

Investigating surfaces of earth-like exoplanets via scattered light

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↓ poster

Investigating surfaces of earth-like exoplanets via scattered light
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CHARACTERIZING EARTH-LIKE EXOPLANETS WITH SCATTERED LIGHT
 Light scattered by a planet carries an important piece of information because the scattering properties depend on the details of the surface and atmosphere. It is also intriguing from the view point of astrophysics: it may also let us probe the existence of ocean. Additionally, vegetation "red edge", dramatic increase in reflectivity at $\lambda \sim 750\text{nm}$ which is related to the system of photosynthesis, may be a potential indicator of exo-life.

► **Reconstruction of planetary surface from multi-band photometry**
 In decomposing the scattered light to extract the information of surface, the total scattered light is modeled with simplifying assumptions into a linear expression. Assumptions are that surface are classified into a few surface types each of which consists of surface with known albedo and an atmosphere, and that they are Lambertian.

$R(\lambda) = \sum_i A_i K_i(\lambda) \int \rho_i(\theta, \phi, \lambda) d\Omega$

4 surface types
 -ocean/soil/vegetation/snow + atmosphere
 Lambertian
 $A_i(\lambda) = R(\lambda) / \text{combined area fraction}$
 surface reflectance
 combined area fraction

Left figure is the result of solving the above matrix equation in terms of A_i , which is a mock total light curves $R(\lambda)$ of a cloudless Earth at 10 pc away seen at quadrature. The error bars come from the Photon shot noise only. Main features such as Pacific ocean and the Amazon forest are recovered. Although ocean is mirror-like and the spectral spot is fairly localized, the combination of ocean + atmosphere is a more Lambertian-like scatterer and it helps us to reliably estimate the weighted fraction of ocean.

ONGOING ISSUES
 Effect of Clouds and decomposition of fit from surface signal
 More realistic computation with radiative transfer beyond the earth model

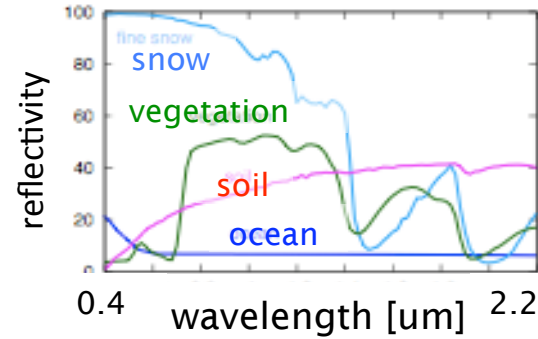
REFERENCES
 *Fujii et al. 2010, ApJ, 715, 866
 Kawahara and Fujii 2010, submitted to ApJ, arXiv:1004.5152

► **Orbital and the diurnal variation of mock cloudless Earth**
 [Input]
 -Reflection property
 Atmosphere: Rayleigh scattering
 Ocean: model (Kawahara & Tanaka 1983)
 Land: MODIS dataset (Rossi-L model) equatorial, no atmospheric absorption, no aerosols
 -Face-on circular orbit
 -5 pc away system
 -O3-like mission with 1.1m aperture
 -real noise, dark noise, exocool noise included
 -cool data for 14 days and fold the light curves to obtain diurnal light curves

► **2-dimensional mapping by combining orbital and the diurnal variation**
 The illuminated and visible region sweeps the planetary surface as the planet rotates around its spin axis and the host star (obliquity=90° is the most favorable for face-on orbit). Thus, in principle, one can obtain 2-dimensional information of planetary surface from overall reflection. Using 4 bands (centered at 0.4 μm , 0.5 μm , 0.8 μm , 0.9 μm) from photometric data, we first decomposed the components of the surface and then mapped the probed surface by solving linear inverse problem with BALS (Bounded Variable Least Squares) algorithm.

► **Obliquity dependence**
 The overall shape of the light curves depends on the planetary obliquity (and orbital parameters). (e.g., on face-on orbit, no phase variation will be seen if the obliquity is 0.) Assuming that the planetary orbit is known, the obliquity is measured by optimizing the mapping in principle. This methodology reasonably works in the case of cloudless Earth 5pc away; for 10pc away case, it is marginal.

Multi-band scattered light



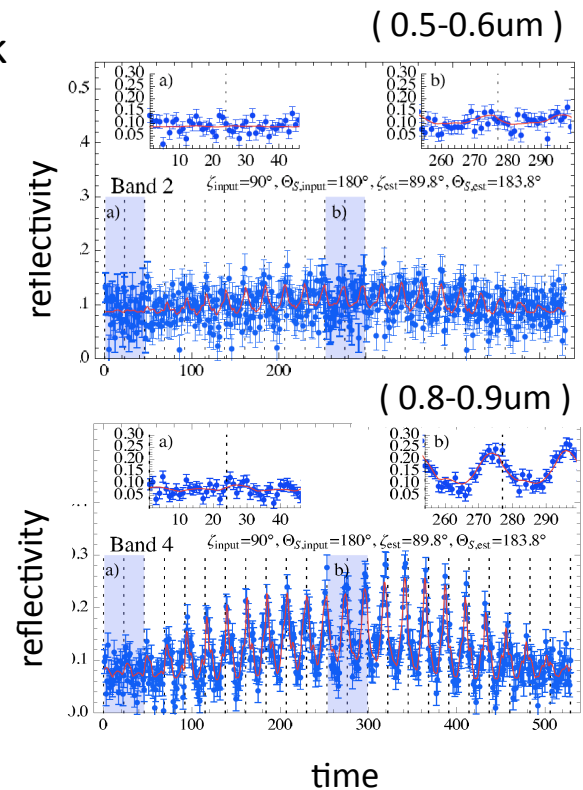
← Typical reflection spectra

ocean : Mclinden et al. 1997

others: from ASTER spectral library

An example of mock light curves of a cloudless Earth

- band 0.8-0.9um
- face-on circular orbit
- 5pc away
- starting from winter solstice
- obliquity:90°



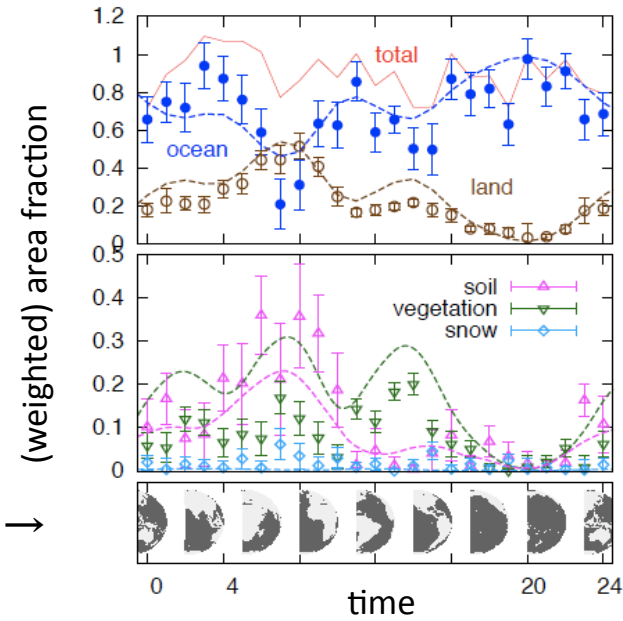
time

Reconstructing the planetary surface

Model : $I_j(t_i) = F_{*j} \sum_k D_{jk}(\tau) A_k(t_i)$

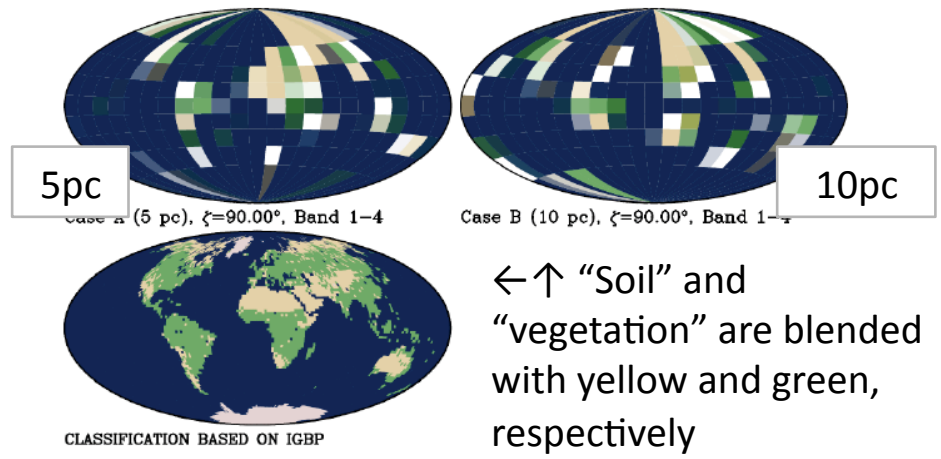
reflection intensity incident flux reflection property weighted area fraction
 (atmos + (snow/soil/vegetation/ocean))

Reconstruction from a diurnal light curves of a cloudless Earth at 10 pc away seen at quadrature →

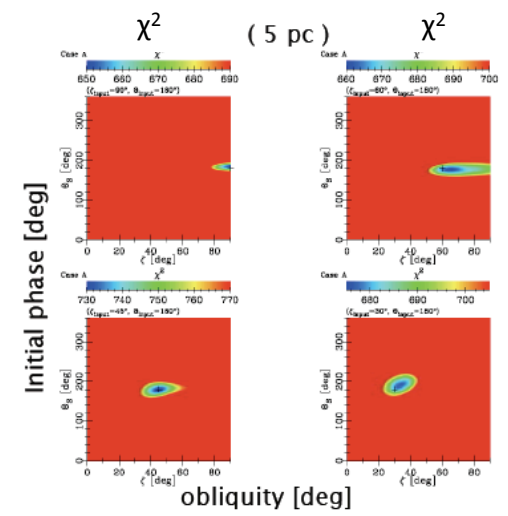


► By combining the diurnal and yearly variation, 2-dimensional map can be derived

(obliquity = 90° case)



←↑ “Soil” and “vegetation” are blended with yellow and green, respectively



estimation of obliquity by minimizing χ^2 of mapping (cross point: input values)