Does a moving viewpoint change the exoplanet sky?

A discussion note from Finding Earth 2.0

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1. Motivation

I have built Finding Earth 2.0, a tool to explore the known exoplanet hosts in their Galactic context. Figure 1 shows the present-day discovery sky (plotted from the current Sun–Earth viewpoint) using the latest catalogue data. It gives a snapshot of where the discovered exoplanet host stars are located in the Milky Way, coloured by distance.

My question is whether a moving observer in the Galaxy would slowly see a different exoplanet sky because both we (the Solar System) and the target systems move with their own velocities. As the Sun moves from point A (today) to point B and later towards C in the Galactic plane, do we pass through changing sightlines and hence a changing set of detectable planetary systems, in the same way that a traveller passes different countries on the way to a destination?

This note is a first step to think about the geometry and relevant timescales. It is a conceptual question about how a changing viewpoint might affect which exoplanet systems become detectable in the future.

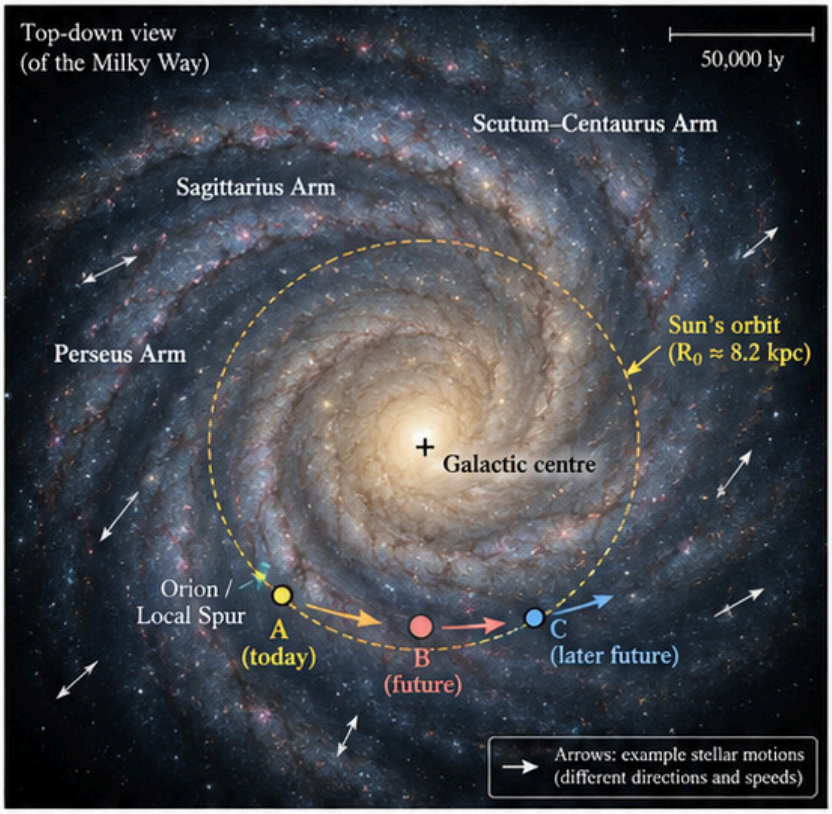


Figure 2. Schematic Galactic motion: both the observer and target systems move; spiral arms are pattern structure, not rigid tracks. Top-down view of the Milky Way (illustration based on astronomical image). The Sun orbits the Galactic centre at $R_0 \approx 8.2$ kpc. The yellow, red and blue points show the Sun's position at A (today), B (future) and C (later future) along its orbit in the Galactic plane. Arrows indicate example motions of surrounding stars/systems with different directions and speeds. The labelled spiral arms (Perseus, Sagittarius, Scutum–Centaurus) are density-wave pattern features, not fixed material tracks.

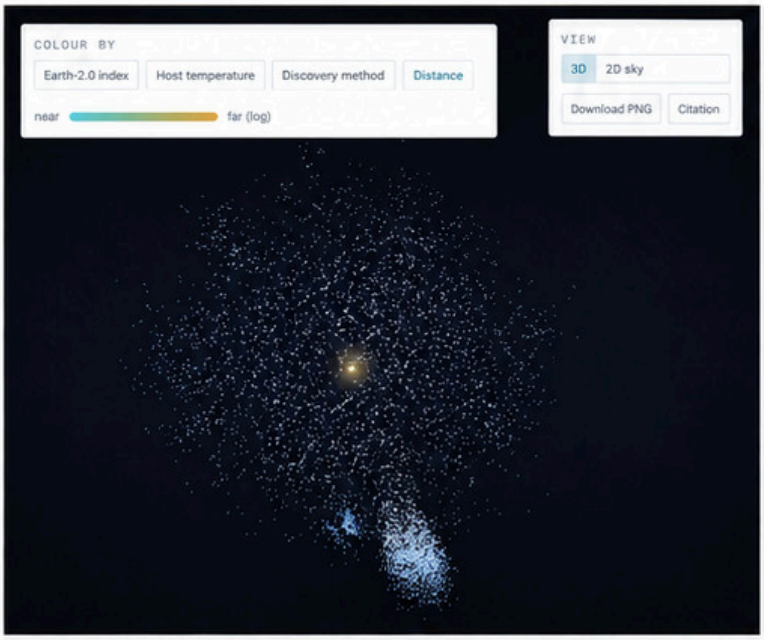


Figure 1. Finding Earth 2.0 present-day discovery map. This is a catalogue snapshot of discovered exoplanet hosts, not a simulation of future trajectories. Each point represents a known exoplanet host star, coloured by distance (nearer: blue, farther: yellow). The map is from the current Sun–Earth viewpoint (see Finding Earth 2.0).

2. What I mean geometrically

Let the observer's position (Solar System barycentre or Earth) at time t be

$$\mathbf{r}_{\rm obs}(t) = \mathbf{r}_{\rm sun}(t) + \mathbf{r}_{\rm earth}(t) \tag{1}$$

For a target star or system i at position $\mathbf{r}_i(t)$, the line-of-sight direction is

$$\hat{\mathbf{n}}_i(t) = \frac{\mathbf{r}_i(t) - \mathbf{r}_{\rm obs}(t)}{\|\mathbf{r}_i(t) - \mathbf{r}_{\rm obs}(t)\|} \tag{2}$$

The change in apparent direction over time t is roughly

$$\Delta\theta_i \approx \frac{|\mathbf{v}_{{\rm rel},\perp}|\, t}{D_i} \tag{3}$$

and the Sun's distance travelled in time t is

$$d_{\rm sun} = v_{\rm sun} t \tag{4}$$

Using $v_{\rm sun} \approx 233$ km s^{-1} (Galactic circular speed), the distance moved by the Sun is:

Time t	$d_{\rm sun} = v_{\rm sun} t$	Approximate distance
10^2 yr	7.35×10^{11} km	0.078 ly
10^4 yr	7.35×10^{13} km	7.8 ly
10^5 yr	7.35×10^{14} km	78 ly

The Sun's present Galactic radius is $R_0 \approx 8.2$ kpc, giving an orbital period $P_{\rm gal} \approx 2\pi R_0 / v_{\rm sun} \approx 2.2 \times 10^8$ yr.

This is only a conceptual question. I am trying to understand whether a moving observer changes the exoplanet sky in a measurable way.

3. Quantifying the idea

My question is not limited to 100 years. I want to think about a moving observer that goes from position A (today) to position *B* (some time in the future) before eventually reaching position C (later in the future), while target stars and planetary systems also move through the Galaxy.

As the observer moves, the line of sight to a given host star changes. At the same time, the host star and its planets also have their own space motions. The key question is whether this changing observer–host geometry means that different planets become geometrically visible or detectable from A, *B* or *C*. In particular, could some systems enter or leave transit visibility, or could the detectability via other methods (such as radial velocity) also change in a meaningful way?

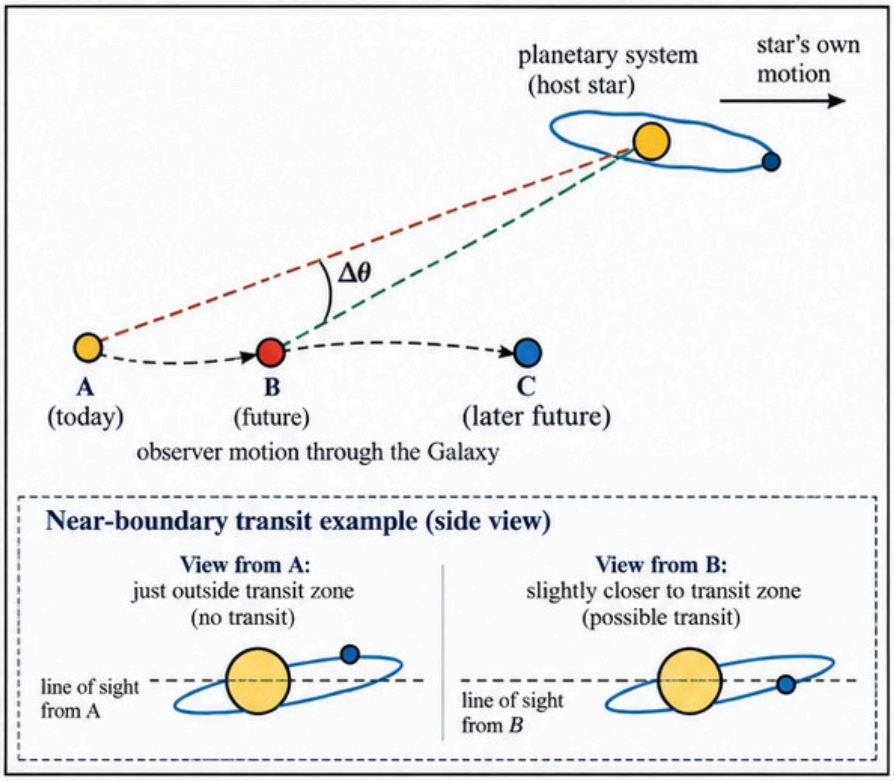


Figure 3. Changing line-of-sight geometry for a moving observer. The observer moves from A (today) to *B* (future) and eventually to *C* (later future). The line of sight to a target planetary system changes by an angle $\Delta\theta$ as the observer moves. The host star also has its own motion. Bottom panels show a near-boundary transit case: from A the planet is just outside the transit zone (no transit), while from *B* the slightly changed viewing angle brings it closer to the transit zone (possible transit).

Key expressions

For a planet on a circular orbit, the (sky-projected) impact parameter for a transit is

$$b(t) = \frac{a\cos(\vartheta_{\rm eff}(t))}{R_*} \tag{5}$$

A transit occurs when the impact parameter is smaller than the sum of the stellar and planetary radii (in units of the stellar radius),

$$|b(t)| < 1 + \frac{R_{\rm p}}{R_*} \tag{6}$$

For a circular orbit, the approximate geometric transit probability is

$$P_{\rm transit} \approx \frac{R_* + R_{\rm p}}{a} \tag{7}$$

The radial-velocity semi-amplitude is given by

$$K \approx \left(\frac{2\pi G}{P}\right)^{1/3} \frac{M_{\rm p}\sin i}{M_*^{2/3}} \tag{8}$$

Transit geometry is the most obviously viewpoint-sensitive case, because a small change in the line of sight ($i_{\rm eff}$) can move a system into or out of the transit zone. *Radial velocity* depends more weakly on viewing direction, through the $\sin i$ term.

Simple example numbers

For a relative transverse speed of $v_{\rm rel} = 30$ km s^{-1} and a host distance of $D = 100$ ly, the angular shift in the line of sight is approximately

$$\Delta\theta \approx \frac{v_{\rm rel}t}{D} \tag{9}$$

This gives:

Time t	$\Delta\theta$ (radians)	$\Delta\theta$ (degrees)	$\Delta\theta$ (arcseconds)
10^2 yr	1.0×10^{-4}	0.0057	20.6
10^4 yr	1.0×10^{-2}	0.57	0.57° = 2,060 ″
10^5 yr	1.0×10^{-1}	5.7	5.7° = 20,600 ″

For an Earth–Sun analogue ($a = 1$ au, $R_* = 1$ R$_\odot$, $R_{\rm p} = 1$ R$_\oplus$), the geometric transit probability is

$$P_{\rm transit} \approx \frac{R_* + R_{\rm p}}{a} \approx 0.0047 \approx 0.47\% \tag{10}$$

This illustrates that even a small change in viewing angle can move a system across the transit boundary in some cases, especially for near-boundary configurations.

4. Questions for experts

This is just a thought I am trying to figure out, and I would genuinely value any expert opinion.

- If the observer moves from A to *B* before eventually reaching *C*, while host stars also move, can the set of geometrically visible planets increase or decrease?
- Could some systems enter or leave transit visibility because the observer–host line of sight changes?
- Would this mainly affect transit detections, or could radial velocity, direct imaging, or microlensing also change in a meaningful way?
- At what timescale does this become scientifically interesting rather than negligible?
- Am I overlooking a simpler geometrical or dynamical argument?

Any experts, please let me know — this is just a thought I am really trying to understand.