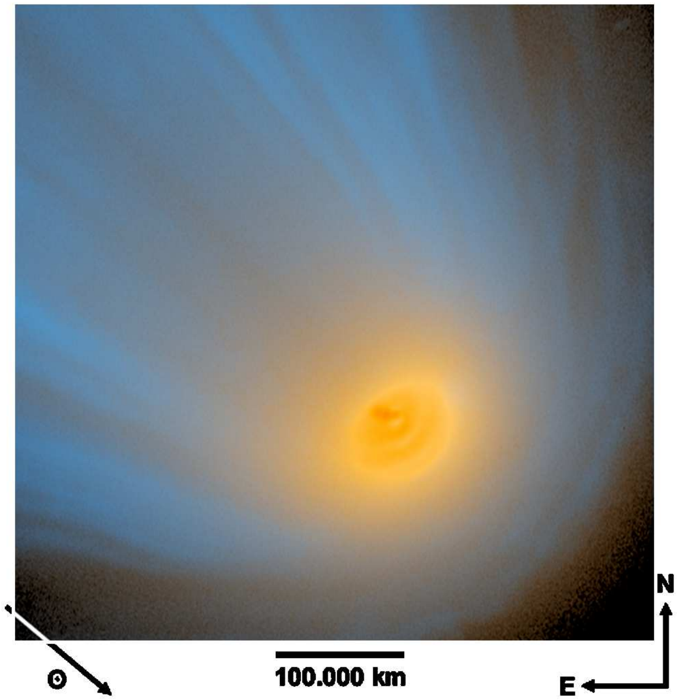

Figure 1. Two-color image of comet C/1995 O1 (Hale-Bopp) obtained with the Two-Channel Focal Reducer on April 13, 1997. The orange color represents the dust grains of the cometary atmosphere. Note the dust spirals observed in this huge comet. The blue color represents the distribution of cometary ions (here the ion OH^+) [1]

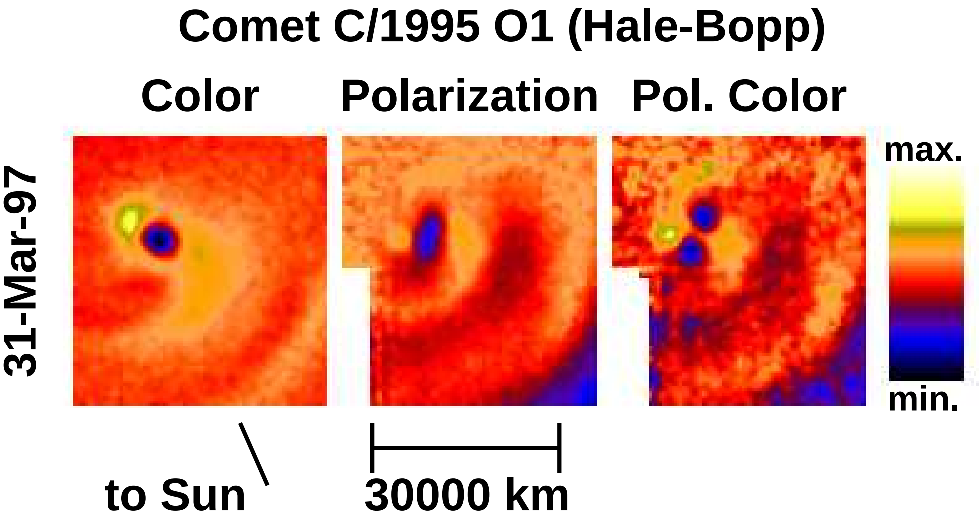

Figure 2. Images of color, polarization, and polarimetric color as observed in comet C/1995 O1 (Hale-Bopp) on March 31, 1997. The displayed range of dust color extends from 0% to 30% reddening per 1000 Å. The polarization range is from 12% to 20%. The polarimetric color $P_{red} - P_{blue}$, measured at 642 and 443 nm, ranges from 1% to 5%

SIX YEARS OF OBSERVING WITH THE TWO-CHANNEL FOCAL REDUCER OF MPAE AT THE TERSKOL OBSERVATORY

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ШЕСТЬ ЛЕТ НАБЛЮДЕНИЙ С ДВУХКАНАЛЬНЫМ ФОКАЛЬНЫМ РЕДУКТОРОМ ИНСТИТУТА АЭРОНОМИИ М. ПЛАНКА НА ОБСЕРВАТОРИИ ТЕРСКОЛ, Йоккерс К. – В 1996 г. на пик Терскол был доставлен двухканальный фокальный редуктор Института аэрономии М. Планка для использования на 2-м телескопе системы Ричи–Кретьена–Кудэ. Этот прибор является единственным на этом телескопе устройством получения электронного изображения. Используя комплекс “2-м телескоп–2-канальный фокальный редуктор”, ученые Германии в сотрудничестве с русскими, украинскими и болгарскими астрономами занимались изучением газа и пыли в кометах, проводили поляриметрию астероидов и кометного газа, а также выполняли работы по астрометрии и фотометрии внутренних спутников Юпитера. Кроме того, исследовались морфология и светимость плазменного тора спутника Юпитера Ио с целью определения его физических характеристик. В докладе дается краткое описание фокального редуктора, возможности комплекса “2-м телескоп–2-канальный фокальный редуктор” демонстрируются на результатах 6-летнего периода наблюдений.

In 1996 the Two-Channel Focal Reducer of the Max-Planck-Institut für Aeronomie was brought to Terskol Peak for the use at the 2-m Zeiss Ritchey-Chrétien-Coudé telescope. Since then it has been the only electronic imaging device available at this telescope. Using the 2-m telescope, the German side, in collaboration with Russian, Ukrainian and Bulgarian astronomers, has studied gas and dust in comets, conducted polarimetry of cometary dust and asteroids, and astrometry and photometry of the inner Jovian satellites. The morphology and brightness of the plasma torus of the Jovian satellite Io has been investigated in order to derive its physical properties. The focal reducer is briefly described, and the capabilities of the telescope–focal reducer combination are demonstrated with results obtained during the six years of observing.

INTRODUCTION

In 1996 the Max-Planck-Institut fur Aeronomie (MPAe) and the International Centre for Astronomical, Medical and Ecological Research (ICAMER) have agreed on the joint use of the Two-Channel Focal Reducer of MPAe at the 2-m RCC Zeiss telescope of ICAMER. Since then six years have passed by. On occasion of the 10th anniversary of the foundation of ICAMER a brief overview of the results achieved by the German side within the framework of the above agreement is presented below.

THE TWO-CHANNEL FOCAL REDUCER AT THE 2-m RCC ZEISS TELESCOPE OF THE TERSKOL OBSERVATORY

The primary aim of telescopic astronomical observations is to get a close-up view on a celestial object. One, therefore, might think that magnifying power, or, if we speak in terms of photography, focal length is the primary figure of merit for an astronomical telescope or, more accurately, for the combination of a telescope with a modern solid state camera employing CCD detectors. There are two main reasons why this is not the case. First, a telescope represents a “light bucket”, *i.e.*, must collect as many photons as possible. The larger the diameter of its primary mirror the more light of a feeble astronomical object is collected and, for a given magnification, the less time it will take to obtain a decent image of the object. On the other hand, the more light enters the telescope, if the exposure time is fixed, the larger can be the magnification of the image we want to get. The second factor limiting the magnification of a large optical ground-based telescope is atmospheric turbulence. Even with the sometimes excellent atmospheric conditions at the Terskol Observatory atmospheric turbulence does not allow to get a resolution much better than 1/20000 of a degree, *i.e.*, 0.18 arcsec. To optimize the scarce and expensive observing time available at large telescopes it is, therefore, important to adjust the focal length of a given telescope to the task of the observations. In its Cassegrain focus the 2-m RCC telescope of the Terskol Observatory has a focal length optimized to the best conditions of atmospheric turbulence. The Two-Channel Focal Reducer of MPAe [2] reduces this focal length by a factor of 2.86 to a resolution of about 1 arcsec. This allows to obtain sharp images even under non-optimum conditions of atmospheric turbulence. At the same time the light gathering power increases by the square of the same factor ($2.86^2 = 8.2$), *i.e.*, less time is needed to get a well-exposed image. As an additional feature the focal reducer has two channels to allow simultaneous images in two colors. In this respect the instrument falls short of an ordinary television camera which has three color channels. But in comparison with a television camera, which is restricted to the natural colors of the human eye, the focal reducer allows filters of wide or narrow bandwidth to be used. In this way the astronomical objects can be observed in the light of important atoms, molecules or ions, or in windows free from such lines (continuum windows), as necessary for the investigated object.

GAS AND DUST IN COMETS

A comet is a "dirty snowball" of a size of about one kilometer. According to present understanding comets were formed from the protoplanetary dust cloud about 4.6 billion years ago at about the distance of present-day planet Neptun. During this long time almost all comets remained at large distances from the Sun and have always been very cold. Therefore, in contrast to the inner, earthlike planets, comets preserved the volatile materials of the early solar system which were lost or modified in the inner solar system where the earthlike planets formed. Despite of most comets being unobservable in the deep voids of the solar system, some are scattered by disturbances of planets or stars into the inner solar system. When they approach the Sun their surface temperature increases and they sublimate their volatile materials (ices). The dust grains (the "dirt" of the dirty snowball) are dragged along with the gases and form the so-called dust coma and dust tail of a comet. The gas molecules of the sublimated ices form the gas coma. They are later ionized, interact with the solar wind and form the cometary ion tail. Despite of the small cometary nucleus, which cannot be resolved with ground-based telescopes, the coma and in particular the dust and ion tails can have a size of many million km and be observed not only in telescopes but also with naked eye. Comet Hale-Bopp was one of these naked-eye objects in spring 1997. In Figure 1 (see page 36) two simultaneous images of this comet, taken with the Two-Channel Focal Reducer, have been combined into a single two-color image. The blue, structured envelopes in the image are representing the cometary ion tail. The arcs form through interaction with the solar wind. The yellow oval in the image is cometary dust. A dust spiral is visible. Dust grains with special properties leave active areas of the cometary nucleus and are dragged into a spiral by the rotation of the nucleus.

We can obtain more information about the dust of comet Hale-Bopp, if besides of investigating dust images we also determine dust color (change of dust brightness with wavelength) and polarization. Images of dust color, polarization and "polarimetric color", *i.e.*, the wavelength dependence of polarization, are shown in Figure 2 (see page 36). The bluer color and reduced polarization at the comet's center as compared to its surroundings has been interpreted as a slow evaporation of a compact organic mantle from a silicate core of the dust grains as the particles leave the cool nucleus surface and are heated by solar radiation [3].

POLARIMETRY OF ASTEROIDS

Asteroids are small bodies in the inner solar system. Most of them orbit the Sun between the planets Mars and Jupiter. They are thought to be left-overs from the small body population ("planetesimals") from which the planets are built. When giant planet Jupiter formed, its gravity increased the relative velocities of neighbouring planetesimals. As a consequence, instead of coalescing and forming another planet, they started to destruct each other. There is evidence for great collisions between asteroids. Their present-day population is said to be in collisional equilibrium, *i.e.*, as a result of collisions smaller and smaller fragments are constantly being formed. These fragments orbit not only between Mars and Jupiter but some of them approach the earth quite closely. One of these objects is asteroid 33342 which, like most cometary nuclei, has a size of about 1 km and approached the earth in Mid-December 2001 to 0.0125 AU. A campaign was organized in order to measure the polarization of this object over a wide range of phase angles (angle Sun-object-Earth). Data were obtained from the Crimean Astrophysical Observatory, the Grakovo station of Kharkov University Observatory and, last not least, from Terskol Peak. The 2-m telescope was used when the asteroid was still faint.

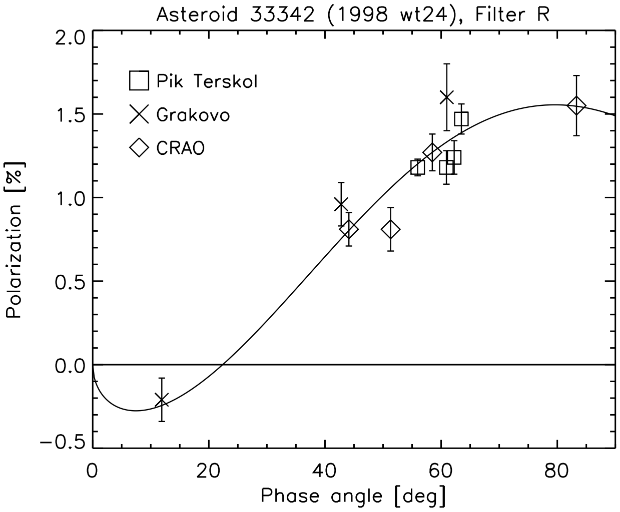

Figure 3. Degree of polarization versus phase angle as observed in asteroid 33342 from several cooperating observatories

The results (see Fig. 3) indicate that the asteroid is of the rare E type (metallic type) with very low polarization. This will help to interpret other data of this asteroid, like, *e.g.*, the first radar data obtained with the help of the Crimean Evpatoria radar.

THE INNER JOVIAN SATELLITES

The four large satellites of Jupiter, Io, Europa, Ganymede and Callisto, discovered by Galileo, were the first objects known to revolve around another celestial body different from Earth or Sun. Inside the innermost of the Galilean satellites, Io, which is at a distance of 5.905 Jovian radii from Jupiter's center, are the inner satellites Thebe, Amalthea, Adrasthea and Metis with semimajor axes of 3.11, 2.54, 1.81 and 1.79 Jovian radii and mean radii of 49.3, 83.5, 8.2 and 21.5 km, respectively. The largest one, Amalthea, was discovered by Barnard in 1892. The other three were detected only during the Voyager mission 1979/80. For ground-based observations they are, like the Jovian ring, normally hidden in the glare of the bright disk of Jupiter. In the last years we have been able to observe them routinely. This is possible partly because of the excellent transparency of the sky at the high altitude site of Terskol Peak, partly because special measures were taken. They are observed mainly in the methane absorption band at 890 nm, where the disk of Jupiter is comparatively dark. In addition, like in a coronograph, a Lyot-stop suppresses the diffraction pattern of Jupiter caused by the telescope optics. An elaborate mask at Cassegrain focus consisting of black glasses of different thickness and absorptivity suppresses the light of Jupiter and of the Galilean satellites, but nevertheless allows their imaging together with the faint inner satellites. This is very important as the images of the inner satellites must be related to calibration objects. The remaining halo of scattered light from Jupiter can be determined from the images and is subtracted during data reduction. Sample images are shown in Fig. 4. Observation of the positions of the inner satellites relative to those of the Galilean ones has allowed to get their accurate astrometric positions, which are needed to correct the orbit predictions for these objects [4]. The inner Jovian satellites are under heavy bombardment by energetic particles of the Jovian magnetosphere. Dust particles are sputtered from the satellite surfaces and are the source for the Jovian ring. To get more information on the nature of the satellite surfaces we have obtained integral photometry of the satellites. In contrast to the existing space observations our observations refer to small phase angles. Observations at very small angles provide the most useful information about the physical structure and texture of the surface layer of the satellite. Due to adverse weather conditions, the minimum angle so far observed is 1.42°. The maximum phase angle was 8.16°. The obtained photometric data allow to measure separately the brightness of both hemispheres with respect to the orbital motion of the satellite, *i.e.*, the brightness of the leading and trailing hemispheres. This investigation may help to understand better the character of the interaction between the satellites and the Jovian magnetosphere. For all satellites the leading hemispheres are brighter than the trailing ones, despite of the fact that the orbital periods of Thebe and Amalthea

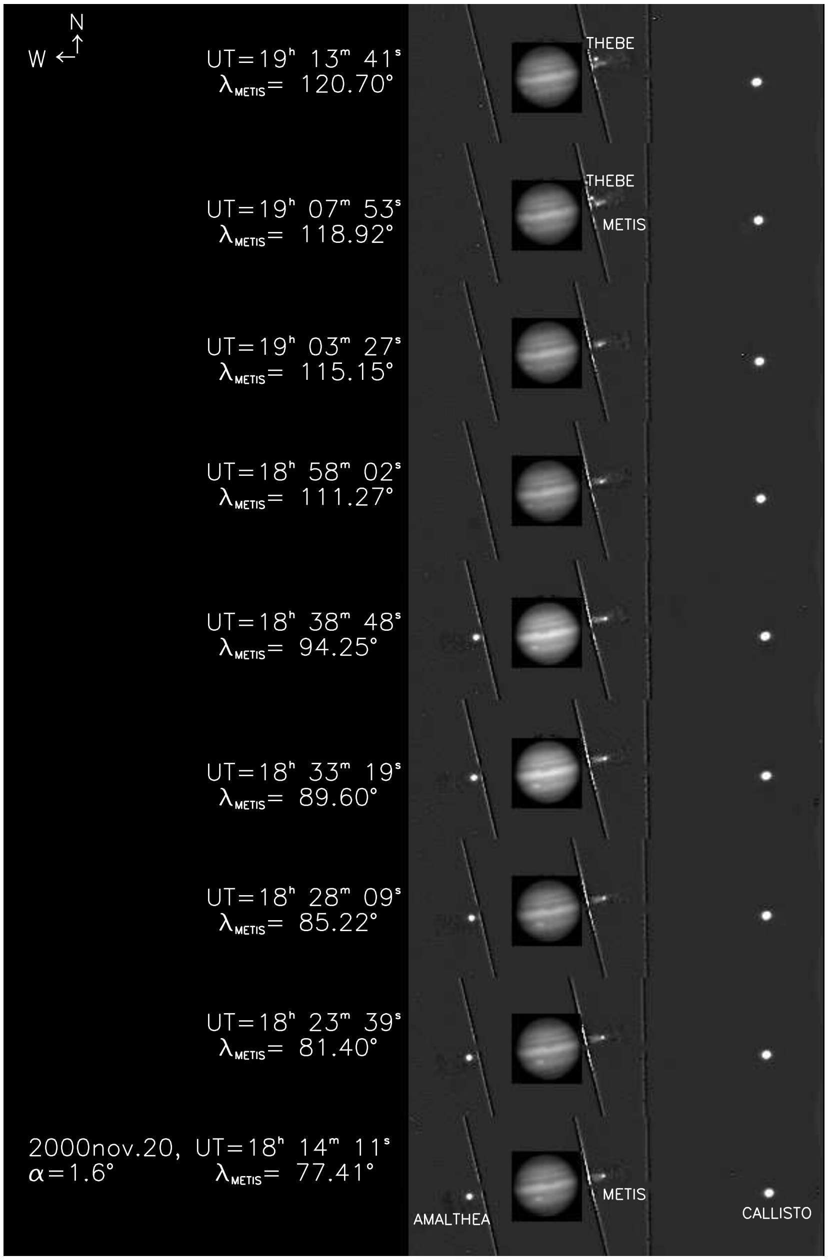

Figure 4. The inner Jovian satellites revealed. The satellite Ganymed is behind a weakly absorbing black glass, and planet Jupiter itself behind a strongly absorbing glass

are larger than Jupiter's rotation period, *i.e.*, the magnetically bound energetic particles hit these satellites on their trailing side, while for Metis the orbital period is smaller, *i.e.*, the particles impinge on its leading side. The albedos of Amalthea, Thebe and Metis decrease with their orbital distance from Jupiter.

THE IO TORUS

Another elusive object in Jupiter's satellite system is the Io torus. The innermost Galilean satellite Io is heated by gravitational interaction with Jupiter and the other Galilean moons. This causes its volcanic activity. Most of its surface is covered by SO_2 frost and there is also a very thin SO_2 atmosphere. The satellite Io orbits in the Jovian magnetosphere, a vast region of corotating ionized

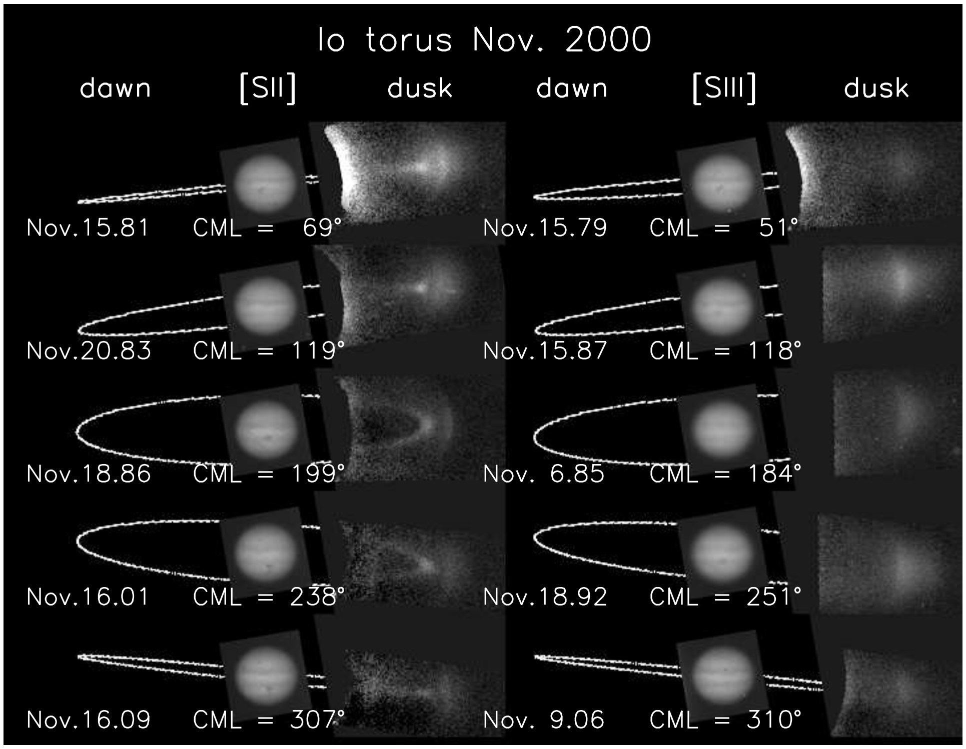

Figure 5. The Io torus, imaged in the forbidden lines of S^+ ([S II]) and S^{++} ([S III])

gas. This magnetospheric plasma dissociates the SO_2 molecules, ionizes them, forces them to rotate around Jupiter and in this way forms the Io torus. As the magnetic dipole of Jupiter is tilted by about 10° with respect to Jupiter's rotation axis, the Io torus is tilted in a similar way. The sulphur and oxygen ions of the Io torus radiate line emission. The strongest lines are due to S^+ and S^{++}. Observations of the torus in the light of these ions allow to determine the torus shape and its density and temperature. Observations of the Io torus are about as difficult as the observations of the inner satellites, for the same reason of scattered light from the bright Jovian disk. A similar setup is used as for the inner moons. In addition, a tunable Fabry-Perot interferometer allows only a very narrow range of wavelengths around the wavelength of the observed ion to be imaged and in this way further suppresses the straylight of Jupiter. Imaging of the Io torus allows to "see" part of the otherwise invisible Jovian magnetosphere and to determine its electron density and temperature. In 1999 and 2000 Jupiter's magnetosphere was investigated by the Galileo space probe, and the observations of the torus conducted at Terskol Peak served as a supplement of the space probe measurements. Fig. 5 shows images of the torus from November 2000 in the light of the S^+ and S^{++} ions. Dawn and dusk are the morning and evening sides of the torus, *i.e.*, the sides where, as seen from an observer in the torus, the sun rises (rotational motion of the torus toward Sun) or sets (rotational motion away from Sun). The ellipsoids represent the location of a ring at Io's distance from Jupiter inclined as the Io torus. An open ellipse indicates that we see part of an open torus. If the ellipse degenerates to a straight line, we see the torus from its side. On the left side of Fig. 5 in the third or fourth panel of the [S II] (S^+) images we see a narrow inner ring (the cold torus) and attached to it a vertically extended feature called ribbon. In the uppermost and lowermost panel of the S^+ images, where we see the torus edge-on, the ribbon continues to be prominently visible. This indicates that it is nearly perpendicular to the plane of the torus. It is caused by warmer ions which, because of their higher temperature, can move up and down along the magnetic field lines of Jupiter. We see from this that the temperature in the Io torus increases with distance from Jupiter. The [S III] (S^{++}) emission comes from hotter regions in the torus. In the light of this ion the cold torus is invisible. In the first row of images bright areas close to Jupiter indicate straylight which could not be properly removed from the images. This happens when during observations a small cloud passed through the field of view of the telescope. A remarkable feature is the separation of cold torus and ribbon which is best visible in the third panel of [S II] (S^+) images. It is not clear what caused this gap. It was not observed in 1999, *i.e.*, in 1999 there was a continuous transition between cold torus and ribbon.

OUTLOOK

For many years the Large Azimuthal Telescope (BTA) of the Special Astronomical Observatory with its 6m mirror has been the largest telescope of the world. In recent years, based on the design of the BTA and improving it, a number of larger telescopes have been built and more of these huge telescopes are under construction. In this new era 2 m size telescopes are considered as survey telescopes to find the objects which then will be investigated more deeply with the huge telescopes. A proper way of operation is provided in the framework of a "virtual observatory", where survey data are made available to all astronomers for use in their different fields. Another way to compete with the huge telescopes has been to specialize on objects which are bright enough to be observable with medium-sized telescopes but which nevertheless have not been studied extensively. As demonstrated in this study small bodies of the solar system are suitable objects partly because of their temporal variability and partly because they require special observing techniques not always available at the huge telescopes. In our cooperative program the 2-m RCC Zeiss telescope of the Terskol Observatory has produced internationally competitive results, and it can do this not only in the field of solar system astronomy. The present author hopes, however, that sooner or later a huge Russian telescope will be available and give the East-European astronomical community the research tool they deserve.

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