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A Long-Term Program for Finding Life Beyond the Solar System

As part of NASA's Origins program, TPF will build on projects like Keck, SIRTF, SIM, Space Technology-3, and NGST and must itself leave a legacy of scientific results and technological capabilities for subsequent missions. Thus, it is important to ensure that in addition to accomplishing its own aims, TPF lead toward long-term goals of the Origins program or other areas of space research. What Origins-related missions might we want to carry out in the decades after TPF? Are there particular choices for TPF's architecture that are likely to open new technological vistas? These questions must be considered carefully as we place TPF within the context of an integrated program lasting 25 years or more.

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And to know the place for the first time.
Through the unknown, remembered gate
When the last of earth left to discover
Is that which was the beginning.

T.S. Eliot from
"Four Quartets," 1942

The design choices described in this report can be extrapolated to future observatories that will improve on TPF's ability to search for life on other planets. After TPF has finished its initial characterization of neighboring planets, one can imagine areas of performance that might be enhanced:

- Increasing sensitivity to enable the comparative study of the atmospheres of planets orbiting thousands of stars, rather than just a few hundred.

- Improving spectroscopic resolution to probe atmospheric conditions using the profiles of strong lines, and to search for weak lines of gases that either singly or in combination with others might offer unambiguous markers of biological activity.
- Operating at visible and near-IR wavelengths to look for additional tracers of life.
- Making the first resolved images of the nearest planets to look for moons and even gross features on the surfaces of planets themselves.

Figures 14.1 and 14.2 describe what the laws of physics (not of engineering and finance) say about enhanced imaging and spectroscopic capabilities. The figures show the telescope aperture and interferometric baseline needed to go beyond TPF's initial search for life, e.g. exploring the questions posed in the lower part of Table 4.1. The size of an individual collector required in a TPF-like interferometer increases dramatically with increasing spectroscopic resolution (Figure 14.1). A spectral resolution of R=1000 might be possible with a second or third generation infrared interferometer (using ~20 m apertures) or with an advanced visible light telescope. Such an instrument would enable a detailed examination of the composition of the atmospheres of distant planets, looking for terrestrial levels of CH_4 and N_2O or for the visible light A-band of O_2. Similarly, the requisite aperture size and array baseline increase dramatically with increasing imaging resolution (Figure 14.2). One might imagine resolving the disk of a planet with a few pixels across it to look for moons and rings or with more pixels for continents, clouds and oceans. In either case, an order of magnitude or greater improvement relative to TPF will require super-lightweight (<1 kg m^{-2}) telescopes 10 to 50 m in diameter constructed using inflatable or electrostatic thin-film mirrors, Fresnel lenses, or some as yet poorly understood technology.

As example of how TPF will pioneer techniques for later missions not associated with planet finding, consider that a separated spacecraft interferometer dramatically breaks the linkage between telescope aperture and maximum baseline. While SIM will take the first steps in interferometry, using numerous small telescopes on a 10 m baseline, TPF will use baselines of hundreds and even thousands of meters, revolutionizing high resolution imaging in a way that can be of use for astronomy missions operating anywhere from the submillimeter to X-rays. Observatories with micro-arcsecond resolution and nano-Jansky sensitivity offer remarkable capabilities for all facets of astronomy, not to mention applications looking at objects in our own solar system, or back at our own planet. A precisely controlled constellation of spacecraft operating as an interferometer is also an enabling technology for space-based gravitational astronomy.

As described in the preceding chapters, the goals of TPF are to address broadly important questions in astrophysics and astrobiology

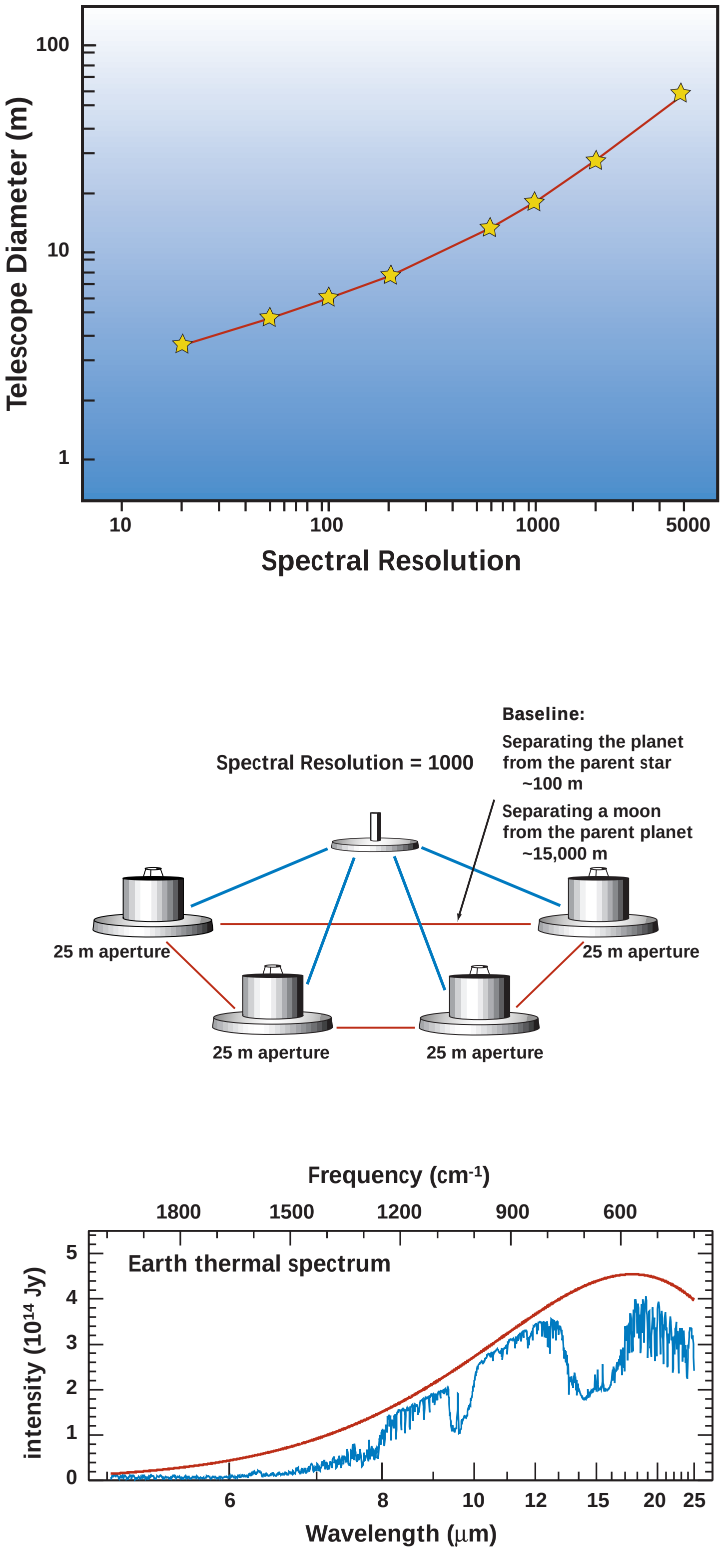

Figure 14.1. An enhanced version of TPF using four 25 m class telescopes could make R ≳ 1000 measurements of the atmospheres of terrestrial planets in one month of integration time. These data could reveal definitive signs of life such as weak concentrations of CH_4 and N_2O. Such a system could operate with a 15-km baseline to separate a planet from its moon. The graph at the top shows the relationship between spectral resolution and collecting area.

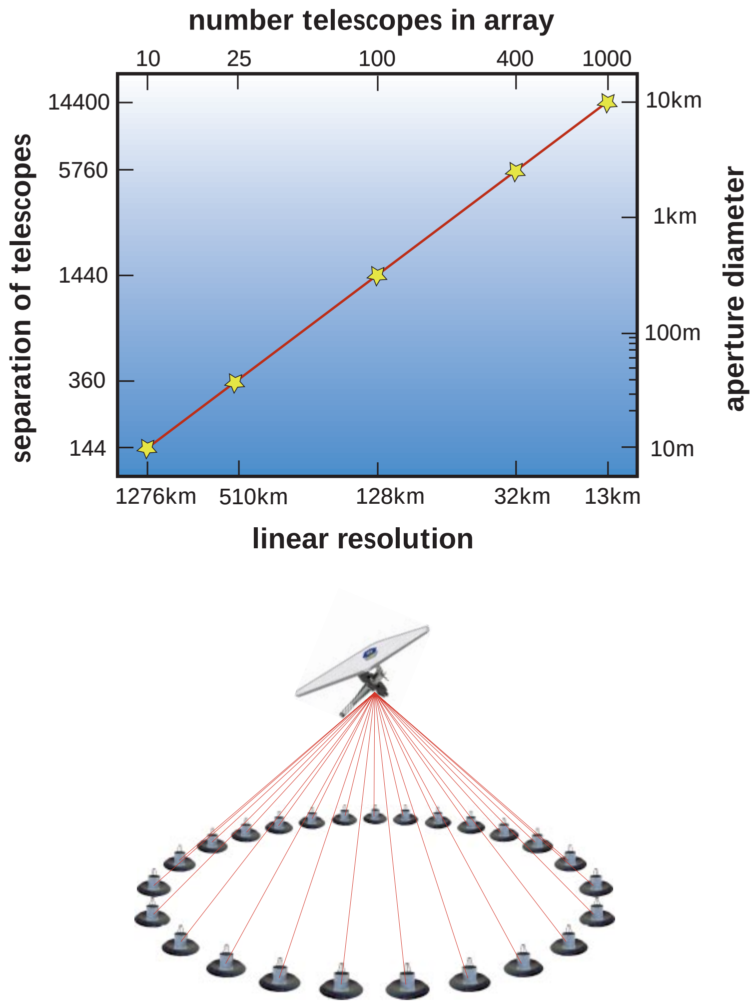

Figure 14.2. A visible light constellation capable of making a resolved 25x25 image of an Earth-like planet 10 pc away would utilize 25 40-m telescopes, each equipped with a coronagraph capable of a 10^{-10} null. The array of spacecraft would operate over a 360-km baseline. The graph at the top relates system baseline, aperture, and linear resolution on the planet.

within a constrained set of resources and to lay the technological foundation for future generations who will raise questions that are presently beyond our grasp or even beyond our imaginations. The Terrestrial Planet Finder is not an end-point of the Origins program, but rather TPF will be a vital way-station in humanity's long quest to discover the origins of life, to learn whether or not the Universe teems with life, and ultimately to deepen and broaden our understanding of ourselves and of our place in the Universe.