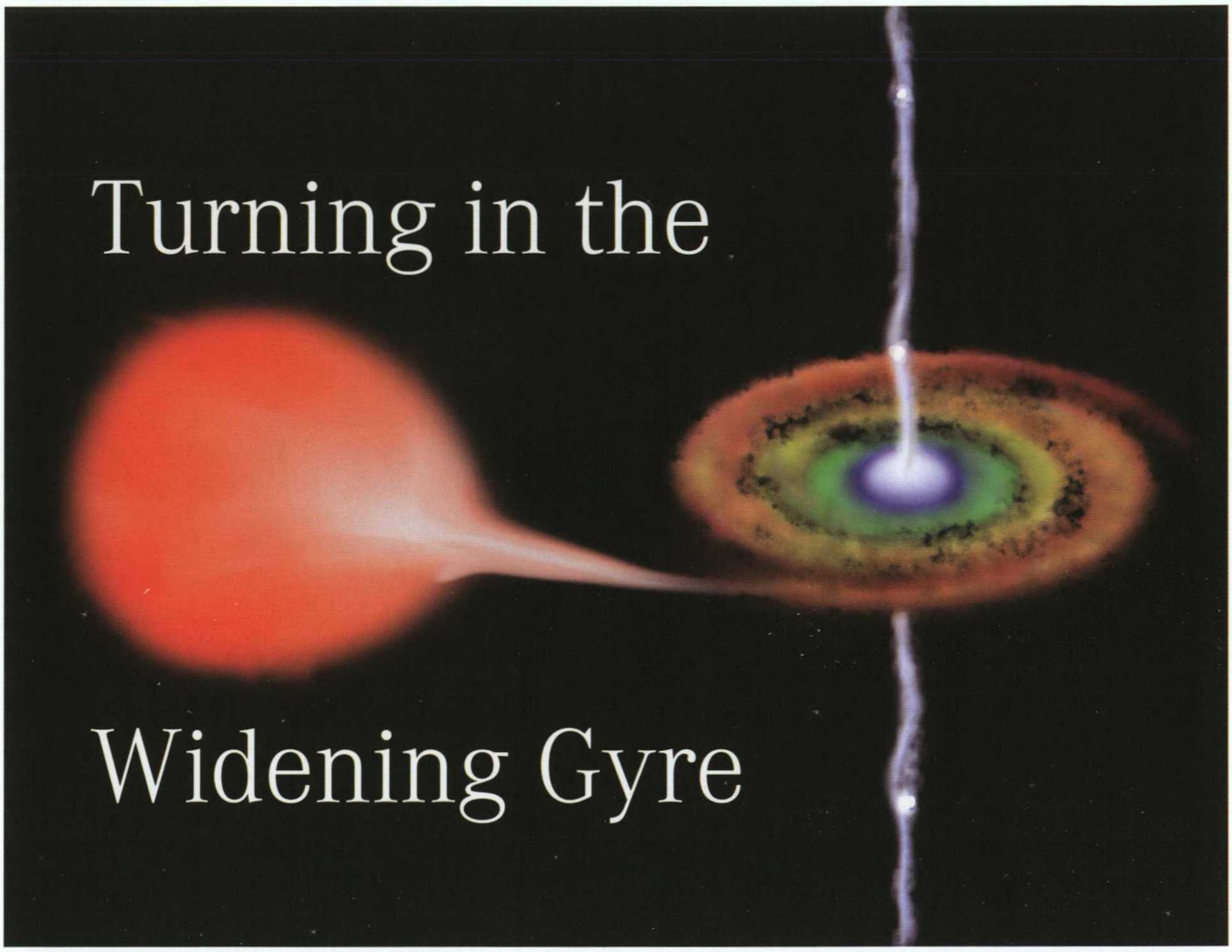
Turning in the Widening Gyre



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Dr. Agata Różańska leads a team modeling radiation emitted by the atmospheres of accretion discs in active galactic nuclei and X-ray binary systems.

Discs: these round, flattened objects have been widely associated with athletics competitions since the Antiquity. Thrown correctly, they spin through the air, and the low friction around them means they can travel a long way. But that's not why discs are important in contemporary astrophysics - here we are interested in the energy they give off

In recent years, we have been witness to major developments in astronomy. We are now able to register high-energy radiation from space, invisible to the naked eye; we are even able to detect the direction and location of its origin. And, since the majority of electromagnetic waves cannot penetrate the atmosphere, we are increasingly relying on satellite telescopes.

For example, X-rays - perhaps best known for their medical applications - are completely absorbed in the upper layers of the atmosphere. The X-ray detector, launched in 1962 on an Aerobe 150 sounding rocket, revealed that X-rays reach us from nearly all directions in the universe. The discovery earned Prof. Riccardo Giacconi the Nobel Prize in physics.

Researchers are still studying the origins of different types of radiation in objects which had previously only been studied in terms of visible

Accretion disc in a binary stellar system. Matter falls onto the black hole from the extensive yet less massive accompanying star

light, observed with small optical ground telescopes. Since research has shifted to satellite telescopes, the seemingly simple sources have largely turned out to be rather complex. For example, we now know that the majority of stars have hot coronae that emit X-rays. Theoretical astrophysicists have yet to determine the origins of these high energy photons.

The history of our understanding of accretion discs follow a similar path to that of hot stellar coronae. The concept of matter rotating around compact objects was first presented in 1973 by Russian theoretical astrophysicists Nikolai I. Shakura and Rashid A. Sunyaev, who explained the vast amounts of energy emitted by quasars (short for "quasi-stellar objects"). In the case of quasars, the central objects are supermassive black holes with a mass comparable to a few hundred millions of our own Sun. However, accretion discs also occur near small black holes (not significantly more massive than our Sun), neutron stars and white dwarfs. The central object of each such source comprises extremely dense matter, and has a correspondingly large gravitational field.

Understanding quasars

The first images of quasars date back to the late 19th century, although many decades had to pass before we began to elucidate their nature. Initially they were thought to be ordinary stars, since their radiation - powerful enough to be recorded by telescopes at the time - resembled that emitted by stars. However, in the 1960s researchers realized that the objects also emit radio waves, which means they cannot be ordinary stars. More detailed studies of quasar spectra show that they are located extremely far away, near the boundaries of our Universe. This means that their radiation must be almost unimaginably bright, since they appear as bright as stars which - in cosmic terms - are practically under our very noses. What physical processes can possibly lead to the emission of such high levels of energy? One thing is clear: it cannot be the same nuclear reactions that are responsible for the glow of stars.

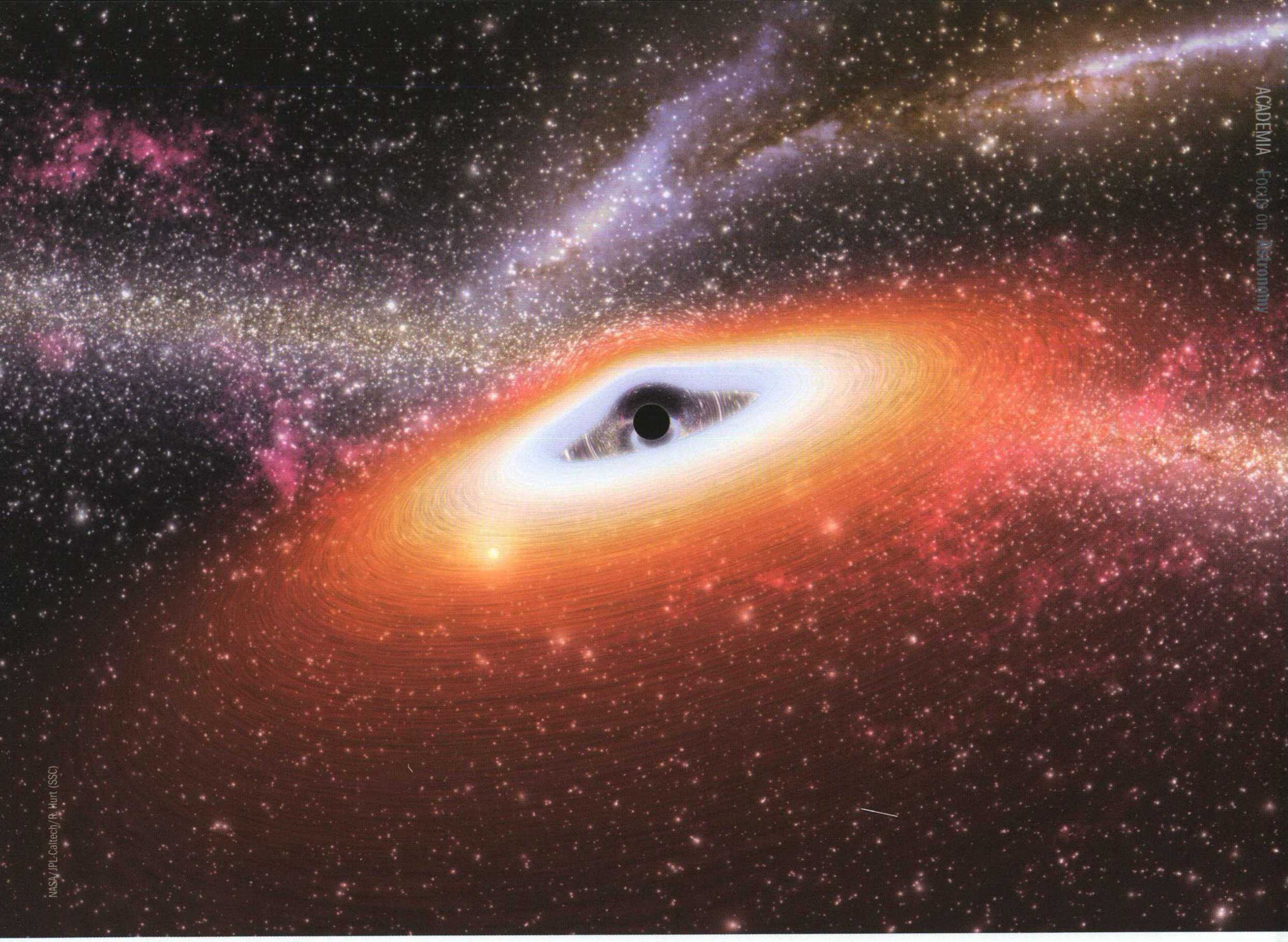
The idea of energy being released through the gravitational fall of matter into supermassive black holes seemed to be the perfect explanation. To begin with, theoreticians assumed that gas falls symmetrically from all directions. However, the mathematical description of the process lacked a few orders of magnitude to correlate the predicted amount of released energy with observational data. It turned out that if the falling matter is also spinning to form a flattened disc, the released energy is significantly greater than if the descent is spherically symmetrical without the rotational element. The amount of energy produced in the accretion disc, calculated by Shakura and Sunyaev, matched the measurements conducted on the brightest quasars.

This was a breakthrough discovery. The flattened disc of gas, which encircles the supermassive black hole and falls into it slowly, is now the natural explanation of the light emitted by active galactic nuclei (a class of objects which includes quasars). We know thousands of such objects throughout the Universe. Luckily for us, the accretion discs in quasars emit radiation in the convenient range of visible light. It is this coincidence that allowed humankind to observe quasars as far back as a century ago, even though scholars at the time lacked any understanding of them.

Similar (although much smaller) discs can also be found around significantly smaller black holes, neutron stars, white dwarfs and other stellar bodies in our own Galaxy. They enable us to observe compact stellar objects, which in and of themselves - without the disc - would be practically invisible.

How do accretion discs work?

In order for gas to start its gravitational fall towards a central object, it needs an initial momentum, however small. This is not difficult under cosmic conditions, with galaxies colliding and stars frequently occurring in binary systems in which matter flows between components to objects with a much greater mass. For the disc to generate energy and the observable radiation associated with it, a process must exist in which momentum is transferred through adjacent gas rings of the disc. Since the gas spins at different speeds depending on its distance from the central object, friction occurs between adjoining layers of the disc. The faster inner layer generates friction against the slower outer layer, transferring some of



An artist's impression of a supermassive black hole at the center of a quasar

its own momentum outward, which in turn pushes it further inwards; this process is known as accretion. For the disc to operate correctly, there must be a mechanism that drives accretion. The Russian scientists were aware of it, although they were unable to fully explain the source of friction in astrophysical discs. They described the mysterious force as an adjustable viscosity parameter, alpha.

Viscous accretion discs near compact stellar objects are clearly far smaller than those found in quasars; smaller, yet more dense. This increased density generates more powerful friction between subsequent rings, and – as a result – it increases the disc's temperature. The extremely hot gas emits waves with higher energies than those of visible light. Small, hot discs in binary star systems emit radiation in the X-ray range, which is why they were only discovered once satellite telescopes were brought into use.

Our team at the PAS Astronomical Centre has been working on creating models of such discs. We calculate how much energy they emit, and study the shapes of their spectra for different masses of central objects. We then compare our results with X-ray data, and we generally find that the fit is good – that is, that our models provide a good representation of reality. However, in spite of numerous ongoing studies, we still do not fully understand the mechanisms driving accretion in discs, leading them to release such high amounts of energy. ■

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Further reading:

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