ASTROBIOLOGY CENTER

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M-dwarfs, relatively small and cool stars, are the most abundant neighboring stars and thus could be the first candidates for searching habitable exoplanets and detecting a sign of extraterrestrial life. One of the most important biosignatures on an exoplanet is a specific reflection pattern on the land surface named 'red-edge' that is caused by land vegetation. On the Earth, red-edge appears between visible light, which is absorbed by photosynthetic pigments, and near infrared (NIR) radiation, which is reflected via leaf structure. In previous reports, it was predicted that red-edge could be red-shifted around M-dwarfs since phototrophs on the exoplanet should use abundant NIR radiation for photosynthesis in addition to visible light. We have proposed an alternative prediction that red-edge could be observed as on the Earth even on exoplanets if the initial oxygenic photosynthesis evolved underwater.

I. Photosynthetically active radiation on the exoplanets around M-dwarfs

We estimated the light conditions expected on habitable planets around an M-dwarf. Assuming that an Earth-like planet is located in the habitable zone around AD Leo, and M4.5eV star located 16 light years away from our solar system, the light conditions on the planet were estimated and compared with solar irradiation on the Earth. The land surface of the M-dwarf planet is illuminated by strong NIR-radiation, while Earth's surface is illuminated by visible light. On the other hand, similar light conditions are expected underwater since only blue-green light can penetrate meters of water (Figure 1).

The visible-light intensity obtained on the land surface of a hypothetical habitable planet around AD Leo is equivalent to that from Earth's ocean at a depth of 15 m. The lower limit of light intensity needed to support the growth of oxygenic marine phototrophs on Earth is about 20 nmol photon m^{-2} s^{-1}, which corresponds to a water depth of 166 m in the model calculation. The same amount of visible light is obtained at a water depth of 123 m on the AD Leo planet. If the origin of life and its early evolution is placed underwater, Earth-type oxygenic photosynthesis may evolve on exoplanets around M-dwarfs.

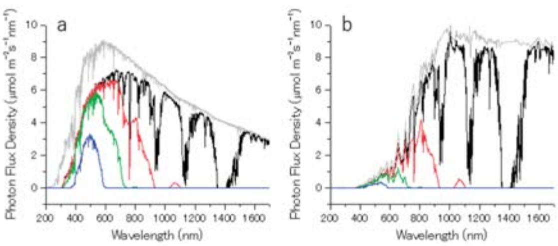

Figure 1. Photon flux density spectra for Earth (a) and a hypothetical habitable planet around AD Leo (b). Gray lines show the spectra obtained at the top of the atmosphere. Black lines show the spectra at the land surface passing through a 1.5 air-mass atmosphere. The underwater PFDs at a depth of 0.1, 1, and 10 m are shown using red, green, and blue lines, respectively.

II. Evolution form water to land under M-star radiation

The adaptive evolution of phototrophs from water to land may eventually also use NIR radiation, by one of two photochemical reaction centers, with the other center continuing to use visible light. These "two-color" reaction centers can absorb more photons, but they will encounter difficulty in adapting to drastically changing light quality and quantity at the boundary between land and water (Figure 2). NIR photosynthesis can be more productive on land, though its evolution would be preceded by the Earth-type vegetation. Thus, the red-edge position caused by photosynthetic organisms on habitable M-dwarf exoplanets could initially be similar to that on Earth. Our studies imply that red-edge is a universal biosignature for life originated underwater.

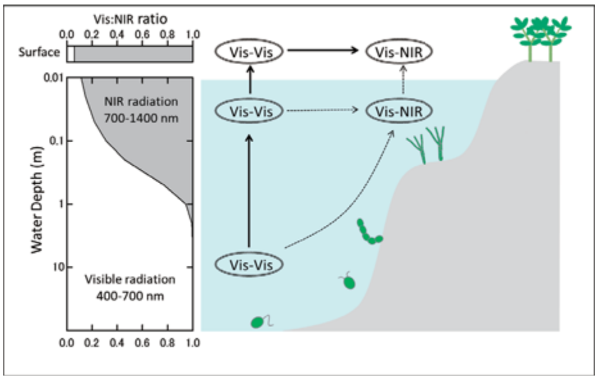

Figure 2. Lighting conditions on a hypothetical habitable planet around an M-dwarf and the evolution of photosynthesis. Ovals and arrows outline the flow of evolutionary paths from a two-photon reaction using visible radiation (Vis-Vis) to a two-color reaction using visible and NIR radiation in separate reaction centers (Vis-NIR). The area graph on the left side shows the visible-radiation/NIR-radiation ratio on the land surface and underwater at different depths.

Publication List:

〔Original paper〕

- Takizawa, K., Minagawa, J., Tamura, M., Kusakabe, N., and Narita, N. (2017). Red-edge position of habitable exoplanets around M-dwarfs. Sci. Rep. 7, 7561.