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From François Arago to small bodies exploration: Polarimetry as a tool to reveal properties of thin dust clouds in the Solar system and beyond

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Abstract

Two centuries ago, elaborate principles of physics were employed for the first time to establish the nature of a celestial body. Thanks to the polarimetric observations of Arago, the presence of dust particles was suspected in what is now named a cometary dust tail. Polarimetry has been used to better understand the properties of thin dust clouds, within the Solar System and beyond, and of airless small bodies. Striking advances in the last decades, together with the ground-truth provided by space missions, have established that polarimetry is a tool of major importance in astrophysics.

1. Historical perspective

1.1 Arago, first polarimetric observations

On 1 July 1819, Johann Tralles discovered a bright comet (C/1819 N1) from Berlin. A few years before, François Arago (1786-1853), a brilliant physicist and astronomer, had invented the polariscope, a device that had allowed him to observe the polarization of the blue sky and of the Moon. He was soon able to turn it into a polarimeter, appropriate to measure the fraction of linear polarization [1].

On 3 July 1819, Arago observed the tail of the new comet Tralles with a small telescope equipped with his polarimeter from Paris Observatory. He calibrated the polarimetric observations on the star Capella and had them cross-checked by Alexander von Humbolt, Alexis Bouvard and Claude Mathieu. On 23 October 1835, Arago performed similar observations on the returning comet 1P/Halley. He later wrote that the faint linear polarization he had observed might come from the "solar-light reflection on sparse patchy material" [2]. Such results, on what is presently named solar-light scattering on dust particles, somehow marked the beginning of astrophysics [3, 4].

1.2. Progresses, 19th and 20th centuries

First polarimetric observations of the zodiacal light also took also place during the 19th century. A.-W. Wright established in 1874 its linear polarization to be faint, about 15%, and its spectrum to be similar to that of sunlight. He suggested this faint glow to originate in light from the Sun "reflected from… small bodies (meteoroids) revolving… in orbits crowded together towards the ecliptic" [5].

More progresses occurred in the 20th century, with photo-polarimetric observations of the zodiacal light by Jean Dufay [6] and of the F-corona by Bernard Lyot [7], to be followed, soon by lunar polarimetric observations, and later by numerous polarimetric observations of asteroids and moons. At the beginning of the space age, while impinging meteoritic dust particles were suspected to be a serious hazard, extensive ground-based observations of the zodiacal light took place. After 1960, René Dumont succeeded to avoid nightglow contamination, and achieving full-sky polarimetric observations from Tenerife Observatory, including the Gegenschein, i.e. the anti-solar region [e.g. 8, 9].

2. Polarization and exploration of small-bodies in the Solar System

2.1. First clues to physical properties of zodiacal and cometary dust

Satellite photometric observations of the zodiacal light at 90° from the Sun soon established the quality of the observations obtained by Dumont [e.g. 10]. We could later derive local properties of the dust and point out a trend to a decrease of the local polarization with decreasing solar distance [11, 12].

In 1986, the ESA Giotto flyby of comet 1P/Halley allowed, for the first (and still only) time, photo-polarimetric observations of dust within a cometary coma to be obtained. Our results indicated a decrease in polarization with decreasing nucleus distance, and suggested the albedo and the density of the dust particles to be extremely low [13]. In subsequent years, remote polarimetric observations of comets, including bright comet Hale-Bopp (C/1995 O1), provided clues to changes in physical properties of dust within the coma [14]. Theoretical studies suggested the dust to be a mixture of porous aggregates of grains mixed with compact aggregates, and to consist of non-absorbing silicates and more absorbing organics [e.g. 15, 16].

2.2. Ground-truth provided by the Rosetta mission

The Rosetta space probe built by ESA provided a long rendezvous with comet 67P/ Churyumov-Gerasimenko. Instruments devoted to dust studies reveal the composition and physical properties of the cometary dust, and confirm, with a much higher accuracy, the interpretation of dust polarimetric observations in cometary comae. Complex organic compounds dominate the refractory organic phase; dust particles are fractal aggregates of grains, with morphologies ranging from extremely porous to extremely compact, and volume filling factors covering many orders of magnitude [e.g. 17].

2.3. Dust clouds and disks elsewhere

Polarimetric images of the Earth-Moon L5 region have recently provided clues to an increase in polarization, which is likely to originate from a change in dust concentration or properties, as previously suspected by Kordylewski [18].

Beyond the Solar System, protoplanetary disks and debris disks have been detected in the visible and near-infrared domains. Polarimetric images and phase functions are obtained, and interpreted through numerical simulations [e.g. 19, 20].

3. Conclusions

Polarimetry has already a long history in studies of thin dust clouds. An other domain - not detailed here and nevertheless of major interest - concerns the polarimetry of airless bodies, typically asteroids (including NEA), moons and some planets. Recent progresses, in instrumentation and interpretation of the observations, should continue to provide unique results from remote observations of celestial bodies.

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