TRANSITING QUASITES AS A POSSIBLE TECHNOSIGNATURE

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A non-stationary test particle in the vicinity of a point mass should be expected to follow a Keplerian orbit. Deviations from strict Keplerian motion arise in a number of contexts though, such as gravitational multipole moments (Tremaine & Tomer 2014), general relativistic corrections (Misner & Thorne 1973) and anisotropic thermal emission (the Yarkovsky effect; see Bottke et al. 2006). One deliberately engineered mechanism for non-Keplerian motion was suggested by Forward (1993) and McInnes & Simmons (1992b), where radiation pressure is used to modify the orbital motion.

In both of these papers, the authors primarily focus on geocentric satellites and suggest that geostationary orbits could be maintained above the equatorial plane through the use of an angled mirror incident to Solar radiation pressure. Forward refers to these objects as "statites", as a result of their apparent static nature in the observer's sky. Recent work by Baig & McInnes (2010) finds that such orbits should be theoretically stable for paths 10-20 km above the equatorial plane, which may help alleviate over-crowding of the geostationary ring.

Although the statite idea largely focussed on the geocentric case (Forward 1993), heliocentric statites should also be possible, as proposed by McInnes & Simmons (1992a), although they refer to such objects as following "halo orbits". Heliocentric statites simply balance the outward radiation pressure with inward gravity, which leads to the following requirement for a 100% reflective statite of mass per unit area (in Solar-projection) of Σ:

$$\Sigma = \frac{L_\star}{2\pi c G M_\star}, \tag{1}$$

where c is the speed of the light in a vacuum, G is the universal gravitational constant, $L_\star$ is the star's luminosity and $M_\star$ is the star's mass. Such objects essentially just remain stationery but would likely require active station keeping given the meta-stable nature of this force balance.

From the perspective of another civilization observing the Solar System, even those who lie in the same orbital plane as the statite, these objects would be difficult to detect as they do not move, making them invariable in direct images, and further would not transit. In canonical units, one can re-write the heliocentric statite requirement as

$$\Sigma = 1.5\,\mathrm{g\,m^{-2}} \Big(\frac{L_\star}{L_\odot}\Big)\Big(\frac{M_\star}{M_\odot}\Big)^{-1}. \tag{2}$$

As a point of context, this is around seven times lighter than the IKAROS experimental sail (Tsuda et al. 2011). However, it is worth noting from the above that since luminosity scales as $M_\star^4$ for $0.4 < M_\star/M_\odot < 2$ (Duric 2004), then statites would be considerably easier to build around earlier type stars than the Sun.

One modification to the statite idea is to simply add more mass, or dirty the mirror, such that the inward gravitational force now exceeds that of radiation pressure slightly. The motion of such bodies is explored in Kezerashvili & Vázquez-Poritz (2009), who find that such objects can maintain apparent Keplerian orbits but the apparent mass of the central body (the star) is shielded such tha $M_\star \to \tilde{M}_\star$ where

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$$\tilde{M}_\star = M_\star - \frac{\eta L_\star}{2\pi c G \Sigma}, \tag{3}$$

where $\eta = 1$ corresponds to the object's mirror exhibiting total reflection and $\eta = 0.5$ total absorption. These objects are perhaps not strictly statites, since they are not static, and not strictly satellites, since they don't follow the Keplerian motion expected given the primary's mass. Accordingly, we will dub these objects as "quasites" in what follows to denote an object in-between in a quasi state between the two extremes.

The orbital motion of these quasites follows a modified Kepler's Third Law (Kezerashvili & Vázquez-Poritz 2009), such that

$$P^2 = \frac{4\pi a^3}{G\tilde{M}_\star}, \tag{4}$$

where P is the quasite's orbital period and a is its semi-major axis. One can easily see that if the quasite has the statite Σ value from Equation (1), then plugging this into Equations (3) & (4) yields an infinite orbital period i.e. the object is static - as expected for a statite.

Quasites are slightly easier to construct than statites, given their less severe Σ requirements, and would not suffer from the same meta-stable nature. One particularly interesting application of a quasite would be to set its orbital period to be equal to that of the Earth, creating a kind of geosynchronous orbit. For a quasite at semi-major axis a, this corresponds to a requirement of

$$\Sigma = \Big(\frac{\eta L_\star}{2\pi c}\Big)\Big(GM_\star - \frac{4\pi^2 a^3}{P_\oplus^2}\Big)^{-1}. \tag{5}$$

Geosynchronous quasites keep a constant line between the Earth and the quasite which is never obstructed by the Sun and always represents the smallest separation between those two orbital radii. In other words, the Earth and the quasite would remain in a state of constant conjunction. This is the optimal configuration for communication with an inner orbiting probe, both in terms of lag-time and communication power requirements. One possible application might be an early warning system for coronal mass ejections, such as the 1859 Carrington event (Ngwira et al. 2014), or climate control star shades analogous to the Lagrangian proposal of Angel (2006).

It is perhaps possible then that intelligent entities residing around other stars might also construct such geosynchronous quasites. Such quasites would benefit by being located in the same orbital plane as the host planet to minimize communication lag. This means that if the host planet has the correct geometry to transit from our perspective, then the interior geosynchronous quasite must also transit, with an impact parameter given by $b_{\mathrm{quasite}}/b_{\mathrm{planet}} = a_{\mathrm{quasite}}/a_{\mathrm{planet}}$. Alternatively, the planet may actually be sufficiently inclined to avoid transiting but the quasite's inner orbit could cause it to still reveal itself.

The quasite's non-Keplerian motion would be immediately suspicious, yielding an anomalously long transit duration enhanced by approximately the semi-major axis ratio. As an example, Figure 1 shows an Earth-Sun transit with $b_{\mathrm{planet}} = 0.5$ and the quasite at 0.25 AU. The quasite is chosen to have an effective radius of one quarter that of the Earth to enhance the effect.

The detection of transiting quasites would only be reasonable if the quasite sails have a cumulative effective area which is large in size, at least a fraction of an Earth radius. This might be expected if the sails are design for deliberate climatic control, as pointed out by Gaidos (2017) in the case of a natural Lagrangian starshade. Alternatively, the quasites may simply be large in number due to economic benefits of such geosynchronous orbits, which echoes the geostationary technosignature suggested by Soccas-Navarro (2018).

In any case, candidate transiting quasites would be a straight-forward phenomena to identify in existing archival transit survey data, and thus we encourage observers to include this as a possible technosignature to monitor for. In the geosynchronous case, they will somewhat resemble the morphology of a rocky ringed planet, due to the symmetric and shallower nature of the dips (Barnes & Fortney 2004; Zuluaga et al. 2015). However, rings extending out to the Roche limit, roughly 2.5 planetary radii, will only increase the transit duration from Keplerian by a percent or so, not by factors exceeding unity.

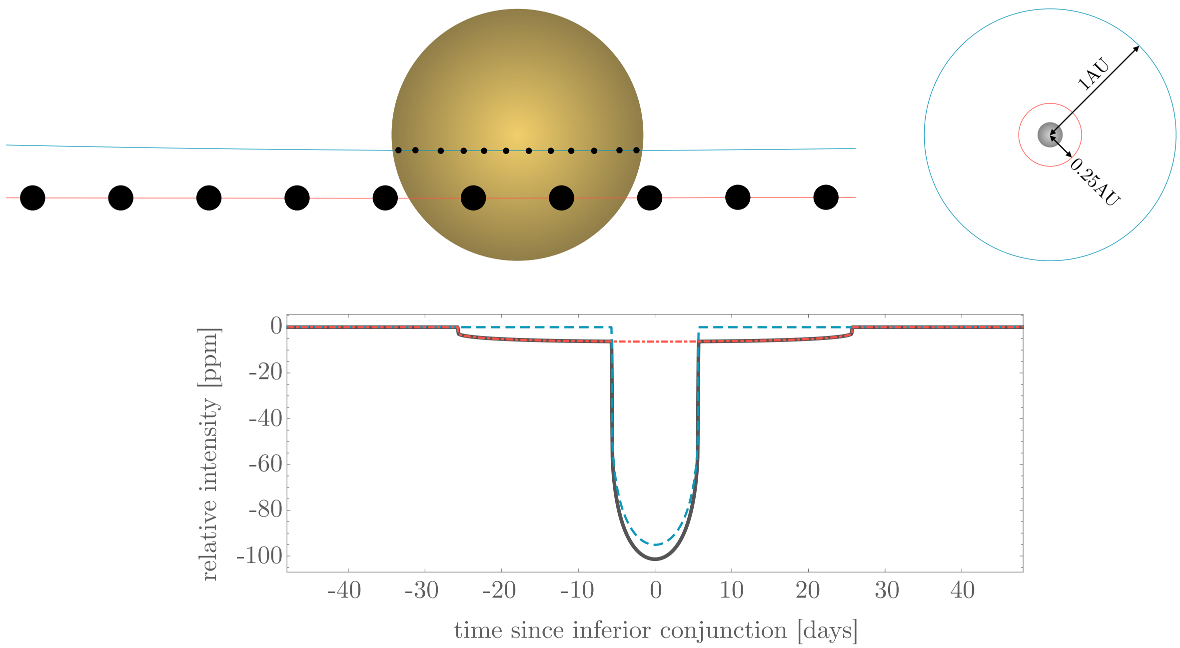

Figure 1. *Bottom: Example transit light curve (dark gray) of a transiting quasite, where the quasite is heliocentric, geosynchronous, and coplanar (as depicted top-right). Here, we use the Earth (blue) orbiting the Sun and put the quasite (red) at 0.25 AU. Upper-left panel depicts the transit geometry. Planets and orbits are not depicted to correct scale.*

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