Dark Matter in Spiral Galaxies

One of the most interesting and burning topics in astrophysics is the unsolved mystery of dark matter. Observation results show that approx. 90 % of the matter in space exists in the form of so-called dark matter. Although this major component of the universe is not luminous and therefore inaccessible to direct observation, it can be inferred indirectly, e.g. by observing rotation curves of remote galaxies. Theoretical astrophysicists at AIP are using state-of-the-art supercomputers to develop numerical simulation calculations to describe the formation of structures in the universe in which the existence of dark matter provides a crucial foundation. For observations, the PMAS team collaborates with M. Verheijen (Groningen, Netherlands) and M. Bershady (Wisconsin, USA) to carry out measurements aimed at determining the distribution of dark matter in and around individual galaxies. These investigations focus on the nearby so-called "face-on" spiral galaxies whose disc structure is fully visible in a perpendicular top view. These very easy to see objects will be used to investigate the exact distribution of dark matter within the disc and out into the halo surrounding the galaxy.

The presence of dark matter is felt by its gravitational effect on the dynamic behavior of the approx. one hundred billion stars orbiting the center of the galaxy. Spectroscopy of the light of stars and the study of the Doppler effect can be used to measure the kinematics of a galaxy. However, most galaxies outside the Milky Way are so remote that the stars cannot be seen individually. They instead blur into a diffuse luminous distribution of light.

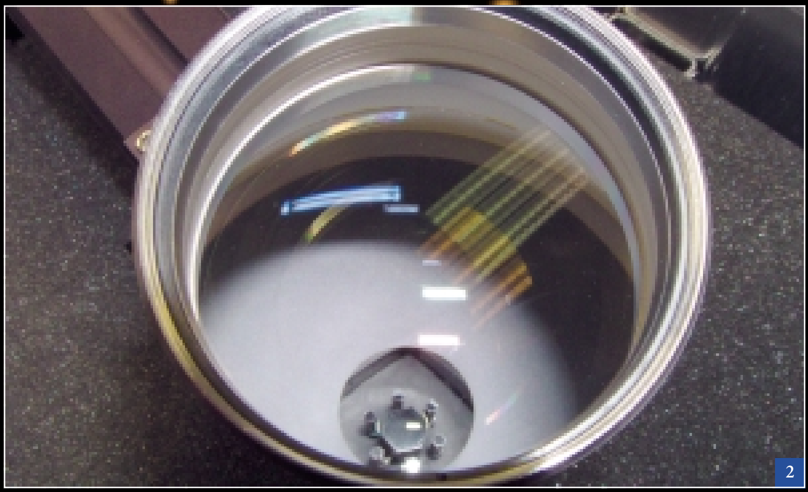


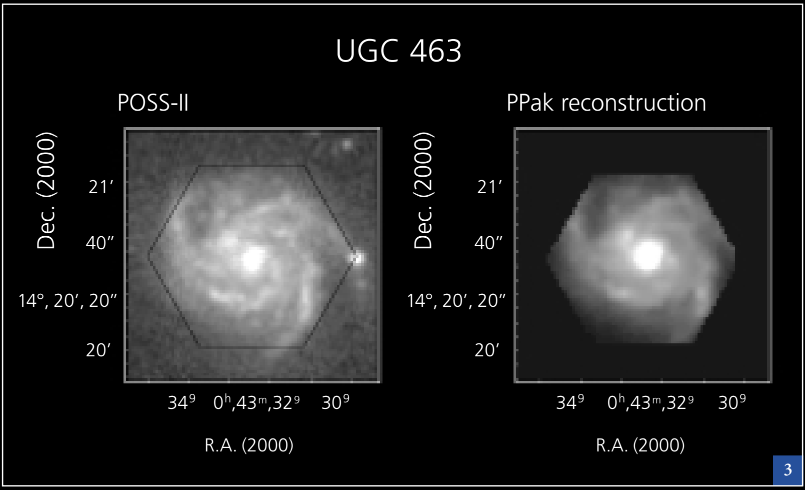
Fig. 1:
PPAK fiber bundle IFU.

Fig. 2:
PPAK fiber bundle with six small auxiliary bundles for measuring the brightness of the celestial background.

Fig. 3:
View of spiral galaxy UGC463 (right) reconstructed from a PPAK recording compared to a direct image taken with the Palomar Schmidt telescope (left). The PPAK-IFU provides the PMAS with the largest field of view of any 3D spectrograph in the world.

Spectroscopy of large plane sources

3D spectroscopy appears to be ideally suited for the spectroscopy of large plane sources. It offers two significant advantages over conventional methods: first, several hundred spectra can be recorded simultaneously in a two-dimensional field of view. Thus, there is no need for time-consuming and costly sequential scanning in the study of large-scale objects, such as the "face-on" galaxies to be investigated. Each image point of the observed two-dimensional field of view yields its own spectrum, i.e. the light of each and every point of the galaxy is analyzed by wavelength. In this fashion, the spectral information is recorded directly as a function of its spatial distribution which is key to measuring dark matter. Second, digital image processing methods allow inclusion of minute luminous sources on the edge of galaxies in the analysis. Previously, not even the world's largest telescopes equipped with the most sensitive instruments were capable of solving this observation problem. The high sensitivity of the PMAS and the application of 3D spectroscopy promised to provide a breakthrough in observation technology addressing this problem.



Innovative upgrade of PMAS

However, the field of view of the instrument was initially optimized for the study of small-scale phenomena and thus was too small to detect entire galaxies in a single exposure. For this reason, the PMAS was enhanced with a technical innovation that enables the instrument to cover the entire field of view required for large disc galaxies. Within a record time of only about half a year, a new integral field unit (IFU) consisting of a new, larger glass fiber bundle and upstream lens optics was developed at AIP: PPAK (PMAS fiber PacK, Fig. 1). This unit started operation in 2004. PPAK consists of 331 densely packed optical glass fibers, each of which observes one image point with a diameter of 2.7 arc seconds in the sky. Six additional glass fiber bundles are used to measure the background radiation of the night sky and 15 more fibers are used for wavelength calibration of the scientific data. In particular, the microscopic arrangement of the 400 fibers in a minute space, i.e. a 5 x 5mm hexagon, presented a major technical challenge to the developers at AIP (Fig. 2). Its field of view of 74 x 65 arc seconds – this corresponds to approx. 0.2 percent of the area covered by the full moon – makes PPAK the largest 3D spectrograph in the world capable of scanning contiguous large-scale objects in the universe.

The first scientific image recorded with the new PPAK-IFU (Fig. 3) shows the UGC463 galaxy (right) with excellent consistency to a direct image recording from the Palomar image atlas (POSS) used as a reference.

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special

Instruments for astronomical observation and calculations

Astrolabe

The astrolabe is an instrument for angle measurement in the sky.

Armillary sphere

An armillary sphere (from Latin armillaris – ring/bracelet) is an astronomical instrument used either to measure coordinates in the sky or to represent the motion of celestial bodies.

Mural quadrant

A historical astronomical instrument used to determine the heights and positions of stars. The mural quadrant consists of a 90° arc with a divided scale, a reading device, a sight and a plumb bob. The star to be determined is sighted, and the position of the plumb bob suspended from the 90° arc indicates the height angle.

Jacob's staff

Jacob's staff (Latin: baculus jacob), or cross staff, is an early astronomical instrument used to measure angles. It was mainly used in nautical travel and is considered to be the functional predecessor of the sextant.

Clepsydra (water clock)

For thousands of years, clepsydras were used as time measuring apparatuses which, unlike sundials, were independent of the time of day and weather conditions.

Sundial

As astronomical instruments, sundials use the sun's position in the sky to approximately indicate the time of day.

Ring sundial

A portable sundial with an accuracy of five minutes.