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Absorption efficiencies of light-harvesting complexes exposed to the photoenvironment of extrasolar planets

KOMATSU, Yu[1*] ; UMEMURA, Masayuki[1] ; SHOJI, Mitsuo[1] ; MEGUMI, Kayanuma[1] ; SHIGETA, Yasuteru[1]

[1]University of Tsukuba

The detectable size of extrasolar planets, which are planets outside our solar system, is getting smaller. Recently, an Earth-size planet has already been discovered in the habitable zone, the region where a planet can hold liquid water on the surface. By obtaining spectra of exoplanets, a lot of information is derived. For instance, the surface type affects the spectral shape. If we detect the signal of vegetation on exoplanets, it will be a direct evidence of trace of life.

However, trace of vegetation on exoplanets is uncertain when the primal star is different from the Sun. As the first step before detecting trace of vegetation on the planets, it should be examined what kinds of photoenvironments are acceptable for photosynthetic organisms on the earth. Significant processes of photosynthesis, light absorption and excitation energy transfer (EET) processes, occur in light-harvesting complexes (LHCs) that contain photosynthetic pigments. Particularly, we modeled the two processes in the LHC in purple bacteria (LH2), which absorb longer radiation than that in plants, since planets around M dwarfs or M stars (cooler than the Sun) will be the observational targets. We investigated how efficiently the LH2 system absorbs light energies depending on stellar radiation using the quantum chemical calculations.

To begin with photosynthetic pigments, the absorption spectra are calculated to evaluate absorption efficiencies under seven stellar radiation spectra at the top of atmosphere (TOA) of the planets. The pigments and LHC have three main absorption bands: Soret, the Qx and the Qy in order of the wavelength. We found that, among the six major pigments, the efficiencies around higher temperature stars, the F, G and K type stars, vary depending on whether Soret bands are placed blueward or redward of 4000 Å break, which is a steep change due to the absorption by some metals in stars below 400 nm. Around the M stars, Soret bands do not contribute the efficiency anymore. Alternatively, Qy bands affect the efficiencies crucially.

Moreover, the EET process in the aggregation system of LH2 is investigated. The EET velocity becomes double when two pigments in the central antenna are exchanged to the pigments with low excitation energies (from 850 to 890 nm). We also found that the efficiencies using estimated spectrum of the 19 LH2 system are maximized offset from the solar effective temperature (5778 K). The Soret band still has a contribution to the efficiency because the band is just around 4000 Å break.

In order to estimate the efficiencies on planetary surfaces where the organisms inhabit, the planetary atmospheric effects are considered using simple radiation transfer calculations. The contribution of Qy region is affected due to absorption bands by water vapor. Atmospheric conditions, i.e. oxidizing earth-like or reducing, vary the efficiencies around M stars significantly than those around the Sun. This is particularly because of the spectral overlapping in the Qy region.

In order to examine conditions which would lead to effective light absorption around M stars, we evaluate the efficiencies with different conformations of the pigments and the LH2 and the solvent. The wavelength of absorption shifts about 120 nm longer in the 19 LH2 system whose central metals of the pigments are exchanged to Pd, compared to that without the metals.

In any conditions as considered the planetary atmospheres, Soret bands contribute the efficiencies due to being enough redward of 4000 Å break. Therefore, in the history of the Earth, there is a possibility for the organisms to have evolved the Soret band to absorb light energies effectively.