7

Target Stars for Planet Searches

A scientifically meaningful search for habitable planets must be designed so that a negative result (no habitable planets found) is statistically significant (cf. Towards Other Planetary Systems (TOPS) Report). In other words, TPF must examine enough stars so that we can draw valid statistical conclusions about the prevalence and properties of planets found in other solar systems. The initial failure to find extrasolar planets of Jupiter-mass was in no way a reflection on the radial velocity technique of the pioneering observers at the Canada-France-Hawaii telescope (CFHT) (Campbell *et al.* 1988). The roughly 25 stars the CFHT group examined simply didn't constitute a large enough sample given that we now know that the Jovian-mass planets that they could have detected appear to be present around only 5% of stars. To avoid a similar failure, TPF must have adequate sensitivity and operational lifetime to provide definitive answers to such questions as:

- How many stars of different spectral types, metallicity, and age have planets of various types?
- What is the range of orbital locations, eccentricities, and masses of detected planets?
- What is the range of planetary characteristics, including temperature, albedo, and atmospheric composition?
- How many planets are habitable, showing a dense, warm atmosphere with water and carbon dioxide?
- How many planets show signs of life via ozone or other tracers of biological activity?

The need to answer these questions with some degree of confidence suggests a minimum sample of at least 100-200 stars spanning a range of spectral types and other stellar properties. The failure to find habitable planets after studying only a handful of the nearest stars would raise questions about the relevance of the sample, not about the frequency of terrestrial planets. The sample size sets the minimum distance within which TPF must be able to detect and characterize terrestrial planets. Obviously, the nearest stars are the most favorable

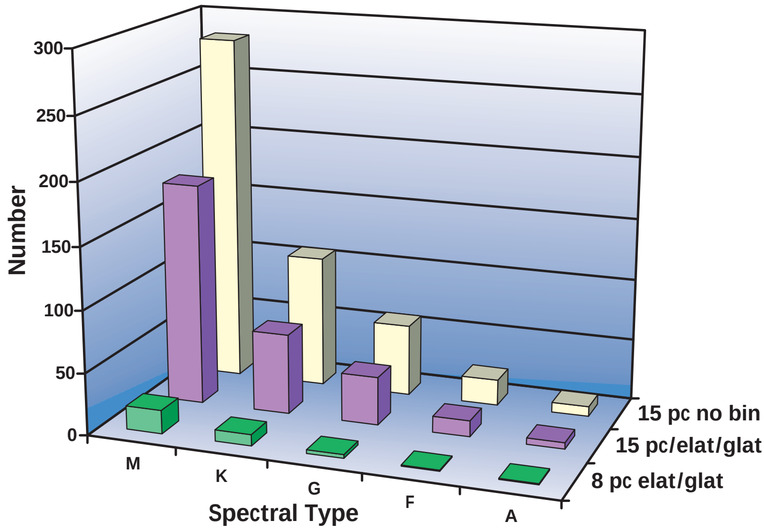

Figure 7.1. Histograms illustrate the variation of sample size and composition as a function of distance and various TPF operational constraints. From front to back, the samples are stars within 8 pc (with ecliptic and galactic latitude constraints), stars within 15 pc (with ecliptic and galactic latitude constraints), and stars within 15 pc with no geometric constraints. In all cases, binaries with separations less than 15" and giants have been removed.

in terms of potentially having the brightest, most widely separated planets. Unfortunately, the local density of stars is low, so that not all spectral types are represented by nearby examples. This chapter addresses the astrophysical and observational constraints that trim the list of available targets from ~500 to ~150 within 15 pc.

It should be noted that while TPF's search for terrestrial planets will be confined to the nearest stars, TPF will be able to study the evolution of giant planets in star clusters such as the TW Hydrae, the Pleiades, and the Hyades clusters and in star-forming regions (Chapter 8). Recent results suggest that while terrestrial planets will not be detectable in these regions, hot young Jupiter-like planets might be (Terebey *et al.* 1998; Becklin *et al.* 1998; Turnbull *et al.* 1998). Observations of these young systems would be valuable for developing a more general understanding of the formation and evolution of planetary systems.

THE NEARBY STARS

Figure 7.1 and Table 7.1 show the distribution, by spectral type, of stars within 15 pc from the Gliese (Gliese and Jahreiss 1991) and Hipparcos (European Space Agency 1997) catalogs. The cooler, less luminous spectral types (K, M) dominate the solar neighborhood while solar type and more massive stars (G, F, A) are rarer and must be examined at larger distances from the sun. Note that the initial search for planets to understand the frequency and character of planetary systems is not affected by concerns relevant to the search for life. We should examine a robust sample of stars of all spectral types. For example, tidal locking of planets around M stars and the brief time possible for the evolution of ecosystems on planets with A-type stars will limit the range of systems in which life may plausibly be sought. Figure 7.1 and Table 7.1 describe three sample sets drawn to satisfy constraints described in more detail below:

Table 7.1. Illustrative Samples of Main Sequence Target Stars

Spectral Type	D<15 pc No binaries<15"	D<15 pc No binaries<15" |Gal. Lat.|>10° |Ecl. Lat|<45°	D<8 pc No binaries<15" |Gal. Lat.|>10° |Ecl. Lat|<45°
A	8	5	1
F	21	13	1
G	58	39	3
K	107	65	9
M	282	179	19
Total*	213	141	33

*Includes only those M stars within 8 pc.

1. Stars closer than 15 pc, but with giants, white dwarfs, and binaries closer than 15″ rejected (see below).
2. As above (#1), but with two geometrical constraints imposed:
   - more than 10° away from the galactic plane to avoid background confusion;
   - within 45° of the ecliptic plane to keep inside the TPF sun-avoidance zone (see below).
3. As above (#2), but with the added constraint that stars be within 8 pc.

An alternative view of the sample is to consider the brightness of an earth (1 $R_\oplus$) in the habitable zone around the suitable nearby stars. Figure 7.2 shows the planet brightness (F_ν(12 µm), proportional to d^{-2}) vs. star-planet separation for a planet in the habitable zone (proportional to d^{-1} and $L_*^{0.5}$). The planet fluxes vary from 0.2 µJy up to almost 10 µJy for the nearest stars. With the sensitivity limits given in Table 6.1, planets 10 pc away would be detectable in less than a day, would be examined for water and carbon dioxide in a few days, and would be searched for ozone in just two weeks.

CONSTRAINTS ON THE TARGET STARS

Binary stars cause a special problem for TPF because nulling can only be accomplished for a single star, seen on-axis. Thus, binary and multiple stars located nearer a certain distance to the target are ruled out. The minimum acceptable separation can be estimated by requiring that the diffracted light from the companion be no brighter than the local zodiacal emission that would otherwise dominate the photon noise. The extra integration time required to reach a given noise level depends on the brightness and separation of the companion and on the aperture of the telescope, which controls the width of

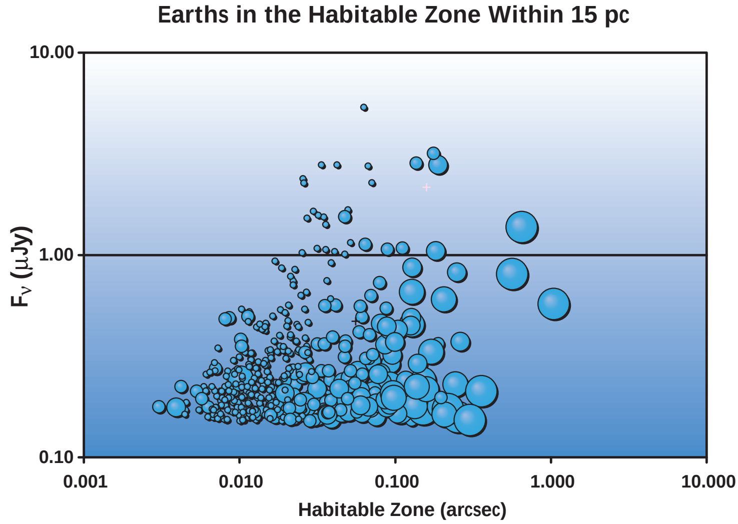

Figure 7.2. Brightness (flux density in µJy) and angular scale of habitable zone for Earth-sized planets around known stars within 15 pc. The symbols denote spectral type with M stars (smallest circles) through A stars (largest circles).

the diffraction pattern. Figure 7.3 shows the excess integration time for companion magnitudes 0, 5, 10 mag at 12 µm and for different telescope diameters (2, 3.5, 5 m). The figure suggests that, using 3.5 m telescopes, TPF will not be able to work on binaries closer together than about 5″ (for 12 µm sources brighter than 5 mag). The calculations ignore scattering (not too severe for telescopes diffraction limited at 2 µm) and diffraction around the secondary support structure (which could be mitigated by an off-axis telescope design) and are thus lower limits. In constraining the samples of the previous section, a more conservative minimum separation of 15″ was used. Roughly 50% of stars have one or more companions within this separation. The detailed source selection for TPF will require a case-by-case examination of the field around each star looking for contaminating stars (or galaxies) with or without a physical association with the target. Spectroscopic or astrometric searches for low mass stellar companions will also be important.

Sky coverage. As discussed in Chapter 11, the passive cooling of the telescopes imposes a sun-avoidance constraint that precludes TPF from observing the entire sky. The present design has an ecliptic latitude constraint of |β|<45°, which eliminates roughly 30% of the celestial sphere. If this constraint can be relaxed to |β|<60°, only 15% of the celestial sphere would be unobservable.

Resolving the star and the habitable zone. Two of the factors affecting the interferometer baseline are the depth of the null and the size of the habitable zone around each star. As the baseline increases the star begins to leak past the deepest part of the null with a rapid loss of sensitivity due to increased shot noise. The leakage constraint is shown as dotted lines in Figure 7.4 for stars of spectral types, F5, G5, K5, and M5 at a wavelength of 12 µm. The maximum baseline limits how much angular resolution can be used to isolate a planet against the zodiacal

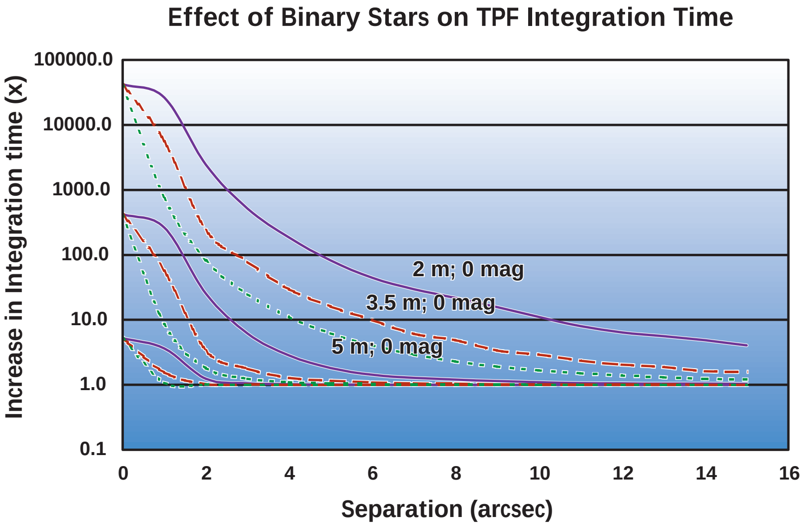

Figure 7.3. The effect of excess photon noise from a companion star on the integration time relative to the zodiacal dust limited-integration time for companions of different brightness (0, 5, 10 mag at 12 µm) observed with telescopes of different apertures (2m, solid blue; 3.5 m, dashed magenta ; 5 m, dotted red).

emission in the target system. At baselines longer than those shown, the stellar leak rapidly becomes too severe to operate.

A constraint on the minimum interferometer baseline comes from the need to resolve a planet in the habitable zone, which for the purposes of illustration we define here as the distance at which the planet's equilibrium temperature $T_p \sim 278\ R_p^{-0.5} L_*^{0.25}$ K could support liquid water at sea-level pressure (273 K). This constraint is shown as solid lines in Figure 7.4. The ability to tune the interferometer spacing in the separated spacecraft option allows TPF to resolve the habitable zones around K stars 15 pc away, as well as for M stars 5 pc away. A fixed baseline system (shown as a dotted black line) would be unable to resolve the habitable zones around more distant K stars, and almost any M stars.

Exo-zodiacal emission. As discussed in Chapter 5, the level of exo-zodiacal light is a fundamental property of target stars that affects the detectability of planets. The integration time for TPF scales roughly as the sum of the local and exo-zodiacal photo-electron counts (see Appendix A). In the case of TPF operating at 1 AU, the total background is dominated by the local emission until the counts from the dust in the target system reach roughly 10× the level of emission in our solar system (Figure 6.2). As discussed in Chapter 6, we know only that about 15% of stars of spectral types A-K have cold dust clouds corresponding to Kuiper Belt debris at the IRAS detection limit or brighter, roughly 100 times the optical depth of the solar system's warmer zodiacal cloud. At this writing, only eight main sequence systems are known with 300 K dust, to an IRAS limit of about 500 Zodi. Since there does not appear to be a direct scaling between outer and inner dust density, observations with SIRTF, and with the Keck and Large Binocular Telescope (LBT) interferometers will be needed to refine our knowledge of this key property of solar systems.

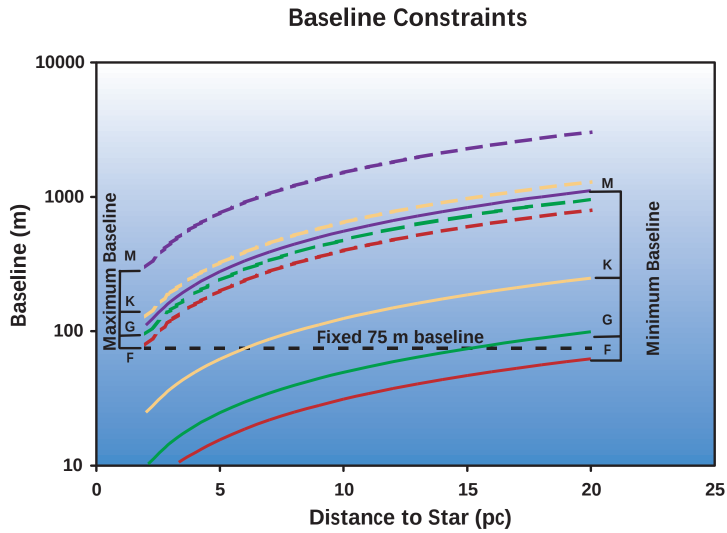

Figure 7.4. The maximum interferometer baseline is set by spacing at which the star begins to leak beyond the edge of the null (shown as dotted lines for various spectral types). The minimum baseline is set by the need to resolve the habitable zone (shown as solid lines). A fixed 75-m baseline is shown for reference.

Orbital Inclination. Simulations show that it is difficult to find planets in the presence of zodiacal emission in systems with inclination angles between about 60° and edge-on. Numerical simulations indicate that different interferometer configurations, including ones with chopping (Figure 6.9) that preserve phase information can reduce the deleterious effects of inclination. This constraint could remove 15 to 20% of target stars for systems with bright exo-zodiacal clouds.

NECESSARY OBSERVATIONS IN ADVANCE OF TPF: THE NEARBY STAR DATABASE

The preceding sections illustrate the challenge of source selection for TPF. The sample of stars within 15 pc will probably contain more than 125 stars and include more than 30 solar type-G stars. There is an urgent need to collect information on the most favorably placed stars in our immediate vicinity, including:

- Accurate distances and proper motions.
- Radial velocity and astrometric searches to rule out stellar companions.
- Radial velocity and astrometric searches to detect and to characterize orbital parameters of giant planets, particularly orbital inclination angle.
- Metallicity.
- Age.
- Rotational velocity and inclination of stellar rotational axis.
- Chromospheric activity.

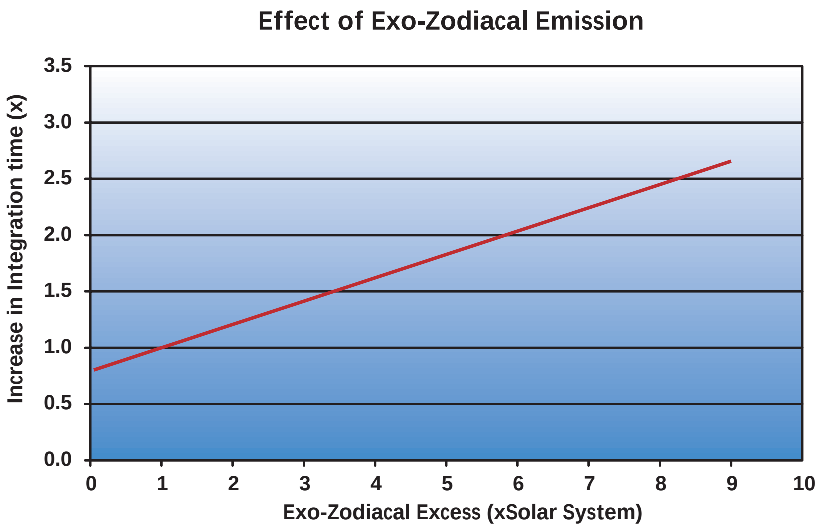

Figure 7.5. The factor by which the integration time must be increased due to increasing noise from the zodiacal emission in the target star (exo-zodiacal emission) for TPF operating at 1 AU (see Table 6.1).

- Background star fields relevant to epoch of TPF mission.
- Level of inner and outer solar system dust emission.

In many cases, reliable data do not exist for these stars and must be obtained within the next decade. Fortunately, many of the relevant data can be obtained using ground-based telescopes of modest aperture. These data should be made readily available via networks and added to, as new observations become available.

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