Global Mapping of Earth-like Planets toward Exo-Habitat Research

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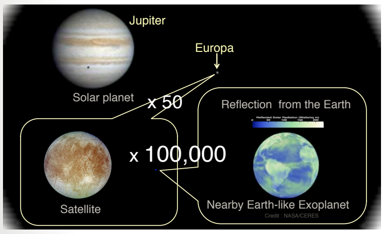
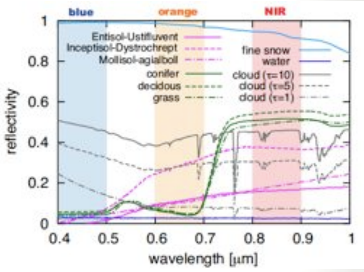
1. How can we take a spatially resolved image of an Earth-like planet ?

It will be important to understand the environment of the planetary surface, in other words, the habitat of the planet. Indeed, diverse surface environments on the Earth including continents, ocean, and meteorological condition serve as the backbone of biodiversity. One of the promising approaches to know the landscape of the terrestrial exoplanets is to identify surface components using the scattered light of the planets through the direct imaging observations.



However, even nearby Earth-like planets are so small (left figure). Using a lot of space telescopes (for instance, 150 x 3m aperture), as proposed by Labeyrie (1999), is one possibility to resolve the nearby exoplanet.

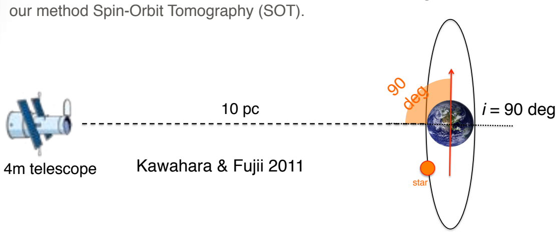
Even if one cannot resolve the planet, scattered light curve from Earth-like planets itself contains information on the habitat on planetary surface, such as clouds, soil, ocean, and vegetation since they have different reflectivity (right figure). Our aim is to develop an inversion technique of annual scattered light curves to sketch a two-dimensional albedo map of exoplanets, which will enable us to indirectly resolve the planet with a single space telescope.

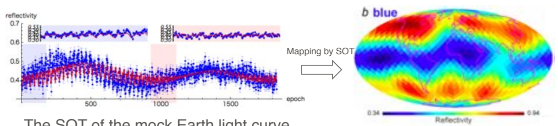


Reflectivity of clouds (gray), soil (magenta), water (blue) , vegetation (green) and ice (cyan); Kawahara & Fujii (2011).

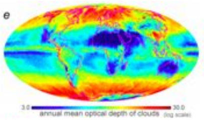
2. Spin-Orbit Tomography: Inversion Technique of the Planetary Surface from Disk-integrated Light Curve

Reflection light from a planet depends on albedo of the visible and illuminated region of the planetary surface, which changes according to spin rotation and orbital revolution. Using this fact, we developed the inversion method to map the reflectivity from the scattered light curve. Since we use diurnal and annual variation of the scattered light, we call our method Spin-Orbit Tomography (SOT).

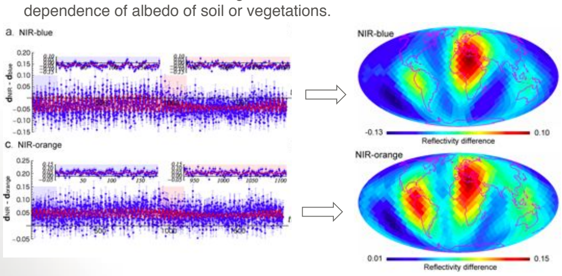




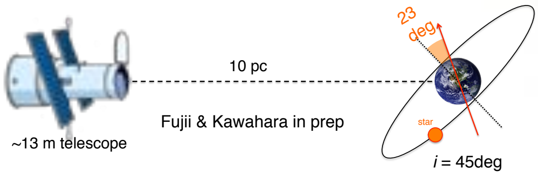
The SOT of the mock Earth light curve primary provides cloud distribution since clouds dominate scattered light.

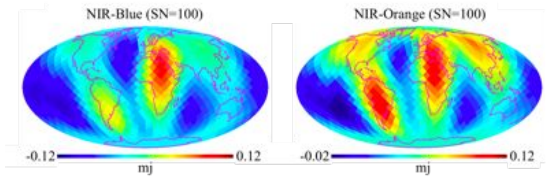


Applying the SOT to the difference of 2 bands, one can sketch the continental distribution due to the wavelength dependence of albedo of soil or vegetations.



Even for low-oblique planet like the Earth, the SOT can reconstruct the continental distribution if statistics is enough. For instance, half year observation of the Earth twin @10pc with a 10-15 m space telescope will give a high quality map of the surface shown below.





Technical description of the SOT

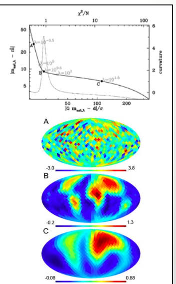
The SOT solves the equation (1) by minimizing the misfit function Q (Tikhonov regularization). The regularization parameter lambda, which balances the noise and spatial resolution, is chosen by the L-curve criterion (Hansen 2010)

Disk-averaged Intensity of light — Albedo

$$d(t) = \int W(t,\phi,\theta;\mathbf{w})\, m(\phi,\theta)\, d\Omega + \epsilon \quad (1)$$

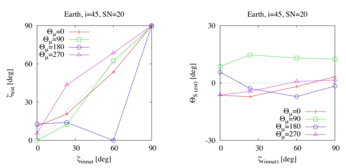
Weight of reflection — Noise

$$Q = \sum_{i=1}^{N} \frac{|d(t_i) - \sum_j W_j(t_i;\mathbf{w}) m_j|^2}{\sigma_i^2} + \lambda^2 |\mathbf{m} - \mathbf{m}_p|^2 \quad (2)$$



3. Simultaneous Estimate of Planetary Obliquity

Planetary obliquity is important to know habitability and constrain to planet formation scenario, but is one of parameters which is difficult to measure. The SOT can simultaneously estimates the planetary obliquity and Equinox (season) as well as the planetary surface.



Obliquity Equinox (The range is -180 – 180 deg)

Estimated vs input of obliquity and Equinox assuming observation Of Earth twins @ 10 pc with 4 m telescope. (Fujii & Kawahara in prep)

4. References

●Spin-Orbit Tomography

1. Kawahara & Fujii, ApJ,720,1333 (2010) *"Global Mapping of Earth-like Exoplanets from Scattered Light Curves"*
2. **Kawahara & Fujii, ApJL 739, L62 (2011)** *"Mapping Clouds and Terrain of Earth-like Planets from Photometric Variability : Demonstration with Planets in Face-on Orbits"*
3. **Fujii & Kawahara, in prep**

●Diurnal Variation of the Scattered Light

4. Ford, Seager, & Turner, Nature, 412, 885 (2001)

●Longitude Mapping and Light Curve Observation/Simulation of the Earth

5. Cowan, Agol, Meadow et al. ApJ 700,195 (2009)
6. Fujii, Kawahara, Suto et al. ApJ 715,866 (2010)
7. Cowan, Robinson, Livengood et al. ApJ 731, 76 (2011)
8. Fujii, Kawahara, Suto et al. ApJ 738, 184 (2011)