

# Absorption efficiencies of antenna complexes in photosynthetic organisms exposed to the photoenvironment of exoplanets.

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**Introduction:** As one of the fruitful results obtained by exoplanet survey projects, an Earth-size planet has already been discovered in the habitable zone. From another point of view, observed spectra of exoplanets give us a lot of information. If we detect the signal of vegetation on exoplanets, it will be a direct evidence of a trace of life.

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

To begin with the photosynthetic pigments, the absorption spectra are calculated to evaluate absorption efficiencies under seven different stellar radiation spectra at the top of atmosphere (TOA) of the planets [1]. Both the pigments and the LHC have three main absorption bands: Soret, the  $Q_x$  and the  $Q_y$  in order of the wavelength (see the Figure). We have found that the efficiencies of the pigments around higher temperature stars, the F, G and K type stars, vary depending on whether Soret bands are placed blueward or redward of the 4000 Å break, which is a steep change due to the absorption by some metals in the stars below 400 nm. Around the M stars, Soret bands do not contribute the efficiency anymore. Alternatively, the  $Q_y$  bands affect the efficiencies crucially.

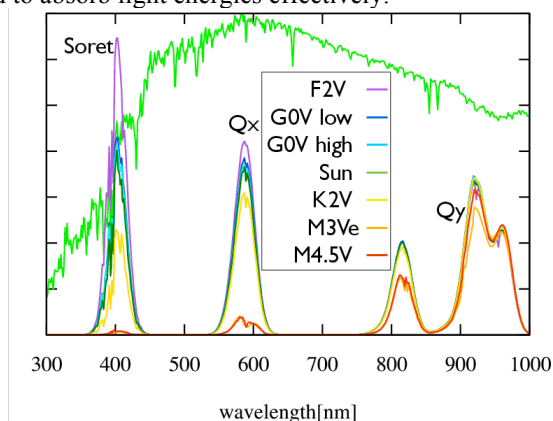
Next, in an aggregation system of the LH2, EET process are examined [2]. In native LHCs, the excitation energies are generally delivered toward sites with lower energies. To reproduce such a phenomenon, two pigments in the central antenna are exchanged to the pigments with low excitation energies (from 850 to 890 nm), so that the EET velocity becomes double. We also have found that the efficiencies using estimated spectrum of a 19 LH2 system are maximized quite

offset from the solar effective temperature. The Soret band still has a contribution to the efficiency because the band is just around the 4000 Å break. The contribution of each band to the efficiency is clearly shown in the Figure.

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

To examine conditions which would enhance the efficiencies around M stars, several possible factors (conformations of the pigments and the LH2 and the solvent) are changed to evaluate the efficiencies. The wavelength of absorption shifts about 120 nm longer in a 19 LH2 system whose central metals of the pigments are exchanged.

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



**Figure:** The product of the absorption intensity of a LH2 system and the photon flux density from seven stars (FGKM in order of decreasing the effective stellar temperature). The normalized solar radiation spectrum is also shown for reference (upper green curve).

**References:** [1] Komatsu Y. et al. *IJA*, accepted in 2014. [2] Komatsu Y. et al. *Mol. Phys.*, accepted in 2015.