NOMADIC EXOPLANETS AND THE NASA STRATEGIC VISION FOR 2050 T. Marshall Eubanks[1], [1]Asteroid Initiatives LLC, Clifton, VA 20124 USA; tme@asteroidinitiatives.com;

Introduction: NASA's strategic goals include the search for planets around other stars, the characterization of their properties, and the identification of exoplanets that could possibly harbor life. In addition, with the discovery of Proxima b, an exoplanet orbiting in the habitable zone of the star Proxima Centauri, the closest star to the Sun, long range planning is beginning to consider its possible *in situ* exploration by spacecraft. These strategic goals should be extended to include nomadic (or rogue) exoplanets, planets not orbiting any star.

While Proxima b will remain the closest exoplanet orbiting a star, microlensing surveys indicate that there are likely to be closer nomadic planets [1]. To date, discovered nomads have been mostly either distant objects found through microlensing, or young, warm, nomads found near star formation regions. However, there should be significant numbers of mature nomadic exoplanets close enough to be discovered with existing or future astronomical resources, including possibly dozens of planets closer to us than Proxima b. Although mature nomads will appear to be very cold astronomically, superEarth nomads can retain heat, be Ocean Worlds and conceivably support exobiologies [2, 3].

Nearby nomadic planets are thus extremely relevant to the Origins, Workings and Life goals of the NASA strategic vision for 2050. Finding the closest nomadic exoplanets should become an important part of NASAs strategic goals, particularly the exoplanets closer, and thus easier to reach, than Proxima b. In order to facilitate the search for nomadic planets, NASA should support a large far-IR (100 μm wavelength) space telescope and support planet searches with long wavelength (1 - 10 meters) radio arrays. Nomadic planet number statistics remain very uncertain for sub-Jupiter masses, and should also be improved through support of high cadence microlensing surveys.

The Expected Distance to the Nearest Nomadic Planets: Gravitational microlensing surveys have shown that Jupiter-mass nomads are more populous than main sequence stars. Sumi *et al.* [4] estimated the ratio of the number density of Jupiter-mass unbound exoplanets, n_J, and the number density of main sequence stars $n_\star$, with $n_J / n_\star = 1.9^{+1.3}_{-0.8}$ from microlensing data. The stellar number density is well known near the Sun [5], yielding an estimate for n_J [1] of

$$n_J = (6.7^{+6.4}_{-3.0}) \times 10^{-3}\,\text{ly}^{-3} \qquad (1)$$

and thus an estimate for the expected mean distance to the nearest Jupiter mass nomadic planet, R_{min}, of

$$R_{min}(M_{Jupiter}) = 3.28^{+0.7}_{-0.6}\,\text{ly}\,, \qquad (2)$$

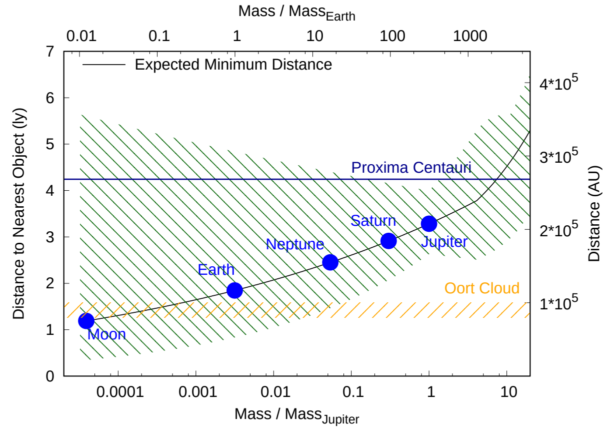

Figure 1: The expected minimum distance, R_{min}, as a function of nomadic planet mass, based on microlensing power law number-density models [1]. Although the uncertainties are fairly large, the nearest nomadic planets are expected to be as close or closer than Proxima Centauri for a wide range of masses. The estimated extent of the Oort cloud and the distance to Proxima Centauri are shown as horizontal lines.

the expected distance of the nearest "dark-Jupiter" being ∼77% of the distance to Proxima Centauri. Sumi *et al.* [4] also provide a power law model for nomadic planet number density as a function of mass. Figure 1 shows the expected minimum distances, R_{min} and these uncertainties as a function of nomad mass [1]. It is necessary to extrapolate the power law density models for masses $\ll$ the mass of Jupiter [6], leading to a factor of almost 6 uncertainty in R_{min} for Earth-mass nomads. Reducing the uncertainty in the nomadic planet number density function at lower masses is essential for better modeling of R_{min} for Earth mass planets. The planned WFIRST telescope should be able to detect and characterize the population of nomadic superEarths in the Galactic bulge with microlensing [7]; it is important that NASA support microlensing surveys by this or a comparable space telescope.

Finding Nearby Nomadic Exoplanets: Figure 2 shows the black body flux density expected from a set of hypothetical planets, matching the Earth, Uranus, Neptune, Saturn and Jupiter in mass, radius and internal heat flux, with each assumed to be at R_{min} for a body of its mass. A super-Jupiter with 10 times the mass of Jupiter is included based on a heat flux scaling model [1]. Figure 2 also shows flux density limits for the ALMA [8], cooled WISE [9], cooled Spitzer [10]), SPICA [11] and JWST [10] instruments. Existing instruments should

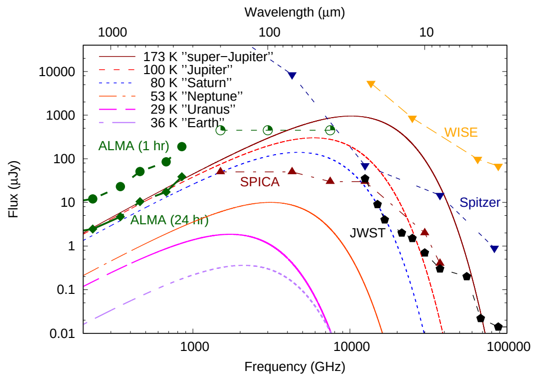

Figure 2: The IR flux density for black bodies with the same radius and internal power generation as the actual Earth, Uranus, Neptune, Saturn and Jupiter, plus a model-derived "super-Jupiter" with a mass of 10 $M_{Jupiter}$, each modeled as a black body at their expected R_{min} [1], together with flux density limits for various actual (ALMA, cooled Spitzer, cooled WISE) and planned (SPICA and JWST) telescopes and arrays.

be able to detect nearby nomadic gas-giants, while detection of nearby nomadic Earths and superEarths will likely require surveys by a new generation of space telescopes, such as the Far-Infrared Surveyor Mission (FIRS) [12] currently under consideration.

A different means of discovering nearby magnetized planets is through the detection of their non-thermal radio emissions. The strongly magnetized bodies in the solar system (the Earth plus the 4 giant planets) all exhibit strong non-thermal radio emissions driven by the electron Cyclotron Maser Instability (CMI) [13]. CMI emissions are generated by celestial bodies moving through a plasma, with either the body or the plasma, or both, possessing a significant magnetic field [14, 15, 16], or even from the rapid rotation of a magnetized body [17]. Such emissions provide a non-thermal means of detecting magnetized exoplanets [18], including magnetized nomads [19, 1]. In the solar system, Jupiter produces a very strong "unipolar" CMI radio flux, primarily due to electrons flowing through the Jupiter-Io flux tube. A Jupiter-Io analogue at the expected distance of the nearest Jupiter-mass exoplanet (see Equation 2) would have a maximum flux of $\sim$10 milliJanskies (mJy) at about 40 MHz [1] with a duty cycle of $\sim$14%. Such sources should be detectable by the LOFAR [20] and other low frequency arrays; if these source mechanisms are common with nomadic planets, the search for CMI emissions may provide the best near-term prospect for discovering neighboring nomadic giant planets from ground-based observations.

Astrobiologies on Nomadic Exoplanets: Nomadic planets could be ocean worlds, with insulated oceans surviving with no stellar heat input [1]. Stevenson [2] proposed that Earth-mass planets could have surface oceans of liquid water, and thus conceivably biologies, with radioactive heat being retained by thick Hydrogen-Helium (H-He) atmospheres with pressure induced far-IR opacity. The discovery that for $M \gtrsim 4\ M_{Earth}$ terrestrial planet radii are roughly $\propto$ mass strongly suggests that H-He atmospheres are common for at least these super-Earths [21, 22]. Nomadic "Steppenwolf" planets, with $M \gtrsim 3.5\ M_{Earth}$, could instead have internal liquid water oceans insulated by a thick shell of ice [3]. There are of course a number of candidate ocean worlds, warmed by tidal heating, in the Solar System [23]; similarly tidally-heated oceans could exist on nomadic exomoons [24]. The exploration of nearby nomadic planets thus has the potential to both benefit from and inform the NASA effort for the exploration of the biological potential of Ocean Worlds in our solar system.

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