Target Stars for Earth-like Planet Searches with the Terrestrial Planet Finder

R. S. Simon (NRAO), S. S. Vogt (UCO/Lick Observatory)

Abstract

There is broad interest in the problem of identifying and characterizing terrestrial (Earth-like) planets outside of our Solar System. Several studies are underway to develop concepts and plans for the Terrestrial Planet Finder (TPF) space mission (see Beichman et al., 1999: "Terrestrial Planet Finder"). TPF, like other missions in the early planning stages, aims to search selected nearby stars for the existence of terrestrial planets, and characterize any planets that may be discovered through low-resolution spectroscopy and other measurements. The high contrast ratio between a star and any nearby planet, the small angular scale required, and the possibility of dust emission masking the planet's signature, combine to make the overall TPF problem challenging.

A vital aspect of instrument and mission design for TPF is selecting appropriate target stars. We report here on the characteristics of a carefully defined complete sample of nearby stars suitable for terrestrial planet searches. Beginning with the more than 7,000 known stars located within 50 parsecs of the Sun, we have applied a number of selection criteria to identify a complete sample of about 160 promising target stars for TPF. Our selection criteria aim towards the ability to detect Earth-like planets: those planets with equilibrium temperature and size similar to Earth. The resulting target list places significant requirements on TPF, if TPF is to search a statistically interesting sample of stars.

An important result is that most stars of interest for TPF will be harder to search for Earth-like planets than an analogue to the Solar System observed from 10parsecs distance. The typical system in our final sample is smaller, and further away than such a Solar System analogue.

Preliminaries

A Working definition for an "Earth Like" Planet:

- Earth size and albedo
- Earth-like equilibrium temperature

Working Definition for the Habitable Zone (HZ):

The size of the HZ is conveniently defined as the distance from a star at which an Earth-like planet would have an Earth-like equilibrium temperature.

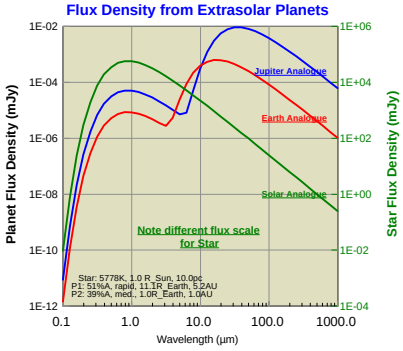
- Using catalogued V-I colors and m_V, estimate Bolometric Magnitude m_{Bol} and star's Effective Temperature T_{eff}
- Use simple model of planetary Equilibrium Temperature to derive angular diameter of HZ (Hipparcos parallaxes yield physical size)
- It can be shown that simple relationship exists between the angular size of the habitable zone, the planetary albedo, the bolometric magnitude of the star, and the stellar effective temperature:

$$HZ\ (mas) = 9.6 \times 10^4\ (1\text{-Albedo}_{Earth})^{0.5} / 10^{(mbol/5)} / T_{eff}^{\ 2}$$

Contrast Ratio Calculation

- Assume the star is characterized by a black-body spectrum at its T_{eff}
- Planetary emission is the sum of reflected plus thermal spectra, corrected to an assumed half-moon phase angle.
- For a planet with a specific assumed temperature, the contrast ratio depends only on the T_{eff} for the star.

Sample Calculation



Calculated thermal and reflected flux density for Sun, Earth, and Jupiter analogues, as observed from 10 parsecs distance.

Author Contact Information:
Richard Simon
National Radio Astronomy Observatory
520 Edgemont Rd.
Charlottesville, VA 22903
rsimon@nrao.edu

Conclusions

For TPF to search a large sample of promising stars for Earth-like planets, it should strive to observe systems with the following characteristics:

- Separation: 50 milliarcseconds or greater between star and planet
- IR Contrast ratio: 5×10^7 or less at 10 microns
- Visible contrast ratio: 3×10^{10} or less at 1 micron

Reducing these limits will substantially reduce the number of stars accessible to TPF. These criteria are **more difficult** than observing the sun at 10 parsecs: The required contrast ratio is about a factor of 10 higher, and the required resolution about a factor of 2 greater.

Selection of Target Stars

TPF target requirements are defined by the fundamental goal of detecting and characterizing Earth-like planets around Sun-like stars. This implies that the most interesting target stars for TPF are long-lived main-sequence stars with low levels of stellar activity or variability. In addition, the difficulties of observing a planet in the presence of the glare from its primary star and considerations of orbital stability rule out close binary stars from any list of the most promising candidate systems for TPF observation. We used the following steps to define the most promising TPF target stars:

(1) Select stars from the Hipparcos catalog (118,000+ stars) closer than 50 parsecs: 7,058 stars meet this criteria. The Hipparcos catalog is complete to fainter than 7th magnitude, and also includes many nearby stars much fainter. The stars that TPF will target are almost certainly brighter than 7th magnitude (as detailed analysis shows), so that the 7,058 stars selected this way includes **all** reasonable TPF targets. Note that distant giants and supergiants are excluded with these criteria.

(2) Using catalogued colors and magnitudes it is possible to calculate the basic parameters for an Earth-like planet near each of the stars, including the diameter of the Habitable Zone (HZ). For these purposes, the HZ is defined as the distance from the star at which an Earth-like planet would have the same equilibrium temperature as Earth.

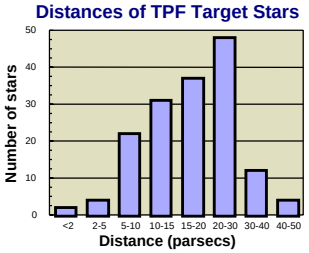
(3) Select those stars for which the HZ is greater than some limit. We have focused on stars for which the HZ is greater than 75 milliarcseconds (641 stars); if the HZ cutoff was decreased to 50 milliarcseconds, the number of stars at this point in the winnowing process would be 1,166 stars. Note that our 75 milliarcsecond cutoff implies a practical resolution limit of about 50 milliarcseconds, to allow reasonable finding probability with unknown planetary phase angles.

(4) Starting with these 641 stars, we have carefully reviewed the literature to confirm spectral types, variability, luminosity class, binarity, and so on. We then **eliminated** stars which met the following criteria:

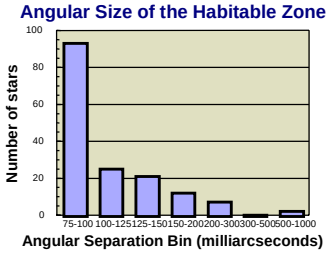
- Known giants or supergiants (luminosity class I, II, or III) (except for one class III with a suspected Jovian-mass companion)
- Known RS CVn's, W Uma's, Algols, roAp's, or A2CVn variable stars
- Known close visual companions (within ~10")
- Known spectroscopic binaries with periods < 5 years
- Main sequence lifetimes of at least 1 Gyr (Sp type >= F0)

The remaining 160 stars are what we have termed the "Golden Oldies", our proposed list of the most promising candidate stars for the TPF mission.

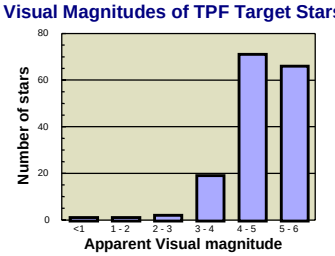
Distances of TPF Target Stars



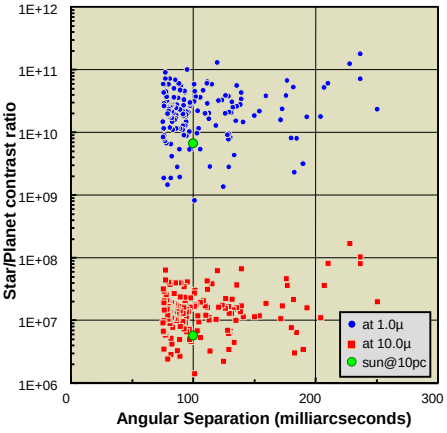
Angular Size of the Habitable Zone



Visual Magnitudes of TPF Target Stars



Star/Planet Contrast Ratio



The TPF "Golden Oldies" Sample:

- 160 Stars
- Closer than 50 parsecs
- HZ >= 75 milliarcseconds
- No obvious companion within 10 arcseconds
- Luminosity class V or IV (1 exception)
- Spectral type F0 or later (long main sequence lifetime)
- Not a known large amplitude variable

Characteristics of the "Golden Oldies":

Percentile	50%	75%	90%	Sun@10pc
Visual Magnitude	4.86	5.17	5.28	4.79
Parallax (mas)	50	35	25	100
HZ Diameter (mas)	95	82	78	100
Contrast Ratio (1μ)	2.8E+10	5.5E+10	9.0E+10	1.0E+10
Contrast Ratio (10μ)	1.6E+7	2.5E+7	4.2E+7	5.7E+6

- Median T_{eff} of 6300 K (compare Solar 5778)
- Median distance of 20 parsecs
- Median Contrast ratio ~3x greater than Sun at 10 parsecs

Flux Density for TPF Target Stars