Identifying nearby Earth-size planets in the Habitable Zone that can be Targets for Spectroscopic studies

Abstract:

The long-term objective of ESA to *"detect biomarkers in Earth-like exo-planets in the Habitable Zone, and the even more ambitious goal of imaging such planets"* requires several steps. In this white paper, we look at the different methods to identify in advance actual nearby telluric targets for a large spectroscopic mission whose aim would be solely to characterize atmospheric gases and search for biomarkers.

We review the different methods (direct detection, radial velocities and astrometry) which could provide a list of targets and analyze their chance of success in function of different criteria including the distance of the star, the expected signal to noise ratio due to possible astrophysical biases like the stellar activity.

The estimates assume that *a perfect instrument* can be built for each technique. The comparison ***is in favour of astrometry*** by one order of magnitude. This is only indicative but points to the interest of building an astrometry instrument that has the ***capability of detecting an Earth-size planet in the Habitable Zone of <u>nearby stars</u>***.

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Although not unique, a sensible road map to characterize habitable planets is:

(1) A statistical determination of the frequency of habitable planets;

(2) The identification of potentially habitable, terrestrial planets around nearby stars that would be suitable for investigation by future spectroscopic missions;

(3) Spectroscopic studies of these planets with the aim of identifying key atmospheric gases for comparative planetology and search for life.

Step (1) should be achieved by already planned missions such as *Kepler* (launch Feb. 2009). The goal of the present White Paper is to discuss the best way to achieve step (2).

1. The need for identification

Planetary transit observations, e.g. by the *Kepler* space mission (launch Feb. 2009) and subsequent Radial Velocity (RV) follow-up should establish the abundance of telluric planets located in the Habitable Zone (HZ) of their parent stars. This should be possible for planets with masses and radii down to Earth values and "easily" performed for larger telluric planets, the so-called *Super-Earths*. The existence of the latter population close to their stars (period < 30 days) has been convincingly demonstrated by recent RV observations with the HARPS instrument (Mayor et al., 2008, arXiv:0806-4587v1, Fig.1), and by micro-lensing (Bennet et al., ApJ, accepted). These objects provide some reason to believe that similar planets could be present at larger distances, e.g. in the HZ.

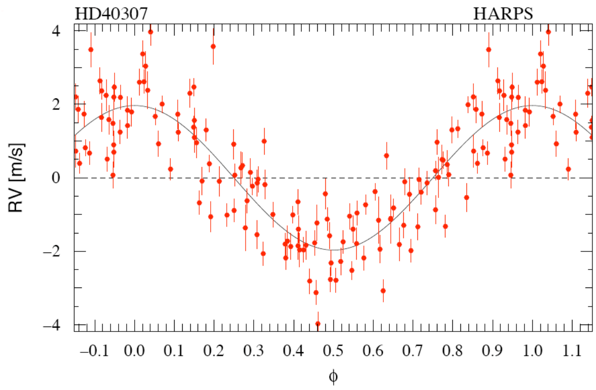

Figure 1: Radial Velocity curve of the lightest of the Super Earths detected in a 3 planet system with M sin(i) and period of 4.3, 6.9, 9.7 M_{Earth} and 4.31, 9.62, 20.5 days, respectively (Mayor et al., 2008)

These precursor observations are extremely valuable for estimating the likely number of planets that a spectroscopic mission could study, but they cannot identify actual targets. The reason for this limitation is that transit missions can detect only a small fraction, typically 0.5%, of the planets that are in the HZ of a Sun-like star. Transit stars are typically located many tens or hundreds of parsec away, making them impossible targets for direct detection missions. Similarly, microlensing detects only planets that are distant from us (distance > 1 kpc) and in geometries that can never be repeated after the short microlensing event is completed. On the other hand, spectroscopic missions can study only nearby planets because photons from exoplanets are very few and angular separations are small. As a consequence, only few, if any, of the targets suitable for spectroscopic studies can be identified by transit mission, even if the latter were able to cover the whole sky. Microlensing can detect none of them.

2. <u>How to perform the identification?</u>

There are a number of possible ways to identify targets for a spectroscopic study:

(1) Using the spectroscopic instrument itself, since it is built to make direct detections of the planetary photons. The detection can be performed using the information from many wavelengths at once, and this multiplex gain makes the detection significantly faster than the spectroscopy. However, such a large mission (IR interferometer or visible coronagraph/occulter) will necessarily be very costly, requiring many years of technology investment before it is ready to move into development. In addition, it would be valuable to save the time needed for the detection phase, since several visits are necessary per star to determine the existence of a planet and its orbit if no prior information is available. In the case of the coronagraph/occulter the inner working angle is likely to be relatively large (25-100 mas for a 4 m coronagraph/occulter), meaning that the planet might spend a considerable part of its orbit inaccessible to the telescope. *A priori* information on the existence and location of the target planet would allow careful optimization of the scientific return of the spectroscopic study.

(2) Building extreme RV instruments and telescopes that can detect Earths in the HZ of the nearby stars. While great progress has been made toward identifying hot Super-Earths, it is quite uncertain whether it is possible, even with a perfect instrument, to push to << 10 cm/s precision needed to detect and characterize 1 Earth mass planets in their HZ across a broad range of spectral types, particularly in the presence of intrinsic astronomical noise sources.

(3) Building an extreme accuracy astrometric instrument that has the capability of detecting these planets. Assuming such an instrument can be built and flown in space, it is again important to address the question of how severe are the astrophysical limitations for this approach.

3. <u>Comparing the ultimate limitations of Radial Velocity and Astrometry</u>

A simple estimate of the limitation due to stellar spots is useful to compare the capabilities of approaches (2) and (3) (M. Shao, 2008, unpublished). A stellar spot covering a fraction ρ of the surface of the stellar disk will have an impact on both RV and astrometric measurements. Both impacts are proportional to the surface coverage so that the comparison between the two techniques is independent of ρ. For numerical estimates we use $\rho = 10^{-3}$, a mean value for a compact group of spots on nearby G stars that are typically twice more active than the Sun.

For RV measurements, the error in determining the stellar velocity is

$$\delta V = c_2 \, . \, V_{rot} \, . \, \rho \tag{1}$$

where c_2 takes into account the variable incidence of the spot when it is close to the stellar limb or to the centre of the stellar disc, as a mean value $c_2 \sim 0.5$; V_{rot} is the linear velocity due to stellar rotation. For a moderate rotator as the Sun, $V_{rot} \sim 2$ km/s near the equator, a value probably representative for nearby stars. The reader should note that, contrary to RV samples dedicated to the study of a given problem, the observer cannot select a special subgroup of stars, e.g. slow rotators, because the list of nearby stars is fixed. With these values, Eq.1 yields a typical velocity error of $\delta v \sim 1$ m/s.

For astrometry, a dark spot will introduce an error on the position of the stellar photocenter. The incidence on the astrometric position is

$$\delta\theta = c_1 \,.\, (R_{st}/D) \,.\, \rho \qquad (2)$$

where c_1 is a constant that takes into account the variable orientation of the spot surface with respect to the sky plane, as an average $c_1 \sim 0.5$, R_{st} and D are the stellar radius and distance of the system, respectively. For a Sun-like star at 10 pc Eq.2 yields $\Delta\theta \sim 0.25$ μas.

The impact of the spot has a different nature and order of magnitude for each technique. To estimate the corresponding limitations for planet detection, these induced errors can be compared to the expected signal due to a planet with mass $M_{pl} = 1\ M_{Earth}$ in the HZ of a Sun-like planet at 10 pc. ***The comparison*** is shown in Table 1 and ***is in favour of astrometry*** by one order of magnitude.

As this hierarchy is true for any spot size, it is also true for a group of several spots distant from another.

Table 1

Incidence of a stellar spot group for Astrometric and Radial Velocity measurements compared to the signal generated by an Earth in the HZ of a G star. The detecting capability of perfect instruments for these two techniques can be estimated by comparing these astrophysical noises to the expected planetary signals.

Source	Astrometry	Radial Velocity
Noise *N* due to a star spot group	0.25 μas	1 m s^{-1}
Signal *S* of an Earth at 10 pc (sin *i* = 1)	0.30 μas	0.1 m s^{-1}
S/N of a single observation	1.2	0.1

The lifetimes of stellar spots are usually somewhat shorter than the stellar rotation period, say $P_{rot}/2$. The corresponding noise for both techniques starts averaging as $t^{1/2}$ only for a time *t* larger than ~ $P_{rot}/2$. Otherwise noises associated with different measurements are correlated ("red noise"). Two measurements made at a short time interval (<< $P_{rot}/2$) will have similar biases because spots will not have moved much.

A factor ~ 12 on the S/N ratio translates into a factor of ~ 144 in integration time. If a SNR ~ 5 is required, ~ 20 measurements are necessary for astrometry to overcome the noise of a $\rho = 10^{-3}$ spot group, and 2500 measurements for RV. With measurements separated by $P_{rot}/2 \sim 15$ days in order to be in the white noise regime, this leads to a ~ 1 yr duration for astrometry and a prohibitive duration for RV.

4. Conclusion

All these estimates assume that *a perfect instrument can be built* for each technique. The comparison ***is in favour of astrometry*** by one order of magnitude. As this hierarchy is true for any spot size, it is also true for a group of several spots distant from another.

The estimates are only indicative[1] but point to the interest of building an astrometry instrument that has the ***capability of detecting an Earth-size planet in the HZ of nearby stars***. This is the goal of the SIM-Lite project by NASA, which is the topic of another white paper.

[1] In particular, we have considered only a mean nearby star instead of an actual list of objects with their activities and the corresponding incidences on both detection techniques