Next-Generation Space Telescope (NGST) and Space-Based Optical SETI

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ABSTRACT

Many new space observatory projects are now being discussed and planned. With the primary goals of useful astronomical research, including detection and characterization of extrasolar planetary systems, the larger of such prospective observatories include the Next-Generation Space Telescope (NGST), Terrestrial Planet Finder (TPF), Darwin, Life Finder (LF), and Planet Imager (PI). Several of these seem particularly useful for SETI searches at optical wavelengths, as do also some smaller proposed space observatories such as Eclipse, Kepler, and GAIA.

The new space observatories offer the following capabilities of particular interest to SETI: (1) single, calibrated instruments providing continuous extended time observing a particular planetary system or a wide-angle region containing many possible systems; (2) sensitivity in wavelength regions difficult to observe through the earth's atmosphere due to absorption or to scattered light; (3) very high photometric accuracy to detect small variations in signal from a planetary system; (4) decreased scattered light from our solar system's zodiacal light, depending on observatory orbit location; and (5) the potential of blocking (nulling) most of a star's light, thereby increasing greatly the signal-to-noise ratio (SNR) for detecting light from objects close to the star.

We offer some suggestions as to how these new space observatories might be employed or adapted to offer optical SETI capabilities, and provide estimates of their potential performance for that mission.

Keywords: SETI, optical, space-based, observatories, NGST, TPF, GAIA, Kepler, FAME.

1. INTRODUCTION: TOP-DOWN -- WHAT WE HOPE TO SEE

Many new space observatory projects may offer capabilities of particular interest to OSETI, the Optical-wavelength Search for Extraterrestrial Intelligence (SETI) at: (1) continuous extended time observing a particular planetary system or a wide-angle region containing many possible systems; (2) sensitivity in wavelength regions difficult to observe through the earth's atmosphere; (3) very high photometric accuracy; (4) decreased scattered light from our solar system's zodiacal light; and (5) the potential of blocking (nulling) most of a star's light, to help detect light from objects near the star.

With no information about actual communication technologies in distant planetary systems, we can only guess what optical signals we might detect. Some likely possibilities include very-high-energy laser beacons highly concentrated in wavelength, time (high-power, short pulses), and angular subtense; ordered signals with mathematical patterns embedded to indicate the presence of an intelligent sender, or even to encode a lengthy and complex message; and redundant transmissions at several wavelengths to reduce our chances of missing the signal or of considering it an isolated false alarm. (In this paper we shall treat only the case of a single-wavelength laser beacon, for simplicity, emphasizing a continuous-wave, CW, laser.) Our galaxy's considerable optical transparency implies that we might detect such beacons in most directions at a range of a kiloparsec or greater. Despite the distance traversed, at optical wavelengths the light would not be significantly degraded in total energy or wavefront, nor dispersed spectrally.

A main assumption might be that the transmitting society is technologically more advanced than ours, since we are not yet making a serious effort to send light signals to other stars. Just the fact that life on Earth has been evolving for billions of years makes it highly improbable for an extraterrestrial intelligence (ETI, the putative advanced society) chosen at "random" to match our "technological age" to within a hundred years. Therefore such an advanced society, if it exists, would very likely be at least centuries ahead of us in development.

When projecting what technologies an ETI might most likely use, people often seem to presume too much similarity to ourselves and our current circumstances. In the mid-20th century, when radio communication was young, many rationalizations were constructed to justify radio-frequency SETI. But after the first working laser was demonstrated on May 15, 1960, it took less than a year for scientists to imagine and propose instead that OSETI had a higher chance of success.

To best detect an ETI way ahead of us, we need to try to stretch our view forward to technologies many centuries ahead, maybe even a billion years in the future, a task challenging even for a Leonardo da Vinci or an Arthur C. Clarke. But to presume simply that ETI would use the oldest technologies that might succeed (such as radio or lasers) would be like expecting today's teenagers to listen to their favorite recorded music on bakelite cylinders or 78-rpm one-side-grooved disks.

Also, the sequence in which another world's technology develops might differ considerably from our own. It now seems a remarkable coincidence that thermonuclear fusion, spaceflight, and the laser all were developed in the same 10-year period. It could distort our estimate of the ETI capabilities for us to presume a similar sequence or coincidence out there. About all we can have much confidence in is that, if centuries more advanced than us, the ETI would at least be capable of anything we can do now.

And members of an advanced ETI, with far more knowledge than we have, should be able to estimate our level of technology better than we can guess theirs. With the strong prospect of our own detection and characterization of many habitable extrasolar planets in the next several decades, we would suspect that the ETI should, if not kiloparsecs away, already know of Earth and its habitability, and the orbits of all our sun's planets. (We'll soon see their planets too, if they're there, out to a distance of 25 pc within 20 years. Extrapolating wildly, we could see them out to 1000 pc within 100 years.)

Knowledge of Earth's orbit and position would give the ETI a capability to tune a laser so we would receive a signal at the rest wavelength of a strong but very narrow atomic or molecular spectral feature. (If uncompensated at the transmitter, Earth's orbital velocity of 30 km/s would cause a shift of up to 0.05 nm in the wavelength of a 500 nm laser.) The ETI might instead choose wavelengths centered in deep Fraunhofer absorption features of its star and our sun, provided the two stars' relative radial velocity was small. In these ways a considerate ETI might make our SETI task easier, since we could then concentrate on the likely ("magic") optical wavelengths.

The ETI might have some reasonable idea of the kind of SETI instrumentation we would be starting out with, especially if we happen to be following a development path like theirs. Then the ETI could figure out how to send us a message our primitive level of interstellar perception might receive successfully. If they thought we were advanced enough in electronics and computers they might choose a very short pulsed signal, as OSETI experts have already extensively considered. But they could instead send longer signals concentrated just in angle or wavelength.

A critical element of ETI long-distance communications activities would be their energy-generation systems. Those are presumed to be highly advanced, perhaps based on local nuclear-fusion generators or involving huge electro-optical arrays (not necessarily as all-encircling as Dyson spheres) to collect distant nuclear-fusion power from their host stars. If there are such huge arrays, the technology may also exist to operate filled-aperture beam transmission optics with diameters of hundreds or thousands of kilometers. If such advanced technology were employed, producing extremely high angular gain, we might even be able to detect optical signals from neighboring galaxies.

2. BOTTOMS-UP -- WHAT WE CAN SEE WITH -- PLANNED OR PROPOSED SPACE MISSIONS OF POSSIBLE USE FOR OSETI

Several types of future space astronomy missions may have potential capabilities for detecting OSETI signals. These missions come in four classes: large general-purpose optical observatories, full-sky astrometric surveys, point-and-stare telescopes to search for indications of planets around other stars, and missions to detect directly the light from extrasolar planets. Advantages of space missions for optical astronomy derive primarily from not having to look through Earth's atmosphere (or being blocked by Earth itself, since ground telescopes rotate with it), and include decreased absorption and scattering in certain spectral bands, higher spatial resolution (because wavefronts are undistorted – this also permits blocking interference from other light sources appearing near the target), greater ease in maintaining a very stable point-spread function (PSF) for accurate photometry, and the potential for very long-term continuous coverage of a great number of stars.

Large General-Purpose Optical Observatories (NGST and TPF)

NGST (Next-Generation Space Telescope)

NGST will be NASA's largest-aperture space mission for optical astronomy when it is launched, probably around 2009. Conceived with a main goal of looking deep into the ancient universe, it has been planned as an infrared telescope with an aperture diameter of 8 m (with a segmented primary mirror), although there is some current discussion on reducing that to 6.5 m. The wavelengths observed will definitely cover the 1 µm to 5 µm band, but may be extended down to 0.5 µm or up to 30 µm. NGST will be sensitive to objects 400 times fainter than those now detectable with large ground-based infrared telescopes or the current generation of space-based infrared telescopes. It will also have a spatial resolution comparable to the Hubble Space Telescope (HST). NGST is to be placed in orbit around the sun at the sun-Earth Lagrangian (L2) libration location.

NGST Performance

Property	**NIR Requirement**	**NIR Goal**	**MIR Requirement**	**MIR Goal**
Wavelength Range (µm)	1-5	0.5-5	5 - 10	5 - 30
Largest Focal Plane Array	4000 x 4000	2000 x 2000	1000 x 1000	1000 x 1000
Pixel Subtense (milliarcsec)	29	29	230	230
Point Source Sensitivity (nJy) (2.8 h exposure, R~5, S/N=10) 1 nanoJansky = AB mag 31.4	2.5 (1µm) 2.6 (2µm) 2.2 (3µm) 9.9 (5µm)		119 (10 µm) 411 (20 µm)	
Q.E. (%)	>80	>90	>50	>80
Dark Current (e^-/s)	<0.02	<0.01	<1	<0.01
Read Noise (e^-), single sample	<15	<1.5	<15	<1.5
Well Capacity (e^-)	>60,000	>100,000	>60,000	>100,000

TPF (Terrestrial Planet Finder)

TPF is also mentioned in this category, both because it is supposed to spend half its operating time making a variety of astrophysics observations, and because it might turn out to be a single large-aperture telescope with a variety of focal-plane instrumentation. If the latter transpires, TPF would have significantly better optical quality than NGST, and cover shorter wavelengths. TPF is discussed in more detail below, in the section on Direct Planet-Light Observation Missions.

Full-sky Astrometric Surveys (FAME and GAIA)

These astrometric survey missions will look at many millions of stars frequently (hundreds of times over a few years), though not continuously. It has been claimed that the very narrow diffraction-limited beams of an optical telescope make it unfeasible to have enough appropriately small pixels constantly covering the whole sky. However, these missions will be measuring very small pixels all over the sky with average revisit rates on the order of once a day, and with many revisits occurring less than an hour apart. This can permit the detection of transient ETI signals, appearing as a brightening of a star in one spectral band, occurring at random times in random places. Photometric precision for single observations would range from 1% to 10% of the star's brightness.

Operation of a laser or other strong radiation source next to a star can also change the apparent position of the star. Since these instruments can achieve angular accuracies of from 4 to 50 microarcsec (20 to 250 picoradians), they can detect apparent stellar displacements down to 0.0004 AU at 100 pc distance. This would require a received signal at least 0.04% of the star's brightness, if the source is located 1 AU (10 milliarcsec) from the star. For single observations, this method would be able to detect the presence of a signal 0.4% as bright as the star.

Should the direct brightening or the displacement detection methods reveal a possible signal, a more directed investigation of the star could be made by other instruments.

FAME (Full-sky Astrometric Mapping Explorer)

FAME is a NASA Medium Explorer (MIDEX) mission led by Dr. Kenneth Johnston (U.S. Naval Observatory), currently scheduled for launch in 2004 to a geosynchronous orbit. FAME's goal is to make precise astrometric measurements of about 40 million stars, a survey complete to V= 15, covering the entire sky hundreds of times in 2.5 years of operation. It will have two apertures, each 0.60m x 0.25m, and rotate every 40 minutes so each 0.206 arcsec (1 microradian) pixel will have an integration time of 0.382 ms. With four spectral bands g′, r′, i′, z′, covering 400 to 900 nm, it will achieve a photometric accuracy of 1 millimagnitude, or about 0.1%.

GAIA (Global Astrometric Interferometer for Astrophysics)

GAIA, an ESA cornerstone mission to be launched between 2009 and 2012 to an L2 Earth-Sun Lagrangian position, will measure extremely accurately the positions of over 1 billion stars in our Galaxy and its nearest neighbors. It will observe each star about 100 times, gather multi-color photometry (1% accuracy to V=17; better than 10% for a single observation) for all stars observed, plus spectroscopically-determined radial velocities for the brighter objects (1-10 km/s at V=16-17) to generate complete kinematical data. Although once conceived of as an interferometer, GAIA now is planned to be a filled-aperture instrument with high angular resolution in the continuously (2 arcminutes per second) scanning direction provided by two mirrors with apertures approximately 1.7 m x 0.7 m. It will repeatedly measure the positions of all objects down to V=20. Onboard object detection will permit variable stars, supernovae, burst sources, microlensing events, and minor planets all to be detected and catalogued to this faint limit. Final stellar astrometric accuracy will be 4 microarcsec at V=10, and 10 microarcsec at V=15. Measured apparent stellar displacements could reveal the presence of planets down to 10 Earth masses at 10 pc. Four broad spectral bands will be in the main astrometric instrument focal plane, and 11 photometric bands will cover the spectral range 280 to 920 nm.

Point-and-Stare Explorers (COROT, Kepler, Eddington, GEST)

These instruments can search many thousands of host stars for Earth-like planets transiting in front of them, which causes a decrease in the brightness of the star for a few hours, or for planets passing in front of a much more distant star and briefly brightening its signal via gravitational lensing. Similar brightening could be due to an ETI signal. Successful detections of such events require staring at many stars for a long time. The main technology challenge for these missions is to have photometrically precise, long-term coverage of large fields of view, which requires a large CCD detector chip array. Data volume, onboard data processing, and communications links present additional challenges.

COROT (COnvection, ROtation and Transits)

COROT, a project of the French space agency CNES, scheduled for launch in 2004, is an Earth-orbiting telescope likely to be the first one to do planet searching, as well as astroseismology observations. Its telescope aperture is just 0.27 m in diameter. It can study, in each 5-month staring time, 30,000 stars down to magnitude V = 15.5, with a photometric accuracy of 1 part in 1400. It will look in several directions toward the Galactic center and the Galactic anti-center.

Kepler

Kepler has been proposed by W. Borucki (NASA Ames), Ball Aerospace, and collaborators for NASA's Discovery Program, and may be launched by 2006 if approved. Its telescope, with 0.95-m aperture and 88 million pixels detecting wavelengths from 400 to 800 nm, would orbit the sun and stare at a single local-spiral-arm field for four years, every 15 minutes reporting changes in the light from about 170,000 stars over a 12-degree diameter field-of-view. The instrument software also permits monitoring changes in 256 stars with a one-minute period (this is primarily for astroseismology). For stars down to V=12, its photometric precision of about 1 part in 100,000 (obtained by averaging measurements of many stars for calibration) should permit Kepler to detect transits of hundreds of Earth-like planets with favorably aligned orbits. Kepler could study the size and orbit of such planets, and also other properties of the planets and their associated stars.

Eddington

Eddington, a recent proposal to the European Space Agency (ESA), would be very similar to Kepler, also using the planetary transit method to search for Earth-like planets near 700,000 stars, as well as to measure stellar properties. It would employ a 1.2-m primary mirror in an optical telescope with a fully unvignetted 3-degree diameter field of view and a mosaic CCD camera covering the field of view. Eddington's launch would occur between 2008 and 2013.

GEST (Galactic Exoplanet Survey Telescope)

GEST, proposed by S. Rhie and D. Bennett of Notre Dame, is now being considered by NASA as a possible Discovery program for launch in 2006. For 8 months during each of three years, it would employ a 1.5-m aperture telescope and 1.3 billion CCD pixels to stare at a 2 square-degree field toward the Galactic center to detect gravitational micro-lensing events. It would look for small, short-term rises in the light of 200 million distant stars due to much nearer planets in our line-of-sight. Those planets would be orbiting a star which also produces such lensing: detecting the latter event would prompt us to search for evidence of a much narrower, planet-caused signal increase soon before or after. GEST is proposed to have about 0.1% photometric accuracy. The other 4 months of each year, GEST could be targeted at other desired observations.

Direct Planet-Light Observation Missions (Eclipse, TPF, Darwin, LF, and PI)

These missions will look for and characterize planets around hundreds of nearby stars, and must reduce the glare from the host stars in order to achieve adequate signal-to-noise ratios in measurements of the direct light from the planets.

Eclipse

Eclipse is a space coronagraphic telescope proposed as a NASA Discovery mission by a team headed by J. Trauger of JPL, for a 2006 launch. In its 3-year mission, Eclipse could block most of the light from a star near us to detect large planets around it, performing the first imaging study of nearby planetary systems and their evolutionary stages. Eclipse would have a 1.8-m aperture, with low optical scattering and precision active optics, as part of a coronagraphic camera designed for high-contrast astronomy. Compared to HST, Eclipse could reduce diffracted and scattered starlight at one arcsecond separation by more than three orders of magnitude, to null the star's signal by a total factor of 10^{10}.

TPF

Initial conceptual design work for NASA's TPF is now being carried out by four independent industry-led teams. TPF has the goal of finding any Earth-sized planets within the habitable zones around at least 150 F, G, and K stars, up to 20 parsecs away from Earth. After identifying such planets, it is also supposed to perform modest-resolution spectrometry in order to indicate the presence of atmospheric biomarkers such as water vapor and oxygen.

Although prior TPF concepts all concentrated on an array of mid-infrared telescopes, with total collecting area of at least 35 m^2, acting in concert as a variable-baseline interferometer nulling the stellar signal by a factor of 10^5 or more, new concepts are being studied too. This is because a single-spacecraft, visible-wavelength coronagraph (which can also incorporate a variety of instruments), with a collecting area near 50 m^2 and stellar leakage reduced to near the 10^{-10} level, may be able to search more efficiently for Earth-like planets around nearby stars.

Though its construction has not yet been funded, TPF is now scheduled for launch in 2013. Many implementation details need to be worked out, and new technologies need to be developed and demonstrated. To minimize thermal distortions and noise in the TPF instrument, most likely it will operate in orbit around the sun, possibly even in a new type of orbit relatively close to Earth yet frequently well above the plane of our solar system's zodiacal dust.

Darwin

Darwin, ESA's version of the TPF mission will, because of funding limitations on both sides of the Atlantic, probably be combined with NASA's TPF sometime in the next several years. At this time, Darwin has concentrated on the infrared nulling interferometer approach, comprising an array of six collector telescopes mounted on individual spacecraft, plus two other spacecraft for combining the light and communicating with Earth.

LF (Life Finder)

LF has been proposed by NASA as the next major observatory to follow TPF, to be launched perhaps in 2018. At present it too is conceived as an interferometer, but with four much larger light-collecting mirrors, probably constructed from thin membranes, one pair with 12.5-meter aperture each, and another pair with 25-meter aperture each. These huge optical components are to enable LF to gather sufficient light from nearby stars' Earth-like planets to permit examining their spectra in great detail. Spectral features indicating the types and amounts of gases in the planetary atmospheres would then yield chemical composition analyses much more detailed than TPF's, really pinpointing those habitable planets which may already have evolved life to various stages.

PI (Planet Imager)

PI is a potential NASA project, very tentatively scheduled for a launch in 2022, planned to follow and build upon the technologies of TPF. PI could permit us to discern actual spatial features on planets like Earth in orbit around other stars, at distances from us of up to 20 parsecs. That requires a spatial resolution not of 15 million km like TPF, but of about 3000 km, 5000 times finer. Looking in visible wavelengths instead of infrared may make that easier, if we learn how to control the host star's glare much better. Nevertheless, PI may have to involve spacecraft spread over a total area of from 40 to 1000 kilometers in diameter. It will also require either many individual telescopes within that area, or a smaller number with very large aperture, at least 40 m in diameter, since the individual resolution elements in the image of the planet will each send us about 500 times less light than the planet as a whole.

3. ASSUMPTIONS ABOUT THE TRANSMITTING ETI

With some guesses about the kinds and strengths of signals coming from an ETI, we can begin to evaluate how well our space observatories could look for and detect them in a planned search of thousands of possible host stars. Assuming the ETI knows we may be here, they can use a very narrow beam aimed right at us. For a CW laser, we have already achieved power levels well above a Megawatt; it is reasonable to assume that the ETI can easily achieve 10 MW.

For a pulsed laser, we are now getting hundreds of Terawatts in short pulses of a few ns; we might then assume the ETI can achieve 1 Petawatt for 10 ns (which, at a 1 Hz repetition rate, also averages out to 10 MW). An emitted signal one hundred-millionth as brief as the time interval between its pulses would look a hundred million times brighter (relative to the nearby star) to an appropriately gated pulse detector than to one designed for CW signals. When the average brightness of a laser is only 1% of the star's brightness, it could appear a million times brighter than the nearby star during each 10 ns pulse, when the laser's repetition rate is 1 Hz.

Since we on Earth are currently considering steerable-mirror ground-based observatories such as the OWL (Overwhelmingly Large) Telescope, with total mirror surface 100 m in diameter, it is reasonable to assume that an ETI can achieve a transmitting mirror diameter of 1 km. Such a mirror could be sending us a 500-nm-wavelength beam with an angular subtense of only 1.2 nanoradians. If it comes from 1000 pc away, that beam would spread out to a diameter of about 40 million km near our earth. 10 MW total power would at Earth then generate a flux of 8×10^{-15} W/m^2.

Were we to observe with even a very modest spectral resolution, say R=5, then in each spectrum bin at $\lambda = 500$ nm a 15th magnitude solar-type star (the brightness for 1000 pc distance) would provide a flux of 3×10^{-15} W/m^2, fainter than the ETI laser beam.

4. DETECTING THE PHOTONS -- OSETI PERFORMANCE OF SPACE OBSERVATORIES

NGST offers greater sensitivity than any ground observatory in many regions of the infrared spectrum. It also permits staring for very long times at parts of the sky, with very stable photometric response, unaffected by Earth's atmosphere. If it were to observe for its nominal 2.8-hour integration time at R=5 and SNR=10, its sensitivity at 1 μm should be 2.5 nJy, or 1.5 x 10^{-21} W/m^2. A very modest ETI laser could produce such a signal here, but the NGST couldn't see it in the presence of undiminished glare from the host star. NGST, with repeated looks, might however be able to detect a measurable brightening due to a laser near a V=15 star (like our sun) at 1000 pc if the laser signal itself were about 600 nJy, or 4 x 10^{-19} W/m^2. Such a signal could be produced by a 2-kW laser and a 1-km transmitting mirror, which, operating at $\lambda = 1$ μm, provides a gain, $\pi^2 D^2/\lambda^2$, of 10^{19}. This then represents a power-gain product of 2 x 10^{22} W.

The scanning, brief-look technologies of FAME or GAIA, might detect a received laser signal about 1% of their in-band star's brightness, either by direct photometry of the star, or by measuring its apparent positional shifts. Then, for a solar-type star viewed at $\lambda = 500$ nm and R=5, the power-gain product would have to exceed 4 x 10^{23}, possibly supplied by a 10-kW laser and a 1-km transmitting mirror on one of the many millions of stars these full-sky missions will observe.

The most sensitive of the space observatories above would be the staring and direct-planet-detection types. In the former category, Kepler, with its high photometric accuracy, should be able to detect the transient signal (lasting 1 minute) provided by a visible-wavelength CW laser signal aimed at Earth, if the power-gain product is at least 10^{22} W. (Of course, Kepler is usually looking for a small decrease in stellar brightness due to a transit even; here, as for a microlensing event, the effect would be an increase in apparent stellar brightness.) Considering that a 100-m diameter transmitter mirror operating at $\lambda = 500$ nm could provide a gain of 4 x 10^{17}, the laser power need only be 25 kW. And an ETI with just a 10-m Keck-type transmitter would still need only a 2.5-MW laser. If the laser signal lasted at least 15 minutes, then Kepler would have this capability for stars to V=12, which would cover G dwarfs out to 250 pc.

For a TPF-type system of the infrared interferometer type, the key is measuring bin-to-bin spectral variations, as discussed by Howard and Horowitz (2001). Assuming a spectral resolution of R=20 at 10 μm, and a 10-m transmitter at 15 pc, and accounting for the noise from exozodiacal dust emission, they find that a CW laser of just 1 kW would permit communication to Earth, assuming a TPF integration time of 28 hours. (This corresponds to a power-gain product of 10^{16} W.) While that is 2500 times less power (for the same transmitter diameter) than needed for detection by Kepler, the range is also far less, and TPF will observe a good deal fewer stars than will Kepler.

A visible-wavelength TPF coronagraph should be sensitive to V=32 planets, assuming an integration time of 10 hours, as discussed by Ball Aerospace at the TPF Preliminary Architecture Review (2000). Such a received planet signal is equivalent to 5 x 10^{-22} W/m^2 at $\lambda = 500$ nm and R=5. For a 10-m diameter transmitter mirror at 15 pc distance, the TPF coronagraph could detect a 1.4-W laser beam, for a power-gain product of 6 x 10^{15} W.

TPF-type systems have significant range limitations because they would not be able to null out a distant stellar signal without also blocking out most light from sources in the planetary system's habitable zone. (Of course, an advanced ETI may have realized that, and placed its transmitter at considerable distance from its star.)

Summary of Space-Observatory OSETI Performance Capabilities

System	Wavelength	Integration Time	Laser Power-Gain Product	Range for OSETI	Number of Stars for OSETI
GAIA	500 nm	0.86 second	4 x 10^{23} W	2500 pc	1,000,000,000
NGST	1 μm	2.8 hours	2 x 10^{22} W	1000 pc	10,000 ??
Kepler	500 nm	15 minutes	1 x 10^{22} W	250 pc	170,000
TPF IR	10 μm	28 hours	1 x 10^{16} W	15 pc	100
TPF Visible	500 nm	10 hours	6 x 10^{15} W	15 pc	200

Of course, adding appropriate subsystems to a space astronomy observatory, such as pulse detection designed specifically for OSETI, could greatly enhance its OSETI sensitivities and detection range.

5. ESTIMATING AN UPPER LIMIT ON THE NUMBER OF LOCAL ADVANCED ETI CIVILIZATIONS

The few stars to be observed by NGST and TPF-like systems will (unless one of those systems detects a real signal!) be too small a sample to tell us much about ETI population density.

The 100,000 stars observed by Kepler (which would over-represent brighter stars compared to a volume-limited sample) represent about one millionth of the fraction of "galactic-habitable-zone" stars. A negative OSETI result for the Kepler mission might then be interpreted as only limiting the number of actively transmitting ETI civilizations in our galaxy to less than 1 million. (This assumes that no bold ETI has migrated to several planets orbiting different host stars.)

Although it varies with position in our galaxy, the fraction of all stars represented by non-multiple G and K main-sequence stars is probably around 7%. There are good reasons to expect that only near such stars could an ETI develop, and that the ETI would only be above our technology level if its star were about 5 billion years old. (Older stars would be deficient in heavy chemical elements.) That would cut to perhaps 1% the number of stars potentially suitable for ETI, which for Kepler's program might then number about 1000. A negative result for Kepler would then reduce the "suitable star" term in the Drake equation by a factor of at least 1000.

If we expect GAIA to be a good detector of any OSETI transmissions coming from the 1 billion stars it would observe in our galaxy, then a negative result from GAIA might cut our estimated upper limit down to just 100 galactic ETI civilizations currently transmitting signals toward us.

6. CONCLUSIONS

Initial efforts to do OSETI from space might depend on serendipitous detection of CW signals by planned space astronomy telescopes with high sensitivity and spatial resolutions (spatial and spectral). These can make a beginning and open the door for more sophisticated systems.

We might also encourage planners at NASA and ESA to seriously consider adding low-cost, pulsed-signal-detection OSETI functionality to a space observatory in the not too distant future. Many people assume that pulsed signals are what would be sent, because they would have very high Effective Isotropic Radiated Power (EIRP) and outshine the ETI's star by orders of magnitude during each short pulse (see Kingsley website). Thus there would be no need to block the light of the star, or to separate the image of the transmitter from the star. Low-cost photon light-buckets could even detect the signals during the day (if the sky is clear)! It might then seem that space observatories would provide little advantage for such detections. However, to detect such pulsed signals in a rigorous, continuous search program, we might also see the value in placing wide-passband, 1-ns, coincidence photon counting detectors in space, on one of the staring-type observatories described above, where they could offer very stable response while staring for a long time at a populous star field.

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