INVERSION OF THE ZODIACAL BRIGHTNESS INTEGRAL : A NEW GEOMETRIC APPROACH SUITABLE FOR THE OUT-OF-ECLIPTIC ZODIACAL LIGHT PROGRAMME

René Dumont
Observatoire de Bordeaux, France

Anny-Chantal Levasseur-Regourd
Service d'Aéronomie, Verrières-le-Buisson, France

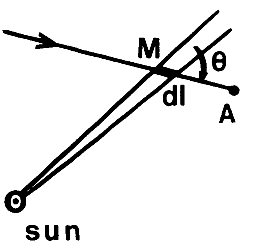
ABSTRACT. - The information provided by measurements of the zodiacal brightness, Z, is discussed as a function of the looking direction, with respect to the velocity vector of the observer through the solar system. In addition to a few directions which allow inversion of the brightness integral completely free of assumptions, it is shown that the orbital plane gives inverting possibilities, based on a single assumption on the heliocentric dependence of the volume scattering efficiency. Important features of the zodiacal cloud distribution, very difficult to obtain from earthbound observations, will easily be derived from the data of the Out-Of-Ecliptic Zodiacal Light Experiment.

INTRODUCTION

The result of any photometric observation of the zodiacal light (z.l.) is a brightness integrated along the line-of-sight :

$$Z = \int \mathcal{I} \cdot d\ell \qquad (1)$$

where the integrand $\mathcal{I}$ is the intensity (per steradian) scattered in the direction of the observer, A, by a unit-volume surrounding a random point, M, of the line-of-sight. Near M, an elemental section of the line-of-sight is denoted by $d\ell$, and the scattering angle is denoted by θ.



OBSERVING DIRECTIONS THAT REQUIRE NO ASSUMPTIONS

The only obvious and rigorous way to invert the integral - a fundamental problem, since the information about the distribution and the optical behaviour of the scatterers lies in $\mathcal{I}$, not in Z - is provided by the observer's motion through the solar system. Let us assume the photometer to look tangentially to the space probe's, or to the Earth's, orbit; and then, to keep the same celestial direction. After an infinitesimal

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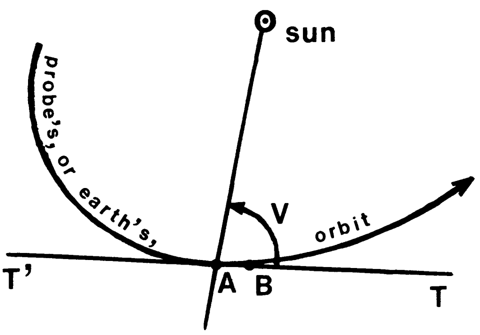
translation AB = ds, the brightness along the direction T of the motion has decreased by $-(\partial Z/\partial s)_{A,T} \cdot ds$, which also is the intensity scattered by the section AB in the antidirection T', i.e. along the scattering angle θ equal to V, angle between the tangent and the solar direction. The inversion at A and for the values V and π-V of θ, i.e. for the scattering directions T' and T, respectively, therefore is obtained completely free of assumptions :



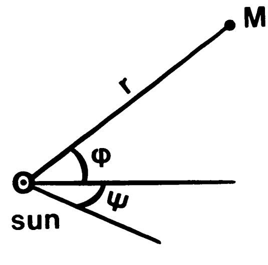
$$\mathcal{J}(A,\theta = V) = -(\partial Z/\partial s)_{A,T}$$
$$\mathcal{J}(A,\theta = \pi - V) = -(\partial Z/\partial s)_{A,T'} \qquad (2)$$

In the case of earthbound measurements, these two solutions practically merge into a single one, since the orbit has too small an eccentricity for sufficient departures of V from 90°. The gradient $(\partial Z/\partial s)$ is then equal to the gradient with elongation along the ecliptic $(dZ/d\varepsilon)$ for the value 90° of the elongation ε. The intensity scattered at right angles by a unit-volume of space situated in the ecliptic at 1 AU from the sun, or by the "last" elemental section of the line-of-sight (the AU remaining the length unit), therefore is directly accessible, and satisfactorily known from the observations (Dumont, 1972, 1973; Dumont and Sánchez, 1975; Leinert, 1975).

In non-tangential viewing directions, arbitrary assumptions cannot be avoided, as soon as the other extremity, B, of the elemental section that we try to isolate from the rest of the line-of-sight, is not visited by the instrument (at least to the 2nd order). Minimizing the level of arbitrariness of these assumptions, in other words using "OCCAM's razor" in order to get better information with the help of less risky assumptions, has to be a fundamental worry.

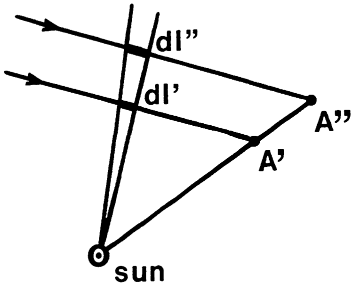
SEARCH FOR CREDIBLE ASSUMPTIONS PROVIDING MORE "INVERTIBLE" DIRECTIONS

An ambitious goal would be to determine the function $\mathcal{J}(\psi,\phi,r,\theta)$ where ψ, φ, r are the heliocentric longitude, latitude and distance of a random point M with respect to an arbitrary reference plane containing the sun (ecliptic or other). Previous results (Dumont *et al.*, 1978 ; Schuerman, 1979) have shown that assuming rotational symmetry, i.e. ruling out the longitude coordinate ψ, leads to an inversion formula valid under the condition that the line-of-sight is in a definite plane, tangent to the orbit. Pioneer 10 observations are being treated in that manner (see Schuerman, this volume). The purpose of the present work is to show that another assumption, which consists in separating the variable r and admitting for it a power law,



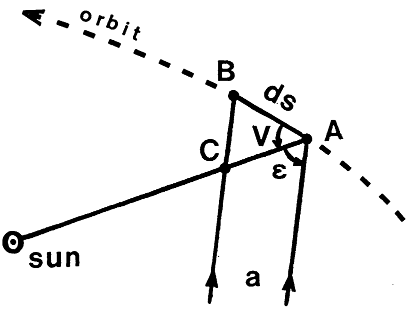
$$\mathcal{I}(\psi,\phi,r,\theta) = r^{-c} \cdot \mathcal{I}_{r=1}(\psi,\phi,\theta) \qquad (3)$$

both has strong observational support, and gives access by inversion to some basic parameters of the zodiacal cloud morphology.



If we compare the brightnesses Z", Z' observed in the same celestial direction from two locations A", A' aligned with the sun, the contributions by the corresponding sections $d\ell''$, $d\ell'$ will differ only by the values of r, and their ratio will be $(\odot A''/\odot A')^{1-c}$, thus invariant as the secant rotates around the sun. After a radial translation of the observer A the brightness will vary like the power (1-c) of the heliocentric distance R of the observer. This is in excellent agreement with the results of the two z.l. experiments aboard Helios 1 and 2 probes (Leinert *et al.* 1978, and this volume), the value of (1-c) in all directions observed being -2.3 ± 0.1.

Assumption (3) allows the integral to be inverted for all viewing directions lying in the orbital plane. After an elemental motion AB = ds, the brightness in the constant celestial direction a (initial value of the elongation : ε) has increased by ds times the derivative $(\partial Z/\partial s)_{A,a}$. Should the new location of the instrument have been C instead of B, the increase would have been $Z_{A,a} \cdot (1-c) \cdot (R_C - R_A)/R_A$. It is therefore possible to isolate the contribution by the section CB : $\mathcal{I}(A,\theta=\varepsilon) \cdot CB = (\partial Z/\partial s)_{A,a} \cdot AB - Z_{A,a} \cdot (1-c) \cdot (R_C - R_A)/R_A$, or, since $CB = ds \sin V/\sin\varepsilon$ and $R_A - R_C = ds \sin(V+\varepsilon)/\sin\varepsilon$,



$$\mathcal{I}(A,\theta=\varepsilon) = (\partial Z/\partial s)_{A,\varepsilon} \sin\varepsilon/\sin V + Z_{A,\varepsilon}(1-c) \sin(V+\varepsilon)/R \sin V \qquad (4)$$

Due to the fact that the same value of $\mathcal{I}$ has to be obtained for $\theta = -\varepsilon$, it follows that equation (4) joined to the similar one derived from the viewing direction $-\varepsilon$ (symmetric of the first with respect to the sun) allows a determination of the constant c :

$$1-c = R \sin\varepsilon \left[(\partial Z/\partial s)_{A,\varepsilon} + (\partial Z/\partial s)_{A,-\varepsilon}\right] / \left[Z_{A,-\varepsilon} \sin(V-\varepsilon) - Z_{A,\varepsilon} \sin(V+\varepsilon)\right] \qquad (5)$$

APPLICATION TO THE DATA OF THE FUTURE "ISPM - ZL" EXPERIMENT

In addition to the interest of the special tangent plane pointed out by Dumont *et al.*, 1978, and Schuerman, 1979, a suggested treatment of the data to be obtained in the orbital plane of the OOE spacecraft by the ZL-Experiment (see Schwehm, this volume) will be the following :

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1. For each position A of the probe, every viewing couple $(\varepsilon, -\varepsilon)$ from the minimal elongation ε_m(30° ?) to 180° will lead, by formula (5), to a value of c. A test for the validity of the assumption (3) will be the invariance of c, as ε varies and as the probe moves.

2. For each position A, a double determination of the local scattering phase function $\sigma_A(\theta)$ will be given by (4) from ε_m to 180°, since the intensity $\mathcal{I}(A,\theta)$ is the product of $\mathcal{I}(A, 90°)$ by $\sigma_A(\theta)$.

3. Finding $\sigma(\theta)$ practically independent of the probe's position, A, would imply a good probability for uniform composition of the zodiacal cloud. Then, the space density would be proportional to R^2 times the intensity at a given θ, or at 90°. This case would in fact merge with the very classical assumption where ϕ and θ are separated, and ψ disregarded : $\mathcal{I}(A,\theta) \sim r^{-c} \cdot f(\phi) \cdot \sigma(\theta)$. The latitude function $f(\phi)$, which is a major feature of zodiacal cloud morphology, would be obtained very directly on the whole range 0 - 90°, in contrast to the great difficulties encountered in disentangling that function from earthbound measurements.

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DISCUSSION

Giese: I think the inversion method pioneered by you is very important for zodiacal light observations from the INTERNATIONAL SOLAR POLAR MISSION. I encourage you strongly to extend your present research to suggest looking directions from out-of-ecliptic spacecraft which provide optimum conditions for application of your method.

Dumont: Certainly. Improving and generalizing inversion processes especially for the needs of out-of-ecliptic zodiacal light experiments is one of our major aims.