Introduction and Background

Barnard’s Star (GL 699; V = +9.51 mag) is a dim, old red dwarf (M3.5 V). At 6 LY it is the 2nd nearest star system. Until recently, Barnard’s Star’s claim to stardom is having the largest proper motion (μ = 10.4’/yr). Recently adding to its fame, Ribas et al. (2018 Nature 563, 365) discovered that Barnard’s Star hosts a super-Earth exoplanet with mass ≈ 3.25 M⊕. Thus, Barnard’s Star is the nearest single star hosting a planet. Barnard b has an orbital period of P = 233 days and a distance of ≈0.48 au. This is nearly the same distance of Mercury from the Sun. However Barnard’s Star is very faint (L∗ = 0.003 K) and its planet has an installation (relative to the Earth) of SSD = 0.20. This value corresponds to the amount solar radiation at 7 μm from the Sun. Thus it is cold (T∗ = −168°C). This face value there appears to be little chance of liquid water (and life) on its frosted surface. (See Fig. 1 and Table 1). But as discussed below, there may still be a chance for Barnard b to be habitable.

X-ray, UV, Optical Irradiances of Barnard b

We compute the X-ray and UV irradiances on Barnard b from its M3.5 V host star. See Table 1. X-ray and UV radiation (and stellar winds & flares) play critical roles on photoionization & photochemistry of planetary atmospheres. This high energy XUV radiation and stellar plasmas can result in the erosion and possible loss of a planet’s atmosphere. The atmospheric loss can be especially severe when the red dwarf is young, rotates rapidly, and is extremely active with strong X-ray and UV emissions that are ~1000-8000% and ~12-15% stronger, respectively than at old age. Also during the star’s pre-main-sequence phase (which lasts nearly 200 Myr) At ~50 Myr Barnard’s Star would be 10% more luminous and the planet’s irradiance would be SSD = 0.2. So that at that age the young planet would be ~80°C warmer. With greenhouse gases it could be possible that briefly Barnard b was warm enough for liquid water.

Table 1

<table>
<thead>
<tr>
<th>Property</th>
<th>Earth-Sun</th>
<th>Proxima b</th>
<th>Barnard b (M = 0.84 M☉)</th>
<th>Barnard b (M = 50 M☉)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (Myr)</td>
<td>4.57</td>
<td>5.1 ± 0.6</td>
<td>8.5 ± 1.0</td>
<td>5.0 Myr</td>
</tr>
<tr>
<td>Radius (R☉)</td>
<td>1.00</td>
<td>1.12</td>
<td>1.15</td>
<td>1.25</td>
</tr>
<tr>
<td>S/Δr</td>
<td>1.00</td>
<td>0.65</td>
<td>0.022</td>
<td>0.2</td>
</tr>
<tr>
<td>de = 0.25 c.g.s.</td>
<td>100</td>
<td>130</td>
<td>250</td>
<td>34</td>
</tr>
<tr>
<td>&lt;f&lt;υ&gt; = 10^{-6}</td>
<td>7.38</td>
<td>130</td>
<td>250</td>
<td>34</td>
</tr>
<tr>
<td>PP</td>
<td>XUV-B</td>
<td>170 [35]</td>
<td>350 [70]</td>
<td>46</td>
</tr>
<tr>
<td>V</td>
<td>10^{-6} + 10^{-11}</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Note: a) The values in brackets correspond to 10% of the equivalent Earth value.

Potential Life on Barnard b: Can Life find a way?

Barnard b receives only 2% light relative to the Earth and thus is cold (T∗ = −168°C). However, all hope for life on Barnard b may not be lost. As a super-earth (M > 3.25 M⊕), Barnard b could have a large iron core that could result in enhanced (and because of its larger mass) prolonged geothermal activity. If water is present, geothermal heating (volcanic plumes, vents etc.) could result in liquid water “life zones” under a possible icy surface. This much like Jupiter’s icy moon Europa that is heated by tidal heating rather than from geothermal energy. More local analogs for subsurface liquid water under ice are the geothermally heated lakes in Antarctica. Although little is definitely known geophysics of super-earth like Barnard b, a large iron core, that could strongly generate geomagnetic fields, could offer protection from strong winds and coronal mass ejections when the star was young & magnetically active. However, if the mass of the Barnard b is much higher than about 7–10 M⊕, its higher gravity could result in retaining a thick H₂–He atmosphere and thus a dwarf gas giant (miniNeptune). In this case all hope for life is probably lost unless by chance Barnard b hosts an icy moon (with a subsurface ocean) that could be tidally heated like Europa.

Imaging Barnard b

The angular separation of the Barnard b from its host star is ~220 mas (0.2”). This is much larger than the maximum angular separation of Proxima b from its Prox Cen of ~40 mas. Although Barnard b is very faint, it may be possible to image it with future very large telescopes. Adopting J-band (0.86 μm) = 0.404 mag, we estimate that Barnard b is ~21.3 mag fainter than the star. Adopting I-band (686 nm) = +6.74 mag and H-band (1.65 μm) = +4.83 mag measures for Barnard’s Star, the reflected light of the planet would be 20 = 2.80 mag and H = 2.81 mag at full illumination. Thus, it may never be possible to image Barnard b in the GMRT, AMI and ELT telescopes as well as with JWST and WFIRST. It may even be possible to see near-IR spectroscopy of the planet. Noteworthy Barnard b is one of only a handful of Earth-like size that can be directly imaged. Such observations will illuminate the atmospheric “surface” and atmospheric “weather” of this planet. In this case all hope for life is probably lost unless by chance Barnard b hosts an icy moon (with a subsurface ocean) that could be tidally heated like Europa.

Fig. 1. Model of the Barnard Star planet system (from Ribas et al. 2018) compared to the inner Solar System. Barnard b orbits at 0.404 AU from its M3.5 V host star and has an equilibrium temperature of T = −168°C. P = 233 days and M p x sin i = 3.25 M⊕.

Fig. 2. Some models of (rocky) Super-Earth planets located near or beyond the cold edge of the star’s habitable zone are shown. Barnard b has M > 3.25 M⊕.

Fig. 3. Possible model of Barnard b based on geothermal heating. If water is present, geothermal heating could create a subsurface ocean where primitive life could exist. The model would be a scaled-up Europa.

Fig. 4. In another scenario if the mass of the exoplanet is > 7 M⊕ then the stronger gravity could cause the retention of its primordial H2/He atmosphere. These planets are known as Mini-Neptunes / Dwarf Gas Giants.

Conclusions

1. The age of the star/planet of 8.6±1.2 Ga was determined from Rotation-Age-Activity relations for red dwarfs from (Engel & Guinan 2018), using input parameters from Toledo-Padrón et al. (2018).
2. Barnard b receives only 2% of radiation as the Earth and is thus cold. But as a super-earth (M > 3.25 M⊕), it could possess a large, hot liquid-iron core & geothermal energy. Geothermal energy could heat the exterior of the planet via plumes and vents. If water is present, the planet would be ice-covered, but due to geothermal heating could have subsurface water that provides niches for life.
3. Although faint, Barnard b proximity & relatively large ~220 mas separation from its host star, makes it an ideal target to try to image. It may be feasible to image Barnard b in Near-IR with JWST.

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Fig. 5. Barnard Star and its planet Barnard b are depicted in this best case scenario for potential life - that geothermal heating melts ice, producing regions of liquid water near the surface. We note that at present there are no data to support this hypothesis.