Journal of Physics Special Topics

An undergraduate physics journal

A6_5 Apparent Magnitudes of "Jupitershine"

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November 21, 2016

Abstract

We use solar irradiance and solid angle to estimate the planetshine apparent magnitudes of the Galilean moons. We estimate these to be -4.79 for Io, -2.54 for Europa, -1.17 for Ganymede and 2.38 for Callisto.

Introduction

Earthshine - a prime example of planetshine - happens when the darker part of the Moon's disk is illuminated by sunlight reflected off Earth [1]. It occurs around a New Moon when the Moon embarks on a new lunar cycle and is still "young" [2] with a lunar phase of ideally 0% - 20%. As the Moon continues orbiting, the directly sunlit area appears brighter due to phase changes and earthshine becomes too faint to detect [1]. In a 2016 paper, D. C. Agrawal estimated the apparent magnitude of earthshine using the photopic spectral luminous efficiency function [2].

Planetshine is not limited to the Earth-Moon system, and in this paper, we estimate the apparent magnitudes of "Jupitershine" (the case of planetshine for Jupiter) of the Galilean moons as would be observed from Jupiter.

Theory

"Jupitershine" will be expected to occur in three stages, namely: solar light reflects off the Sun-facing side of Jupiter onto the Jupiter-facing side of one of its moons and then back to Jupiter [2].

Jupiter receives solar irradiance $I_\odot = 50.26$ Wm^{-2} [3] - defined as the total radiant solar power divided over 4π sr of a sphere [4] received at Jupiter's orbit. We assume hemispherical reflecting surfaces for Jupiter and its Galilean moons and an isotropic reflection of light. The reflected irradiance then depends on surface albedo [2], ε, and the ratio of solid angle subtended by the reflecting body, Ω, to the solid angle of observable sky, $\Omega_S = 2\pi$ sr.

This is expressed in Equation 1 which gives the solar irradiance reflected by Jupiter, I_J, onto a Galilean moon as:

$$I_\odot \varepsilon_J \cdot \frac{\Omega_J}{\Omega_S} = I_\odot \varepsilon_J \cdot \frac{\pi}{2\pi}\left(\frac{R_J}{d_{JM}}\right)^2 = \frac{I_\odot \varepsilon_J R_J^2}{2d_{JM}^2} \quad (1)$$

where $\varepsilon_J = 0.52$ and $R_J = 69{,}911$ km are the surface albedo and radius of Jupiter [3], respectively; and, d_{JM} is the orbital semi-major axis of a Galilean moon with Jupiter - this will vary for each moon. Ω_J is the solid angle subtended by Jupiter at a Galilean moon.

By analogy, the solar irradiance reflected by the surface of a Galilean moon, I_M, back to Jupiter is expressed in Equation 2 as:

$$I_J \varepsilon_M \cdot \frac{\Omega_M}{\Omega_S} = \frac{I_J \varepsilon_M R_M^2}{2d_{JM}^2} = \frac{I_\odot \varepsilon_J R_J^2 \varepsilon_M R_M^2}{4d_{JM}^4} \quad (2)$$

where ε_M and R_M are the surface albedos and radii of the Galilean moons, respectively. Ω_M is the solid angle subtended by a Galilean moon at Jupiter.

"Jupitershine" apparent magnitudes, m, can then be calculated using Equation 3 [5]:

$$m = -2.5 \log \left(\frac{I_M}{I_0} \right) \quad (3)$$

where $I_0 = 2.52 \times 10^{-8}$ Wm^{-2} is the reference intensity of Vega, an apparent magnitude zero star [5].

Results

We use Equations 2 and 3 and Table 1 to estimate the "Jupitershine" apparent magnitudes of the four Galilean moons.

Galilean moon	ε_M	R_M (km)	d_{JM} (km)
Io	0.62	1,821.5	421,800
Europa	0.68	1,560.8	671,100
Ganymede	0.44	2,631.2	1,070,400
Callisto	0.19	2,410.3	1,882,700

Table 1: Key physical and orbital parameters of the Galilean moons [6].

Substituting each of these values in turn for each moon into Equation 2 gives I_M. I_M values are then substituted into Equation 3 to calculate the "Jupitershine" apparent magnitudes, m.

Galilean moon	I_M (Wm^{-2})	m
Io	2.08×10^{-6}	-4.79
Europa	2.61×10^{-7}	-2.54
Ganymede	7.41×10^{-8}	-1.17
Callisto	2.81×10^{-9}	2.38

Table 2: Reflected intensities, I_M, and "Jupitershine" apparent magnitudes, m, of the Galilean moons.

Discussion

The absence of reliable albedo variation profiles means we are unable to provide credible uncertainties. However, we can qualitatively assert that our estimates are subject to fluctuation due to a number of factors. For example, we only consider the idealised case of perfect isotropic reflection and neglect both atmospheric seeing effects on Jupiter and changes in orbital parameters. Furthermore, we used solar irradiance - which includes all wavelengths on the electromagnetic spectrum - to estimate visible-range apparent magnitudes. We would expect our estimates to be further reduced if we also accounted for this discrepancy.

It appears that the unpredictability of the Jovian system would make it difficult to carry out an accurate error propagation in this educative exercise. The best suggestions may be to model some of these issues. For instance, we could consider how light reflects off surfaces in the Solar System in more detail; and, simulate some selected seeing effects of the Jovian atmosphere.

Conclusion

"Jupitershine" apparent magnitudes can only ever be measured from within the Jovian system. While this is arguably not yet possible with current technology, a way of verifying these estimates could be to use the free planetarium computer program Stellarium. Users can set their location on different celestial objects (including Jupiter) and "observe" the sky from there.

Possible further work could include applying this model to other planet-moon systems.

References

[1] Moore, P.; Astronomy encyclopedia; London: Philip's, 2002; page 123.

[2] Agrawal, D. C.; Apparent magnitude of earthshine: a simple calculation; European Journal of Physics, Issue number 3; Vol. 37; 2016.

[3] `https://goo.gl/gp8yP1` accessed 31/10/16.

[4] Barkley, M.; Climate Physics - Lecture 2: Solar & Terrestrial Radiation; 2016; page 24.

[5] `https://goo.gl/iMkVFP` accessed 26/10/16.

[6] `https://goo.gl/bkDNh6` accessed 31/10/16.