

How to find ET with **infrared light**

The search for extraterrestrial intelligence has mostly revolved around radio signal detection, but such a civilization's heat signature also could give away its location. **by Jeff R. Kuhn, Svetlana V. Berdyugina, David Halliday, and Caisey Harlinton**

More than 50 years ago, while discussing the lack of evidence of extraterrestrials during a lunchtime conversation with colleagues, physicist Enrico Fermi voiced the famous question: Why do we seem to be alone in the universe? His query is now even more perplexing given the large number of planets that NASA's Kepler mission and other projects have discovered. In fact, Kepler scientists say that more than half of stars host at least one world. Another study found that about one-third of stars similar to the Sun likely harbor at least one Earth-sized or larger planet orbiting in the star's habitable zone (HZ) — a region with the right temperature to allow liquid water on a world's surface.

Our exploding awareness of extrasolar planets in our cosmic neighborhood makes the alien silence more than a bit mysterious. Is advanced life so tenuous and short-lived that no civilization ever advances to a point where it can reach out to its cosmic neighbors? Perhaps the eerie silence reflects a well-developed survival instinct to avoid calling attention to itself for fear of, for example, being eaten?

If we, as humans, could uncover extraterrestrial civilizations (ETCs) without announcing ourselves, it seems possible that we would learn something about how to prolong our planet's occupancy. Current and emerging earthbound technology makes it possible to obtain a

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census of ETCs within about 60 light-years of us — just by evaluating the heat signatures of nearby stars. With this in mind, we organized a team of engineers and scientists devoted to planning and constructing a ground-based instrument that has the ability to detect nearby ETCs within five to 10 years.

Thermal tracking

Hunting for ETCs on the basis of unknowable alien sociologies is like participating in a search party that isn't sure of what it's seeking. So far, most searches for extraterrestrial intelligence have sought beamed messages from presumed gregarious ETCs. But there's an alternative: looking for an unintentional or unavoidable ETC signal.

In the 1960s, physicist and mathematician Freeman Dyson first suggested that an extremely advanced civilization might satisfy its power needs by capturing the total luminosity of its host star. Perhaps the ETC would build a spherical structure surrounding the star with a radius from the planet to that sun — a "Dyson sphere." The ETC would then reradiate into space the waste energy, with an infrared radiation profile similar to the planet's natural heat. Thus, a way to find such an advanced ETC (which would be far more technologically innovative than Earth-based societies) is to look for stars that are invisible or faint at optical wavelengths but bright in infrared emission.

Unfortunately, a recent search for these Dyson spheres using data of some 250,000 sources in the all-sky Infrared Astronomical Satellite catalog came up empty.

Current technology, however, makes it possible to find even weaker heat signals from less advanced (and, therefore, Earth-like) ETCs. These signals aren't from a

An extremely technologically advanced civilization might build a mechanism to harness all of its star's energy, instead of the small fraction that a planet typically receives. Searches for such a "Dyson sphere" have so far come up empty. LYNETTE COOK FOR ASTRONOMY



On Earth, civilization geographically clusters, as shown in this image of the infrared radiation from lighting at night across Europe, Africa, and the Middle East. NASA EARTH OBSERVATORY AND NOAA NATIONAL GEOPHYSICAL DATA CENTER

star-enclosing power source (like the Dyson sphere), but instead from the civilized planet directly. Any Earth-like ETC uses power, and by the laws of thermodynamics, that power eventually shows up in the planetary environment as heat. This consequence is as unavoidable as death or taxes, and it gives scientists a method for possibly finding ETCs on planets orbiting nearby stars. The consequences of a sensitive search, regardless of the outcome, might help us understand how fragile civilization on Earth really is. A tool for understanding this is similar to SETI astronomer Frank Drake's equation used to estimate the likely number of Milky Way civilizations.

We can estimate how likely it is for an Earth-like civilization to survive by examining all of the bright stars

within about 60 light-years of the Sun (N_s) and postulating that civilizations that develop on planets within their stars' HZs either live on forever or become extinct within a few thousand years, and that they can be detected, even if they don't want to be spotted. In our study, N_s is 600, the fraction of stars that have planets (f_p) is about 0.5, and the number of those worlds that are in the HZ (n_{HZ}) is perhaps 0.5. If we restrain humans' bias of self-importance in the universe, then we can expect that the fraction of those planets that develop civilizations that are more advanced than Earth's (f_{BE}) are both 0.5. The above estimates yield the number of ETCs detected by such a census: $N_D = N_s f_p n_{HZ} f_c f_{BE} f_s = 38f_s$, where N_D is the number of ETCs detected and f_s is the fraction of civilizations that are "successful." f_s is what we can learn from an ETC census.

Even if only one in 20 advanced civilizations survive, we will get a detection. And if we don't find any signal, it would lead to the important conclusion that any given ETC has at most a few percent chance of surviving after it reaches a certain technological level. So, how could we carry out this census?

As energy usage increases

The energy footprint of life and civilization appears as infrared heat radiation, and a convenient way to describe the strength of this signal is in terms of the total stellar power that is incident on the host planet. Earth's current global terrestrial power production is 15 million million watts (terawatts)

— that's 0.04 percent of the total solar power Earth intercepts. (Let's call the ratio of an ETC's power production to the amount of solar power it receives Ω .) Meanwhile, the total power used for photosynthesis on Earth is about 0.2 percent of the total light falling on the planet from the Sun; it fuels most of the terrestrial food chain and illustrates that Earth's civilizations consume only 20 percent as much power as biological processes. The power we radiate into space from our lighting is less than 10 percent of the total human power consumption.

As Earth-like civilizations evolve, they use more power. For example, in Roman times, we estimate Ω was about $\frac{1}{1,000}$ what it is today. Humans' global power consumption is growing by about 2.5 percent per year, even though the world's population is growing at less than half this rate. In contrast, our knowledge base (the combined total of all recorded information) doubles in just two years. As cultures advance, their information

content also must grow, and the power required to manipulate this knowledge eventually dominates a civilization's total power use.

Naturally absorbed starlight heats the planet, but a civilization's power generation also contributes to the global temperature. The best energy policy for such a civilization would be to absorb and utilize the power from *all* incident starlight; this would both heat the planet and power the ETC's needs. It also would decrease the planet's reflectance (or "albedo") and increase Ω toward 1. Any ETC that doesn't "go stellar" for its power, or wants to exceed an Ω of 1, must either moderate its power consumption or migrate to another planet as its non-stellar power sources overheat the planet.

Global planetary warming sets a fundamental limit on the power a civilization can consume. This phenomenon also provides a potential way to find an ETC — from its waste heat radiation. Earth-based researchers can use any residual reflected light from the planet to learn about the geographic variation of its surface. With sensitive new technology, we can

improve on Dyson's idea and look for the heat from advanced alien cities as they rotate in and out of view of Earth — even with a telescope that couldn't otherwise directly image ETC cities from Earth.

We've seen on our planet that civilizations tend to cluster geographically. Populations on Earth concentrate into urban centers, and we expect ETCs to follow the same trend. The geography of a planet and the need for efficient agricultural and urban land use forces civilizations to clump. Although direct images of an ETC aren't possible with any foreseeable telescope, the clustering is detectable. From Earth, we can see the radiated ETC heat as a time variation from the rotational and orbital motions of the planet around its host star as alien cities rotate onto the side of the planet facing Earth.

The heat's source

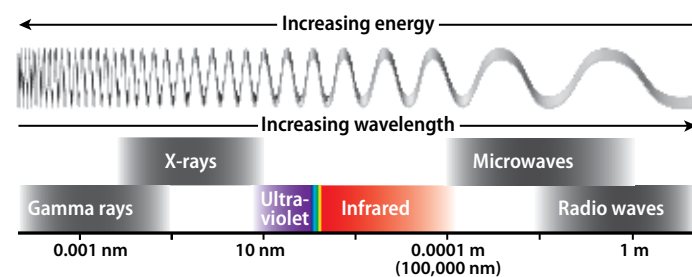
Astronomers study changes in a star's brightness to learn about, for example, "starspots" on its surface. Analogously, scientists can study extrasolar planets' brightnesses to investigate their surfaces as they rotate (unless the planet's spin aligns with our line of sight). Such time-varying brightness signals are observable with ground-based telescopes and could tell us about clumpy heat sources on the planet.

Numerical simulations suggest that measurements of a planet's brightness variations in both visible and infrared radiation make it possible to "see" an ETC. A large infrared-sensitive telescope could observe even those civilizations that utilize 1 percent of the total

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A large infrared-sensitive telescope could observe even those civilizations that utilize 1 percent of the total solar power they intercept.

Radiation differences



The electromagnetic spectrum spans a huge range of energies. While we're most familiar with visible light, astronomers have instruments that can observe radio waves, gamma rays, and everything in between. The research described in this article focuses on infrared emission. ASTRONOMY: ROEN KELLY

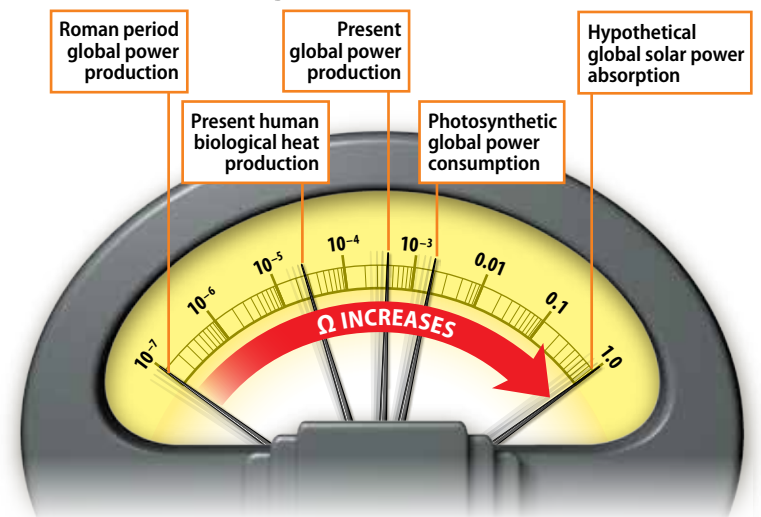


An advanced extraterrestrial civilization that uses all of the power its planet and moon intercept from its star is illustrated here. (The planet is at the right; the moon at the left.) Because such an alien technology would use almost all of its incoming radiation, the planet and the moon would have a very low optical brightness. DARYA RIOS

solar power they intercept. By combining visible and infrared observations of the planet, we can separate the signature of the ETC from natural variations (due to geography) on the rotating planet's surface.

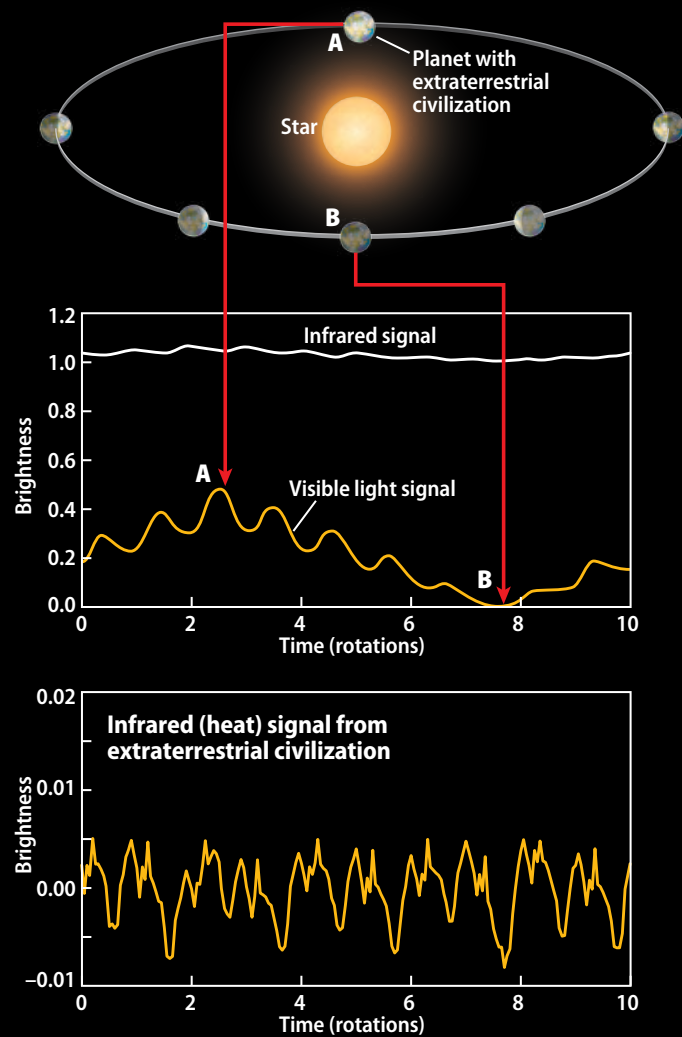
Unlike natural planetary heat sources (like volcanoes) and absorbers (like clouds), a civilization's thermal footprint is likely to have a temperature only slightly higher than the planet's average. The laws of thermodynamics tell us that the most usable power (for example, to heat alien buildings, run light bulbs, or operate computers) occurs when the waste heat is returned to the planetary environment at temperatures close to ambient. The ETC thermal signal may be obscured by "noise" from the planet's natural radiation, but specific measurements could help us identify it. For

Power usage



This diagram illustrates the ratio Ω of a global civilization's power production to the amount of stellar energy its planet collects. The total power produced during Roman times is far less than it is today, which is less than a hypothetical civilization that uses all of the power its planet intercepts from its star. ASTRONOMY: ROEN KELLY, AFTER JEFF R. KUHN

Uncovering ET's signal



An exoplanet with an intelligent civilization — similar to humans — that uses 1 percent of the energy it receives from its star shows its presence in varying infrared and visible light signals. This simulation shows how scientists would tease the alien heat signal out of observations. *ASTRONOMY; ROEN KELLY, AFTER JEFF R. KUHN*

spans about 100 milliarcseconds.) The brighter exoplanet targets are those that are closer to their host stars or larger in diameter because they reflect more light. Thus, the brightest and most detectable civilizations in our team's census will live on planets orbiting cooler stars that are nearby. We'd like to target all the known stars within 60 light-years of Earth that are in a similar evolutionary phase to the Sun (those that fuse hydrogen to helium in their cores).

Measuring the signals from our stellar neighbors requires a telescope with two important qualities: It must be large to collect enough photons from the alien planet to reliably detect a civilization's heat, and it must be able to distinguish the optical and infrared signal of the planet from that of its nearby host star. The telescope also must be sensitive enough to distinguish between the faint thermal radiation from the extrasolar planet and that from Earth's warm environment.

Pushing the technology

A host star might be some 100 million times brighter than a planet within its HZ, so to distinguish the faint glow of a civilization requires a telescope and detector system that removes the glare of the star to see the orbiting extrasolar planet. In theory, a perfect telescope system places all of the captured light from a star into a pointlike image, but this doesn't happen in practice. Observers must cope with Earth's weather and atmosphere, which can blur the radiation and create what astronomers call "scattered light" glare that works against us by obscuring the faint exoplanet. To work around this problem, we use specialized adaptive optics and an instrument (a coronagraph) that removes additional light scattering called diffraction. Some groups are building adaptive-optics/coronagraph systems that are nearing the sensitivity to detect extrasolar planets just 1 in 100 millionth as bright as their host stars in the same field of view: SPHERE at the European Southern Observatory's Very Large Telescope in Chile and GPI attached to the Gemini South Telescope, also in Chile.

The smallest angle a telescope can resolve (called the "diffraction limit") decreases as the diameter of its primary mirror increases. To resolve and distinguish an HZ exoplanet from its star with a ground-based telescope requires two things: a large collecting area and an adaptive-optics system that reaches the diffraction limit of the scope while also correcting the blurring effect of Earth's atmosphere. The volume of space we can observe, and therefore the total number of stars we can sample, increases rapidly with the diameter of the telescope; this relationship follows the diameter cubed. So, the telescope's size is critical to this problem.

We know the locations and temperatures of most of the stars within 60 light-years of the Sun. This means we can accurately estimate the number of potential ETCs we might find based on the size of the telescope, the resolution of an

adaptive-optics system, and the instrument's contrast sensitivity at visible and infrared wavelengths.

As expected, the number of observable exoplanets in HZs increases rapidly when we factor in a larger mirror, greater coronagraph sensitivity, and a bigger planet diameter. If we want to detect at least 100 Earth-sized or slightly larger planets, we will need a telescope with a large diameter. The three largest infrared-sensitive scopes now in their planning stages (the Giant Magellan Telescope, the Thirty Meter Telescope, and the European Extremely Large Telescope) might be capable of detecting 10 HZ planets and, if scientists are lucky, perhaps one highly advanced ETC; they won't be large enough nor designed to minimize scattered light, so they won't make a dent in an ETC census. A telescope with a primary mirror about 250 feet (77 meters) in diameter, however, could find hundreds of Earth-sized or larger HZ planets, and perhaps dozens of ETCs, using a sensitive coronagraph — and the technology to build such an instrument exists.

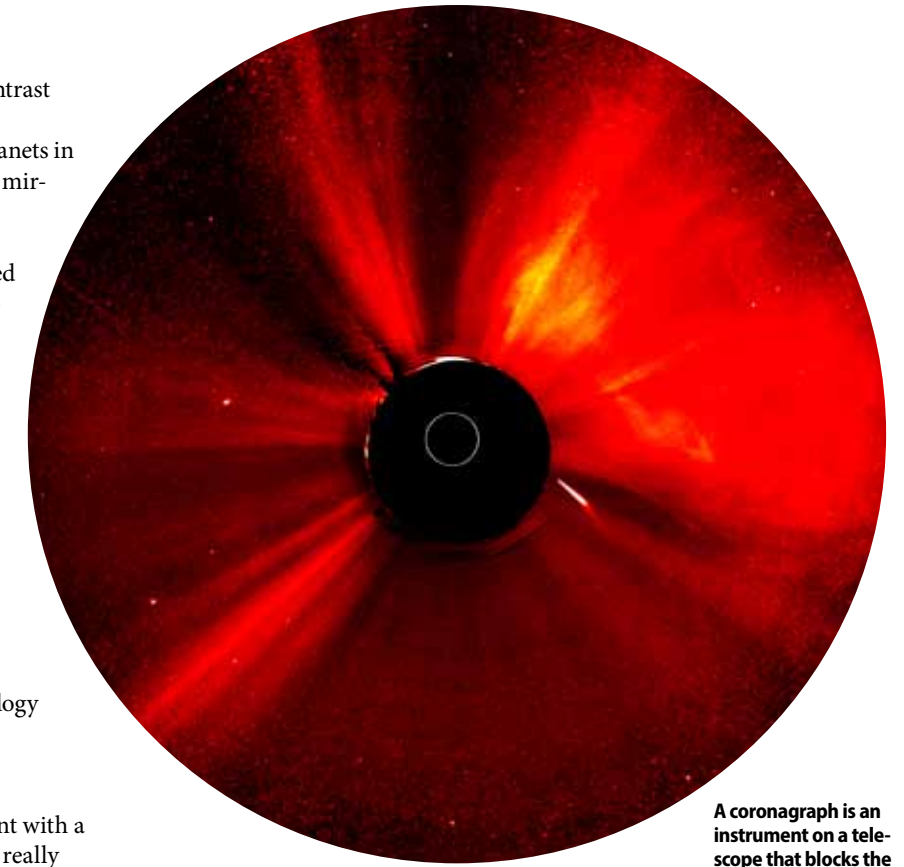
Expanding our horizons

Yes, that's a huge telescope. Could an instrument with a mirror diameter nearly as big as a football field really be built? Such a colossus would have a light-

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collecting area an order of magnitude larger than the Giant Magellan Telescope, which is currently the large-telescope project furthest along. A group of

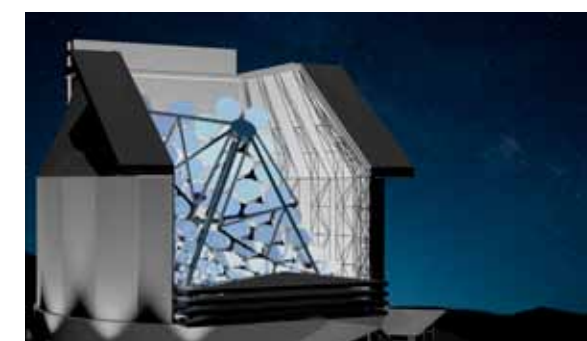
physicists, engineers, telescope builders, philanthropists, and businessmen — and the writers of this article — have spent two years studying exactly this question and concluded that building such a telescope is imminently doable, but it will require abandoning many of the assumptions and requirements researchers have made for the other huge scopes. For example, the "Colossus," as our team calls it, would not have a wide field of view like most giant telescopes, but instead would observe only a few arcseconds of the sky at a time. By decreasing the field of view, we can construct a telescope much larger than the current designs at less cost. This instrument also would use relatively few mirror elements — each one with the largest practical area possible — instead of hundreds of small segments. (Colossus' funding and location are as yet undetermined.)



A coronagraph is an instrument on a telescope that blocks the light from a star so that a nearby faint object is visible (and not washed out due to the star's glare). In this image, NASA's Solar TErrestrial Relations Observatory (STEREO) captured Comet SOHO 2143 that passed near the Sun on October 1, 2011, and was subsequently destroyed. *NASA/STEREO*

Because of its narrow field of view, Colossus would observe starlike sources and would be ill-equipped to look at, for example, isolated distant galaxies. In addition to furthering our understanding of extrasolar planets and civilizations, we'd use this telescope for research topics like the study of stellar surfaces, black holes, and quasars — which are objects that appear smaller than 1 arcsecond across on the sky.

So, while the telescope required for our search for civilizations on other worlds doesn't exist yet, the technology does. We anticipate finding dozens of signals of life as we expand our understanding of the nearby cosmos. The Colossus would give us insight into whether civilization is a fragile development or if it is common. And we'd learn this without announcing ourselves. ☞



The Colossus telescope, shown here in this artist's rendering, would have a primary mirror nearly 250 feet (77 meters) wide. Scientists think this instrument would be able to resolve the infrared radiation that results from technologically advanced civilizations living on exoplanets within 60 light-years of Earth.

example, with infrared data at two wavelengths, we could distinguish the civilization's thermal signal from other natural heat signatures. Measurements like these would reveal the distinguishing emission profile of such hotter or colder natural radiation noise.

The targets

Nearby Earth-like exoplanets with liquid water are arguably the most likely to harbor life that we might eventually communicate with and learn from. Because such HZ planets in Sun-like star systems lie close to their stars (roughly the Earth-Sun distance or less), we'll need the technology to resolve such small separations. These correspond to angles on the sky of about 50 to 800 milliarcseconds. (For comparison, Pluto's disk

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