PH.D. THESIS SUMMARY

Determination of the physical parameters of asteroids and comets with photometric methods

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1. Introduction and scientific rationale

Since spring, 1997, I have obtained CCD-photometry of asteroids and morphological examinations of comets. Later I joined the statistical examinations of the Sloan Digital Sky Survey Moving Object Catalog (SDSS MOC). In the dissertation I summarize the significance of such studies in contemporary astronomy, discuss the power and perspective of ground-based observations, and present my own results.

The small bodies of the Solar System

The investigation of the Solar System is a part of astronomy which is linked to several fields of contemporary astrophysics.

1. Asteroids and comets contain the oldest primordial matter in the Solar System. They inform us about the origin and evolution of the Sun, the closest star to us. Therefore the investigation of the small bodies in our Solar System gives us basic knowledge in the **evolution of stars, protoplanetary disks and planetary systems**.

2. There are known examples of **small bodies in exoplanetary systems.** The investigation of their belt is related to the evolution of solar systems. Knowlegde of the Sun's asteroid belt supports these studies.

3. We wish to know the Solar System as our **nearest cosmic environment**. Besides the scientific research, „civil" interest is arisen here concerning e.g. the defense against the impacts, or the technical innovation of space vehicles visiting the small bodies or crossing the asteroid belt.

4. From the physical point of view, we observe the **matter in a state which is not reproducible in laboratories**. The cometary tails are rarer than the best artificial ultravacuums; the huge energy produced by collisions (e.g. of two asteroids having about 100 km diameter and a few km/s velocity) cannot be studied in laboratories at all.

Photometric methods

The asteroids rotate around their spin axis, while vary their light. Measuring this (lightcurve) we conclude the shapes, spin axis directions and periods of rotation. While the asteroids are unresolved in common ground-based telescopes, in the most cases this is the only way to investigate these parameters. With multicolor photometry, the chemical composition can be studied, and albedo variegation (colored spots on the surface) may be revealed. The physics of comets is closely connected to their matter production rates, originated by the solid nucleus. The dust is widely characterized with its relative linear filling factor ($Af\rho$) inside the coma. With help of imaging with interference filters, different parts of the cometary spectrum can be separated, therefore the dust and the different gas components can be studied individually. The ejected matter evolves in the interaction with the solar wind and radiation pressure, which all can be studied using photometric tools. On the other hand, we can directly observe the molecular transition probabilities in very rare gases, from which we can conclude the free timescales, too.

Statistical methods

The all-sky surveys do not observe a certain asteroid frequently, and do not cover its rotation cycle, which disables the classical lightcurve analysis. However, they observe thousands of asteroids and produce a homogeneous sample for statistics. From individual multicolor measurements both the size and chemical composition distributions can be determined. Comparing pairs of multicolor observations – which therefore refer to independent rotational phases – the brightness variation (statistics of asphericity) and the albedo variegation (statistics of surface spots) can be studied. The statistical examinations of comets (e.g. comparison of published results) is more difficult, mainly because of the relatively few known comets. A first step in having wide sample may be the launch of observing campaigns, especially dedicated to the desired quantity.

2. Thesis points

1. Using a C-11 telescope (Szeged Observatory), a 60/180 cm Schmidt-telescope (Konkoly Observatory), and a 1.23 meter telescope (Calar Alto Observatory) I obtained new photometric observations of 31 asteroids. For 5 objects I calculated shape and rotation models. I applied the widely used AM-method, determining the dependence of the lightcurve amplitude on the aspect data (aspect angle of the rotation axis, solar phase etc.). I calculated the axis ratios of the triaxial ellipsoid shape model, the period of rotation and the direction of the spin axis. The epoch-methods examine the time differences between minima, as they slightly depend on the aspect angle of the spin axis and the motion of the asteroid. With examining these differences explicitely on the ecliptic longitude base I presented a new approach to epoch-methods ($O - C'$). By calculating the delay of times of minima during a revolution, this method gives the sense of rotation and the pole coordinates independently to the AM-methods. In the case of the asteroids that could be modeled with both methods, the pole coordinates agreed well.

I observed further 10 asteroids with available published photometric data. In the case of two long-period asteroids (288 Glauke and 499 Tokio) I disproved the presence of a previously suspected short-period component. There were 15 asteroids for which I obtained the first lightcurve in the literature. The amplitude and the period of rotation were calculated for 6 of them, for the 11 remaining, the rotational cycle was not totally covered (Szabó et al., 2001, Kiss et al., 1999, Sárneczky et al., 1999, Szabó, 1999).

2. I observed and analysed 11 comets at large heliocentric distances (8 of them farther than 2.7 AU, 5 of them farther than 5.5 AU). In most cases, high activity was detected. The sizes of the nuclei were roughly estimated, and those values should be considered as an upper estimation because of the errors. The nuclear regions of the Comet Skiff and C/1999 N4 showed slight light variation. The main sources of errors were the active coma and the seeing. (Szabó et al., 2001b, Szabó & Kiss, 2001).

I demonstrated the advantage of the intermediate-bandpass (Gunn v,g,r,z + 753/30 interference) filter set in the morphological studies of the gas components. With narrow-band comet filters I compared the morphology, column density and production rates of different (CN, CO^+, C_2, dust) components. Finally, I introduced an image processing tool, where the non-radial parts are emphasized by azimuthal renormalization. In order to characterize the deviance from circular coma, I defined the lc parameters (type and value). I detected the known „antisolar fan" in the coma of 19P/Borrelly, the effect of the spinning nucleus in the active coma of 29P/Schwassmann-Wachmann, and the peculiar chemical composition of C/2001 A2. In the latter case, the ratios of production rates evolved to normal values in the case of outburst.

3. I reported on the detection of statistically significant color variations for a sample of 7531 multiply observed asteroids that are listed in the Sloan Digital Sky Survey Moving Object Catalog (SDSS MOC). Using 5-band photometric observations accurate to $\sim$0,02 mag, the color variations were in the range 0,06-0,11 mag (rms). These variations appeared uncorrelated with asteroids physical characteristics such as diameter (in the probed 1-10 km range), taxonomic class, and family membership. The observed color variations were incompatible with photometric errors, and, for objects observed at least four times, the color change in the first pair of observations is correlated with the color change in the second pair. The color variations can be explained as due to inhomogeneous albedo distribution over an asteroid surface. Although relatively small, these variations suggest that fairly large patches with different color than their surroundings exist on a significant fraction of asteroids.

4. From the SDSS MOC I designed the automatic selection of 480 known and 891 undiscovered Jovian Trojan asteroids. The completeness of the sample was about 60%, whith less than 5% contamination of main-belt objects. Based on submitted results, the L4 swarm contained significantly more (with about a factor of 2) asteroids than the L5. The color distributions were also different in the two swarms, while in L4 swarm the color correlated to the inclination, too. These asymmetries may imply different evolution of the two swarms.

5. In contribution with the Italian Astronomical Union and amateur astronomers from Slovenia, Spain, France and Australia, we launched the project CArA (Cometary Archives for Amateurs, cara.uai.it), which aims collecting photometry of the brightest comets. I pointed out that the required homogeneity and simplicity meets to CCD-measurement of $Af\rho$; the suggested ρ radii were fixed in terms of length; and I defined the records and the format format of archival. As data are produced by amateur astronomers, we developed a user-friendly, graphical surface-based image processing code especially for the required reduction, which is based on my algorithms. The project collected 1050 points between summer, 2002 and December, 2004, which often do have the quality for detailed analysis and publication.

Refereed papers associated with the theses

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