A POSSIBLE TEST OF THE TERRASCOPE CONCEPT USING JUPITER & JUNO

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Recently, this author suggested that the Earth's atmosphere could be used to amplify distances point sources through atmospheric refractive lensing (Kipping 2019). The "Terrascope" is predicted to amplify light by up to $\simeq 50,000$ for a 1 meter detector beyond the inner focus point, located at approximately 300,000 km for the Earth. This has therefore has the potential for a small CubeSat detector have the same effective collecting area of a ∼40-50 m class telescope. However, it also argued in Kipping (2019) that the Earth's foreground light would need to be nulled using a large shade (e.g. ∼40 m for a CubeSat at the Hill sphere). This makes a simple test of the Terrascope concept challenging without significant investment, and so it is considered here whether the concept could be tested in a more cost effective manner.

NASA's Juno mission entered an elliptical 53.4 day polar orbit of Jupiter in July 2016. As a gaseous planet, Jupiter certainly has sufficient atmosphere to lens high altitude rays - thus presenting a possible means to demonstrate a "Jovoscope" using Juno. Indeed, refractive lensing through a giant planetary atmosphere has already been observed by Hubbard et al. (1987) with Neptune. Detailed modeling of the lensing amplification, extinction and focal distance (as was done for the Earth in Kipping 2019) is beyond the scope of this work, but a simple estimate is offered here to provide some insight. Using Equation (32) of Kipping (2019), the amplification expected is

$$\mathcal{A} \simeq 8\epsilon H_{\Delta}/W, \tag{1}$$

where ϵ is the effective transparency of the atmosphere, H_{Δ} is the refractive scale height and W is the detector size. Attempting to image sources behind Jupiter without a shade would not be feasible, but the lensing effect can be used in reverse to turn the telescope into an antennae. The closely related concept of the gravitational lens (von Eshleman 1979) has long recognized this possibility too, and indeed the idea of using lensing to create enormous antennae has been suggested a means of creating an interstellar communication system (Maccone 2010). With Juno's $W = 2.5\,\mathrm{m}$ high gain antennae, and Jupiter's greater scale height, an amplification of $\mathcal{A} \simeq 70,000$ could be achieved.

Juno was originally planned to reduce it's orbit to 14 days but due to concerns with the helium valves, it remained in it's original wider orbit. This is fortunate for the Jovoscope as wide separations are needed to catch the lensing effect. For Jupiter, there is strictly no inner focus point like the Earth because there is no physical "surface" presenting a hard boundary condition. The H/He composition of the Jovian atmosphere means that the refractivity is about half that of our own. If the refractivity were the same, then simple geometry implies that the one-bar surface inner focus would move out by $R_{♃}/R_{\odot}$. With the halved refractivity this becomes $2R_{♃}/R_{\odot}$ which equates to 6.7 million km. Juno's apojove is at 8 million km and is likely sufficiently distant to exploit the Jovoscope lensing effect.

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For the signal to be received back on Earth, the orbit of Juno would have to be carefully aligned such that apojove lines up with the Earth-Jupiter line. This may present an unacceptable deviation from the mission goals and tolerances, but if viable then Juno could active it's high gain antennae to send a signal back to the Deep Space Network (DSN) on Earth. With $\simeq 70,000$ times more photons, the signal-to-noise would increase by 264.5 or 24.2 dB. The DSN is typically able to download data from Juno at a rate of 200 kb/s. Since data capacity is proportional to $\log_2(1+\mathrm{S/N})$ via the Shannon-Hartley theorem, then one might expect the capacity to rise to 53 Mb/s, comparable to the speed of 4G cellphone connection (assuming that the Jovian atmosphere is not opaque to the 8.4 GHz frequency used by Juno). Thus, planetary atmospheres could potentially offer a pathway for future missions achieving much higher data transmission rates, forming the basis of a high speed interplanetary internet. Future

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