Kardashev scale

The **Kardashev scale** is a method of measuring a civilization's level of technological advancement based on the amount of energy they are able to utilize. The measure was proposed by Soviet astronomer Nikolai Kardashev in 1964.[1] The scale has three designated categories:

- A Type I civilization also called a planetary civilization—can use and store all of the energy available on its planet.
- A Type II civilization also called a stellar civilization—can use and control energy at the scale of its solar system.
- A Type III civilization also called a galactic civilization—can control energy at the scale of its entire host galaxy.
- A Type IV civilization also called a universal civilization—can harness the energy from the known universe.
- A Type V civilization also called a multi-universal civilization—has knowledge of the multiverse.

The scale is hypothetical, and regards energy consumption on a cosmic scale. Various extensions of the scale have since been proposed, including a wider range of power levels (types 0, IV through VI) and the use of metrics other than pure power.

Contents

Definition

In 1964, Kardashev defined three levels of civilizations, based on the order of magnitude of power available to them:

Type I

Technological level of a civilization that is "close to the level presently attained on earth, with energy consumption at $\approx 4 \times 10^{19}$ erg/sec" (4×10^{12} watts).[1] Currently, the civilization of Type I is usually defined as one that can harness all the energy that falls on a planet from its parent star (for Earth–Sun system, this value is close to 1.74×10^{17} watts), which is about four orders of magnitude higher than the amount presently attained on Earth, with energy consumption at $\approx 2 \times 10^{13}$ watts. The astronomer Guillermo A. Lemarchand stated this as a level near contemporary terrestrial civilization with an energy capability equivalent to the solar insolation on Earth, between 10^{16} and 10^{17} watts.[2]

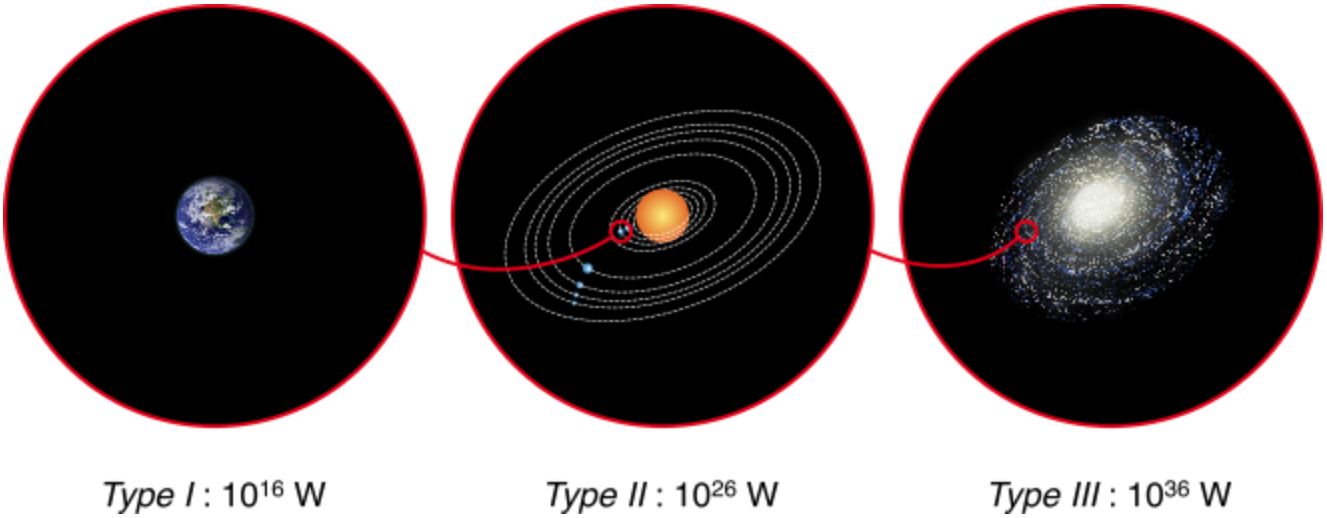
Type II

A civilization capable of harnessing the energy radiated by its own star—for example, the stage of successful construction of a Dyson sphere—with energy consumption at $\approx 4 \times 10^{33}$ erg/sec.[1] Lemarchand stated this as a civilization capable of utilizing and channeling the entire radiation output of its star. The

energy utilization would then be comparable to the luminosity of the Sun, about 4×10^{33} erg/sec (4×10^{26} watts).[2]

Type III

A civilization in possession of energy at the scale of its own galaxy, with energy consumption at $\approx 4 \times 10^{44}$ erg/sec.[1] Lemarchand stated this as a civilization with access to the power comparable to the luminosity of the entire Milky Way galaxy, about 4×10^{44} erg/sec (4×10^{37} watts).[2]

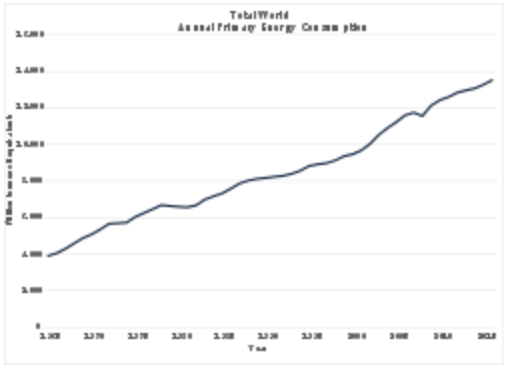


Energy consumption estimated in three types of civilizations defined by Kardashev scale

Kardashev believed that a Type 4 civilization was impossible, so he did not go past Type 3. However, new types (0, IV, V, VI) have been proposed.

Current status of human civilization

At the current time, humanity has not yet reached Type 1 civilization status. Physicist and futurist Michio Kaku suggested that humans may attain Type I status in 100–200 years, Type II status in a few thousand years, and Type III status in 100,000 to a million years.[3]



Total World, Annual Primary Energy Consumption.

Carl Sagan suggested defining intermediate values (not considered in Kardashev's original scale) by interpolating and extrapolating the values given above for types I (10^{16} W), II (10^{26} W) and III (10^{36} W), which would produce the formula

$$K = \frac{\log_{10} P - 6}{10},$$

where value K is a civilization's Kardashev rating and P is the power it uses, in watts. Using this extrapolation, a "**Type 0**" civilization, not defined by Kardashev, would control about 1 MW of power, and humanity's civilization type as of 1973 was about 0.7 (apparently using 10 terawatts (TW) as the value for 1970s humanity).[4]

In 2017, the total world energy consumption was 13,730 Mtoe (159,679.9 TWh),[5] equivalent to an average power consumption of 18.23 TW; the total human population by the end of 2017 was approximately 7.6 billion,[6] while the average power output of the human body is an estimated 100 W,[7] giving an average of 0.76 TW generated from human respiration in 2017. Adding the values gives an estimated lower bound of 18.99 TW for the average total human power output in 2017, equivalent to a value of 0.7279 on Sagan's Kardashev scale to 4 significant figures.

Observational evidence

In 2015, a study of galactic mid-infrared emissions came to the conclusion that "Kardashev Type-III civilizations are either very rare or do not exist in the local Universe".[8]

On October 14, 2015, the detection of an unusual light curve for star KIC 8462852 raised speculation that a Dyson Sphere (Type II civilization) may have been discovered.[9][10][11][12][13] The SETI Institute's initial radio reconnaissance of KIC 8462852, however, found no evidence of technology-related radio signals from the star.[14][15][16]

In 2016, Paul Glister, author of the Centauri Dreams website, described a signal apparently from the star HD 164595 as requiring the power of a Type I or Type II civilization, if produced by extraterrestrial lifeforms.[17] However, in August 2016 it was discovered that the signal's origin was most likely a military satellite orbiting the Earth.[18]

According to the astronomer Carl Sagan, humanity is currently going through a phase of technical adolescence, "typical of a civilization about to integrate the type I Kardashev scale."

Energy development

Type I civilization methods

- Large-scale application of fusion power. According to mass–energy equivalence, Type I implies the conversion of about 2 kg of matter to energy per second. An equivalent energy release could theoretically be achieved by fusing approximately 280 kg of hydrogen into helium per second,[19] a rate roughly equivalent to 8.9×10^9 kg/year. A cubic km of water contains about 10^{11} kg of hydrogen, and the Earth's oceans contain about 1.3×10^9 cubic km of water, meaning that humans on Earth could sustain this rate of consumption over geological time-scales, in terms of available hydrogen.
- Antimatter in large quantities would have a mechanism to produce power on a scale several magnitudes above the current level of technology. In antimatter-matter collisions, the entire rest mass of the particles is converted to radiant energy. Their energy density (energy released per mass) is about four orders of magnitude greater than that from using nuclear fission, and about two orders of magnitude greater than the best possible yield from fusion.[20] The reaction of 1 kg of anti-matter with 1 kg of matter would produce 1.8×10^{17} J (180 petajoules) of energy.[21] Although antimatter is sometimes proposed as a source of energy, this does not appear feasible. Artificially producing antimatter—according to current understanding of the laws of physics—involves first converting energy into mass, which yields no net energy. Artificially created antimatter is only usable as a medium of energy storage, not as an energy source, unless future technological developments (contrary to the conservation of the baryon number, such as a CP violation in favour of antimatter) allow the conversion of ordinary matter into anti-matter. Theoretically, humans may in the future have the capability to cultivate and harvest a number of naturally occurring sources of antimatter.[22][23][24]
- Renewable energy through converting sunlight into electricity—either by using solar cells and concentrating solar power or indirectly through biofuel, wind and hydroelectric power. There is no known way for human civilization to use the equivalent of the Earth's total absorbed solar energy without completely coating the surface with human-made structures, which is not feasible with current technology. However, if a civilization constructed very large space-based solar power satellites, Type I power levels might become achievable—these could convert sunlight to microwave power and beam that to collectors on Earth.

Type II civilization methods

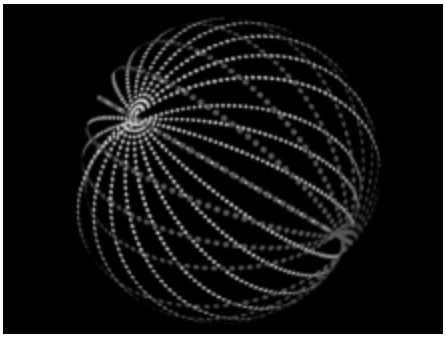


Figure of a Dyson swarm surrounding a star

- Type II civilizations might use the same techniques employed by a Type I civilization, but applied to a large number of planets in a large number of planetary systems.
- A Dyson sphere or Dyson swarm and similar constructs are hypothetical megastructures originally described by Freeman Dyson as a system of orbiting solar power satellites meant to enclose a star completely and capture most or all of its energy output.[25]
- Perhaps a more exotic means to generate usable energy would be to feed a stellar mass into a black hole, and collect photons emitted by the accretion disc.[26][27] Less exotic would be simply to capture photons already escaping from the accretion disc, reducing a black hole's angular momentum; this is known as the Penrose process.
- Star lifting is a process where an advanced civilization could remove a substantial portion of a star's matter in a controlled manner for other uses.
- Antimatter is likely to be produced as an industrial byproduct of a number of megascale engineering processes (such as the aforementioned star lifting) and, therefore, could be recycled.
- In multiple-star systems of a sufficiently large number of stars, absorbing a small but significant fraction of the output of each individual star.

Type III civilization methods

- Type III civilizations might use the same techniques employed by a Type II civilization, but applied to all possible stars of one or more galaxies individually.[28]
- They may also be able to tap into the energy released from the supermassive black holes which are believed to exist at the center of most galaxies.
- White holes, if they exist, theoretically could provide large amounts of energy from collecting the matter propelling outwards.
- Capturing the energy of gamma-ray bursts is another theoretically possible power source for a highly advanced civilization.
- The emissions from quasars can be readily compared to those of small active galaxies and could provide a massive power source if collectable.

Civilization implications

There are many historical examples of human civilization undergoing large-scale transitions, such as the Industrial Revolution. The transition between Kardashev scale levels could potentially represent similarly dramatic periods of social upheaval, since they entail surpassing the hard limits of the resources available in a civilization's existing territory. A common speculation[29] suggests that the transition from Type 0 to Type I might carry a strong risk of self-destruction since, in some scenarios, there would no longer be room for further expansion on the civilization's home planet, as in a Malthusian catastrophe. Excessive use of energy without adequate disposal of heat, for example, could plausibly make the planet of a civilization approaching Type I unsuitable to the biology of the dominant life-forms and their food sources. If Earth is an example, then sea temperatures in excess of 35 °C (95 °F) would jeopardize marine life and make the cooling of mammals to temperatures suitable for their metabolism difficult if not impossible. Of course, these theoretical speculations may not become problems possibly through the applications of future engineering and technology. Also, by the time a civilization reaches Type I it may have colonized other planets or created O'Neill-type colonies, so that waste heat could be distributed throughout the planetary system

The limitation of biological life-form and the evolution of computing technology may lead to the transformation of the civilization through Mind uploading during the transition from Type I to Type II, leading to digitalized civilization).

Extensions to the original scale

Many extensions and modifications to the Kardashev scale have been proposed.

- **Types 0, IV, and V Kardashev rating:** The most straightforward extension of the scale to even more hypothetical Type IV beings who can control or use the entire universe or Type V who control collections of universes. This would also include Type 0 civilizations, who do not rank on the Kardashev scale. The power output of the visible universe is within a few orders of magnitude of 10^{45} W. Such a civilization approaches or surpasses the limits of speculation based on current scientific understanding, and may not be possible.
  - Zoltán Galántai has argued that such a civilization could not be detected, as its activities would be indistinguishable from the workings of nature (there being nothing to compare them to).[30]
  - In his book *Parallel Worlds*, Michio Kaku has discussed a **Type IV civilization** that could harness "extragalactic" energy sources such as dark energy.[31]
- **Kardashev alternative rating characteristics:** Other proposed changes to the scale use different metrics such as 'mastery' of systems, amount of information used, or progress in control of the very small as opposed to the very large.
- **Planet mastery (Robert Zubrin):** Metrics other than pure power usage have also been proposed. One is 'mastery' of a planet, system or galaxy rather than considering energy alone.[32]
- **Information mastery (Carl Sagan):** Alternatively, Carl Sagan suggested adding another dimension in addition to pure energy usage: the information available to the civilization.
  - He assigned the letter A to represent 10^6 unique bits of information (less than any recorded human culture) and each successive letter to represent an order of magnitude increase, so that a level Z civilization would have 10^{31} bits.
  - In this classification, 1973 Earth is a 0.7 H civilization, with access to 10^{13} bits of information.
  - Sagan believed that no civilization has yet reached level Z, conjecturing that so much unique information would exceed that of all the intelligent species in a galactic supercluster and observing that the universe is not old enough to exchange information effectively over larger distances.
  - The information and energy axes are not strictly interdependent, so that even a level Z civilization would not need to be Kardashev Type III.[4]

- **Microdimensional mastery (John Barrow):** John D. Barrow, going by the fact that humans have found it more cost-effective to extend any abilities to manipulate their environment over increasingly smaller dimensions rather than increasingly larger ones, reverses the classification downward from Type I-minus to Type Omega-minus:
  - **Type I-minus** is capable of manipulating objects over the scale of themselves: building structures, mining, joining and breaking solids;
  - **Type II-minus** is capable of manipulating genes and altering the development of living things, transplanting or replacing parts of themselves, reading and engineering their genetic code;
  - **Type III-minus** is capable of manipulating molecules and molecular bonds, creating new materials;
  - **Type IV-minus** is capable of manipulating individual atoms, creating nanotechnologies on the atomic scale and creating complex forms of artificial life;
  - **Type V-minus** is capable of manipulating the atomic nucleus and engineering the nucleons that compose it;
  - **Type VI-minus** is capable of manipulating the most elementary particles of matter (quarks and leptons) to create organized complexity among populations of elementary particles; culminating in:
  - **Type Omega-minus** is capable of manipulating the basic structure of space and time.[33]
  - According to this scale, humans, having wide expertise in various branches of chemistry and biology, have passed the stage of Type III-minus. Type IV-minus technologies (that have had practical and widespread applications) have been seen in areas like nanotechnology, semiconductors, materials science and genetic engineering, whereas Type V-minus has seen large scale application in the field and subfields of nuclear physics. Type VI-minus has had tentative research in the field of particle physics with particle colliders such as the Large Hadron Collider.
- **Civilizational range (Robert Zubrin):** Robert Zubrin adapts the Kardashev scale to refer to how widespread a civilization is in space, rather than to its energy use.
  - In his definition, a Type I civilization has spread across its planet.
  - A Type II has extensive colonies in its respective stellar system, and
  - A Type III has colonized its galaxy.[32]

Criticism

It has been argued that, because we cannot understand advanced civilizations, we cannot predict their behavior. Thus, the Kardashev scale may not be relevant or useful for classifying extraterrestrial civilizations. This central argument is found in the 2002 book *Evolving the Alien: The Science of Extraterrestrial Life*.[34]

See also

- Astronomical engineering
- Clarke's three laws
- Drake equation
- Gerhard Lenski
- HD 164595
- KIC 8462852
- Orders of magnitude (energy)
- Orders of magnitude (power)
- Terraforming
- White's law
- World energy consumption

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External links

- Kardashev civilizations (http://www.daviddarling.info/encyclopedia/K/Kardashevciv.html)
- Astrobiology: The Living Universe (https://web.archive.org/web/20130514085824/http://library.thinkquest.org/C003763/index.php?page=concepts04)
- Detectability of Extraterrestrial Technological Activities (http://www.coseti.org/lemarch1.htm)
- Flash Animation on Civilizations (http://www.ibiblio.org/astrobiology/index.php?page=concepts04#1)
- After Kardashev: Farewell to Super Civilizations (https://web.archive.org/web/20070108010029/http://contactincontext.org/cic/v2i2/farewell.htm)
- Exotic Civilizations: Beyond Kardashev (https://web.archive.org/web/20090220193345/http://astranaut.org/library/exotic-civilizations-beyond-ka.php)
- Description of civilization types from Dr. Michio Kaku (http://bigthink.com/videos/the-birth-pangs-of-a-planetary-civilization)
- Search for Type III civilizations (http://www.theskepticsguide.org/alien-super-civilizations-playing-great-game-of-hide-seek)