NASA/JPL-Caltech

SZYMON KOZŁOWSKI
Astronomical Observatory, University of Warsaw
simkoz@astrouw.edu.pl

Dr. Szymon Kozłowski is the winner of the Stefan Pieńkowski Science Award (physics and astronomy) from Division III of the Polish Academy of Sciences (2014) and the Young Scientist Award from the Warsaw University of Technology (2014), and he has been awarded the Outstanding Young Scientist grant from the Ministry of Science and Higher Education (2011). He is a member of the OGLE team, where he searches for quasars and studies their variability. He is interested in extragalactic astrophysics, in particular in gravitational lensing (and microlensing), and transient phenomena such as supernovae.

Far Behind the Magellanic Clouds

Looking for a needle in a haystack? That's a piece of cake in comparison with scouring through thousands of images packed with hundreds of millions of stars, trying to spot a few hundred unique objects which very much resemble stars but are actually quite a different type of object. But let's start from the beginning: why are we searching for quasars by looking at the Magellanic Clouds in the first place?

If there is something humans are good at, it is clearly being curious about the world around us. It is this curiosity that has driven us to make great discoveries and develop our civilization. We could not imagine the world without electricity, modern medicine or the Internet. One of the early pioneers driven by curiosity - although no doubt also by a thirst for fame and riches - was Ferdinand Magellan, the Portuguese sailor, explorer and captain of the first successful voyage around the world. The southern skies which he and his sailors beheld, invisible from Europe and Asia, were almost unknown to European civilization at the time. Magellan's journals describe the Crux (Southern Cross) constellation and two strange cloud-like objects in the sky, which were later named the Magellanic Clouds in his honor. As recently as 90 years ago, astronomers still did not know what these objects were, but like other nebulae they were believed to be a part of our galaxy - the Milky Way.

Clouds or galaxies?

We have since discovered that the majority of nebular objects in the sky are actually other galaxies; just like our very own Milky Way they are separate islands of billions or even hundreds of billions of stars, dust, and gas. Galaxies are usually separated by vast regions of "emptiness," although they can also form enormous superstructures.

The Magellanic Clouds turned out to be some of our nearest neighbor galaxies. As is often the case, they were almost immediately

An artist's impression of a quasar. Hot matter spins around a supermassive black hole, creating a hot disc and slowly falling into the hole

assumed to be satellites of our own galaxy. After all, what could be more natural than two smaller galaxies orbiting a larger and heavier one, just like the Moon orbits the Earth and the Earth orbits the Sun? And yet a few years ago astronomers started to realize that this picture does not fit the facts: increasingly precise measurements of the motion of the Magellanic Clouds revealed that they travel at speeds far too great to be satellites of the Milky Way. So might they go right past us and disappear off into the far reaches of space?

Let's start with the basics: how do we measure the movement of a nearby galaxy in the first place? First we need to measure its position with respect to another stationary point or system of reference. Then we use the information on the changing location over time to calculate the velocity. For the Magellanic Clouds, the most appropriate stationary points of reference are quasars.

Blinking quasars

Quasars are also galaxies, but different from "ordinary" ones in that they are very distant and also extremely luminous - in fact they are the most luminous continuously-glowing objects in the Universe. Their great luminosity is the result of matter giving away its energy when falling onto the supermassive black holes found at their centers. Astronomers believe that most - or even all - galaxies contain supermassive black holes, and, as such, given the right conditions, every galaxy can become a quasar, even if just for a short time (in astronomical terms). Matter falling onto such a supermassive black hole forms a disc, which is the source of light visible from Earth.

The number of known quasars is approaching a million. They are relatively easy to identify in "empty" regions of the sky. They seem to change luminosity at random, appearing as though ten billion stars were being switched on and off over the course of just a few months (equivalent to a single small galaxy being switched on and off). So far, no one understands how this happens or why. In fact, until 2009 astronomers did not even really know how to model such bizarre changes of luminosity, and only studied the phenomenon sporadically. The breakthrough came with the development of stochastic processes, especially the "damped random walk" model. We tested many versions of this model, and found that it can describe changes in quasar luminosity very accurately. I will not describe its details here, but it is important to remember that each light curve describing changing luminosity with time can be represented by two parameters of the model: the timescale and amplitude.

This model turned out to be essential in conducting searches for new quasars. Based on the distribution of quasars and their typical luminosity, astronomers expected to find around a thousand such objects beyond the central regions of the Magellanic Clouds. However, after several decades of efforts, the total number of quasars identified had remained around 80. The main difficulty was the vast number of stars within the Magellanic Clouds themselves - only approx. 30 quasars are expected to be discovered for each million stars. Stars appear as bright points in the sky, and quasars generally look much the same. Of the 80 quasars known before we commenced our research, the majority were discovered on the basis of "strange" changes in luminosity, although these discoveries were often serendipitous.

OGLE

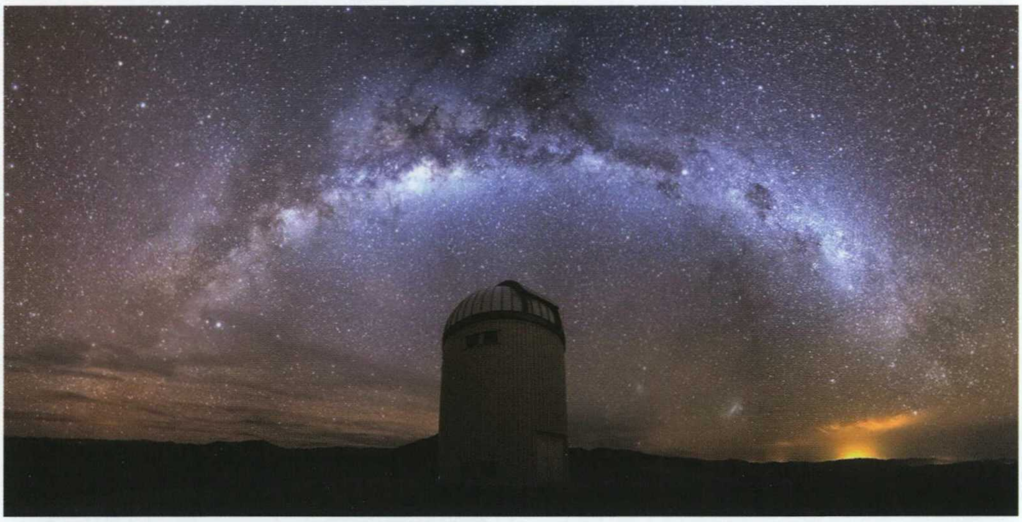
The Magellanic Clouds are one of the main observational targets of the Optical Gravitational Lensing Experiment (OGLE). For the last 18 years, this Polish project has been monitoring the luminosity of approx. 100 million stars in the Magellanic Clouds, including many as-yet unidentified distant quasars. We used the damped random walk model to analyze light curves provided by OGLE for all objects in the vicinity of the Magellanic Clouds which showed any signs of variability. In other words, for each object with varying brightness, we generated two model parameters: the timescale and amplitude. By plotting all such objects on a plane with timescale and amplitude axes, we learned that distinct classes of variable objects tend to clump at different points in the space described by these two parameters. This became a new tool for identifying quasars and other classes of variable objects.

Additionally, we know that accretion discs of matter around supermassive black holes are hotter the closer they are to the center, and cooler at greater distances. At a certain distance, the temperature falls below that of dust sublimation, allowing for the formation of a thick dust torus. It absorbs some of the radiation from the accretion disc, and reemits this energy at longer wavelengths (in infrared). In a sense by a lucky coincidence, the Spitzer Space Telescope, designed to conduct observations of the sky in the infrared, scanned the entire Magellanic Cloud region a decade earlier. It generated huge images in four infrared bands, with wavelengths between 3 and 8 microns. By subtracting these images such that the stellar light cancels out, what remains are objects with a high dust content. They include quasars, as well as young protostars (precursors of new planetary systems), planetary nebulae and stars ejecting dust. This provided us with another tool for identifying quasars in dense stellar regions. The next logical step was to combine the two methods, which allowed us to obtain a sample of four thousand quasar candidates behind the Magellanic Clouds.

758 quasars

By splitting the light emitted by any object into its individual components (known as the spectrum), we can determine what the nature of the object actually is. We needed an instrument, however, able to conduct spectroscopic observations of four thousand quasar candidates, which was quite a tall order. The only telescope in the southern hemisphere capable of achieving this difficult task in a finite amount of time

Dr. Krzysztof Ulaczyk, OGLE project



The Magellanic Clouds (two pale clouds low above the horizon on the right) and the Milky Way above the dome of the Polish OGLE telescope

is the four-meter telescope in Australia, able to measure the spectra of 400 objects simultaneously. We conducted observations of approx. 3000 candidates over eleven observing nights. Analysis of their spectra confirmed the identity of 758 quasars (close to the expected number of 1000) as well as many young protostar systems, dusty stars, and planetary nebulae.

So what happens next? It turns out that this is the largest existing sample of known quasars having such high quality and long-term observations. Our goal now is to find out whether their variability depends on their physical parameters, and if so, how. We also hope to discover why quasars change luminosity at all. We were recently awarded a dedicated OPUS 8 Grant from the Polish National Science Centre to continue our research.

Quasars form a dense, uniform network of stationary reference points in the sky. Watching how the Magellanic Clouds move against this background grid of points will provide information about their past and their future. In 2013, we used the Hubble Space Telescope to conduct the first observations of 30 new quasars behind the Small Magellanic Cloud. They will be repeated towards the end of 2015. The observations should finally answer the question of whether the Magellanic Clouds are in fact satellites of our galaxy, or whether perhaps we happen to live in this lucky time when we are able to admire them up close, before they disappear into the distant cosmos.

The OGLE project underwent a major upgrade in 2010. The Polish telescope in Chile came to be equipped with a gigantic mosaic camera, increasing the area of observations near the Magellanic Clouds twelvefold. The extended observing region should now include several thousand quasars, which must have been observed for the last five years; we just do not know yet which objects they are. Light curves describing their brightness changes will allow us to use the damped random walk model to select the most likely candidates. By another lucky coincidence, another space telescope, the Wide-Field Infrared Survey Explorer, also conducting observations in the infrared part of the spectrum, recently completed observations of the entire sky. Once again, by combining the two methods, we should be able to increase the sample of known quasars near the Magellanic Clouds by another order of magnitude, to reach approx. ten thousand.■

Further reading:

Kozłowski S., Onken C. A., Kochanek C. S. et al. (2013). The Magellanic Quasars Survey. III. Spectroscopic Confirmation of 758 Active Galactic Nuclei behind the Magellanic Clouds. *The Astrophysical Journal, 775*, A92, 1-13.

Kozłowski S., Kochanek C. S., Udalski A. et al. (2010). Quantifying Quasar Variability as Part of a General Approach to Classifying Continuously Varying Sources. *The Astrophysical Journal, 708*, 927-945.

Kozłowski S., Kochanek C.S., Jacyszyn A. M. et al. (2012). The Magellanic Quasars Survey. II. Confirmation of 144 New Active Galactic Nuclei behind the Southern Edge of the Large Magellanic Cloud. *The Astrophysical Journal, 746*, A27, 1-13.