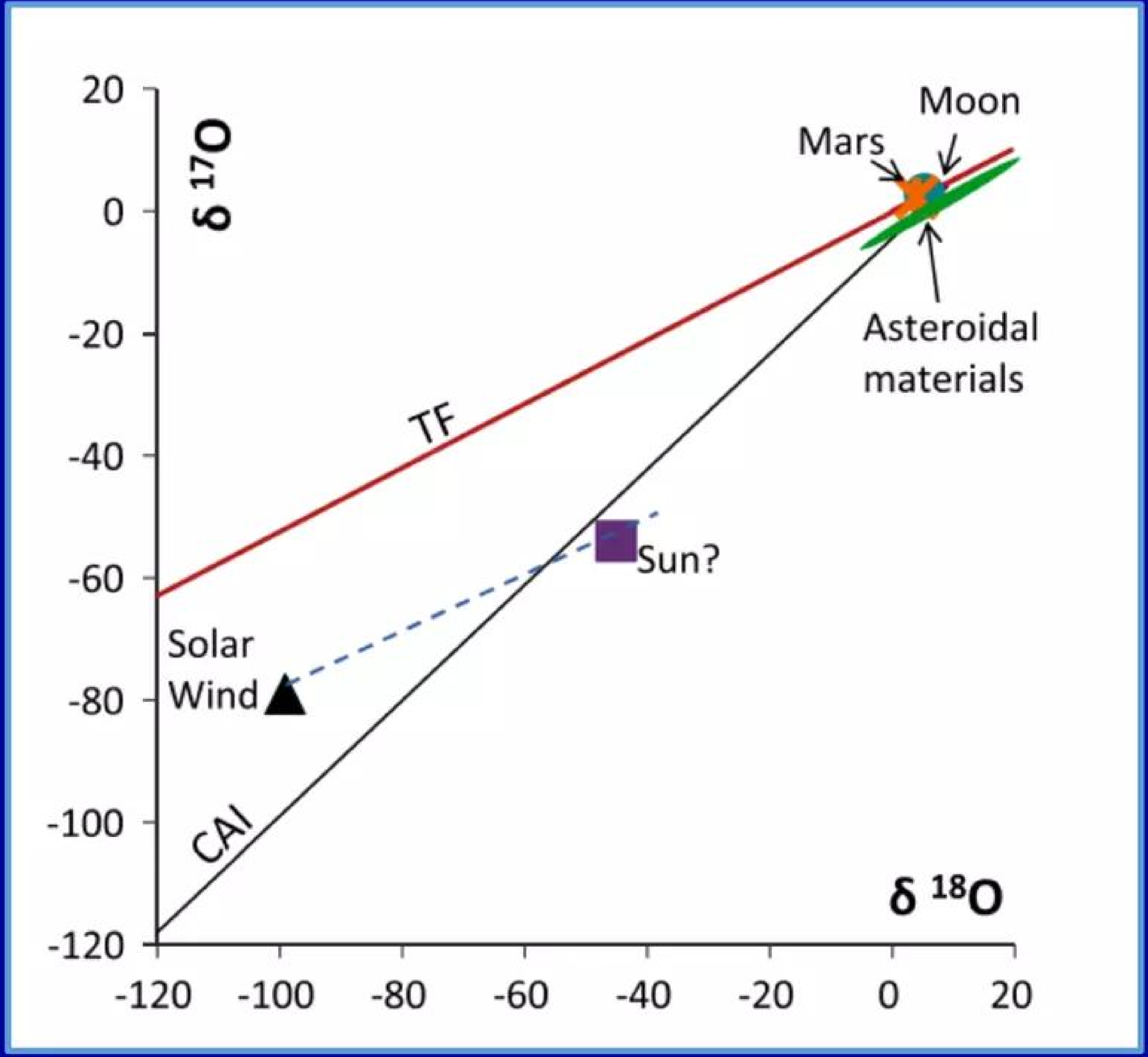
“Solar composition from the Genesis Discovery Mission”
D. Burnett and the Genesis Science Team
PNAS Early Edition doi:10.1073/pnas.1014877108 (2011)

http://www.pnas.org/content/early/2011/05/05/1014877108.full.pdf

“Several well studied natural processes exist which fractionate isotopes relative to the assumed Standard Model values, but none of these explain the variations shown on Fig. 3.”

Quoting: “Fig. 3. A mass spectrometer measures separately the ion currents for the different isotopes of an element. Oxygen has three isotopes, allowing two isotopic abundance ratios to be calculated. Intersample variations are calculated as the fractional deviation δ of the measured $^{18}O/^{16}O$ or $^{17}O/^{16}O$ from terrestrial ocean water (‰ units are permil, parts in 1,000). **Terrestrial geochemical processes produce a wide range in O [Oxygen] isotope fractionations, but these variations lie almost entirely on the line labeled TF (terrestrial fractionation). The Genesis solar wind composition (8) is very different from the major inner solar system objects (Earth, Moon, Mars) and most asteroidal (meteoritic) materials, but lies close to the trend set by unique high temperature Ca-Al-rich inclusions (CAI).** Theoretically, solar wind acceleration fractionates isotopes by the amount shown by the line between the solar wind and the Sun? point (9).”

Figure 3. Burnett *et al.* (2011)



Astrophysical/geochemical paradigms may require revision

LENRs explain certain isotopic anomalies that are otherwise inexplicable

- ✓ Lattice comments: present astrophysical and geochemical paradigms assume that fresh local nucleosynthesis of elements/isotopes (out beyond the photosphere of early solar system's protosun) must have effectively ceased prior to condensation of materials comprising the primordial presolar nebula into a myriad of various-sized solid bodies, prior to Earth becoming recognizable as a fully-formed rocky planet
- ✓ Under older now-dominant paradigm, only unstable radioactive isotopes with very long half-lives, e.g., progenies of the U-series, Th-series, and ^{40}K, would exist long-enough to still be producing radiogenic heat inside planetary bodies comprising today's modern solar system
- ✓ If one grants the possibility that LENR nucleosynthesis can occur (albeit at vastly lower aggregate reaction rates compared to what occurs inside hot stellar cores or supernovas) outside of Sun's inner core as well as elsewhere in the solar system of today, then many of the very puzzling isotopic anomalies revealed in the Genesis Discovery Mission's data --- that are inexplicable with present theories of chemical fractionation processes --- might be better understood by utilizing LENR processes to explain indigenous element production and related isotopic ratios

Importance of electroweak reactions

Artist's impression shows surroundings of supermassive black hole
Credit: ESO / L. Calçada

"Neither of these two great theories [QCD and QED], however, incorporates processes whereby protons transform into neutrons and vice-versa. How can we account for them? To explain these events, physicists had to define one more force in addition to those of gravity, electromagnetism, and the strong force.

This new addition, the fourth force, is called the weak force. The weak force completes our current picture of physics: the Core.

Life on Earth is powered by a tiny fraction of the energy released from the Sun, captured as sunlight. The Sun derives its power by burning protons into neutrons, releasing energy. The weak force, in this very specific sense, makes life possible."

....

"These [various weak force reactions] give rise to many forms of nuclear decay (radioactivities), destabilize other hadrons, and drive many transformations in cosmology and astrophysics (including the synthesis of all the chemical elements, starting from a primordial mix of protons and neutrons).

Frank Wilczek, "A beautiful question" (2015)

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Many-body collective effects accelerate particles in magnetic flux tubes

Condensed matter

Condensed matter

"Ultra low momentum neutron catalyzed nuclear reactions on metallic hydride surfaces"
A. Widom and L. Larsen
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$\text{Energy}_{\text{B-field}} \rightarrow e^- + p^+ \rightarrow lepton + X$

$\text{Energy}_{\text{B-field}} \rightarrow e^- + p^+ \rightarrow lepton + X$

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http://arxiv.org/pdf/1512.00838v1.pdf

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Many-body collective effects accelerate particles in magnetic flux tubes

$Energy_{B\text{-field}} \rightarrow e^- + p^+ \rightarrow lepton + X$

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arXiv:1511.08502v2 [astro-ph.GA] (December 9, 2015)
http://arxiv.org/pdf/1512.00838v1.pdf

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D. Uzdensky
38th COSPAR Scientific Assembly, Bremen, Germany, p.2, July 18-15, 2010
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$Energy_{B\text{-field}} \rightarrow e^- + p^+ \rightarrow lepton + X$

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