Clark and colleagues' work identifying VLDLR and ApoER2 as alphavirus receptors also demonstrates that the receptors' function is evolutionarily conserved for the human, mosquito and horse versions of these proteins. Thus, the authors not only provide information on important receptors for SFV and EEEV, but also offer a possible explanation for how these alphaviruses infect such a wide range of hosts.

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Astronomy

The glowing dusty heart of a hidden quasar

Robert Antonucci

The torus of dust surrounding a quasar — a very luminous supermassive black hole that accretes matter from its surroundings — has now been captured with high-resolution infrared imaging. **See p.403**

An active galactic nucleus is a relatively tiny region at the centre of some galaxies that has abnormally high luminosity. Quasars are the most powerful active galactic nuclei. On page 403, Gámez Rosas *et al.*[1] report very sharp and sensitive imaging of a nearby active galactic nucleus, showing a glowing doughnut-shaped object surrounding the central black hole.

Such 'dusty tori' are generic to supermassive black holes that are accreting matter at rates high enough to produce conspicuous amounts of light (Fig. 1). They are essential to the widely accepted unified model for active galactic nuclei, which itself derives from optical polarimetry measurements. The dust in the torus must re-radiate the optical-light energy it absorbs from the quasar in the infrared, and this infrared emission is well studied spectrally. But the obscuring torus is very compact and it has never been imaged satisfactorily. Now, Gámez Rosas and colleagues have taken the first crude picture of the torus glow.

The story of the unified model began around 1980 when I was in graduate school at the University of California, Santa Cruz. I was keen to work on active galactic nuclei, but my adviser Joe Miller described the field as mere 'stamp collecting' because of the wide variety of inexplicable behaviours seen among this seemingly highly heterogeneous group.

These behaviours include central luminosities up to thousands of times that of entire galaxies from regions no larger than the Solar System; apparent faster-than-light motion in radio images; and pairs of synchrotron-radiation-emitting clouds that span hundreds of thousands of parsecs (1 parsec is 3.26 light years) and can contain 10^{54} joules of energy or even more. We know today that these beacons lie at the centres of galaxies, and they are all ultimately powered by the gravitational potential energy of matter falling towards supermassive black holes with masses millions to billions of times that of the Sun.

Most of the optical–ultraviolet spectra for active galactic nuclei fall into two classes. In the spectra for type 1 objects, one sees a powerful variable continuum, which most people assume is thermal radiation from hot accreting gas, although there is no successful predictive model for the actual accretion and radiation process[2]. The inner region of quasars also hosts a site comprising many dense, rapidly moving gas clouds, known as the broad emission line region. This continuum and these fast-moving clouds are signatures of the black hole. Well outside these features lies the narrow-line region, consisting of rarefied ionized gas, on scales of 10 to 1,000 parsecs. For type 2 objects, only the narrow-line region is seen.

Miller had built a unique instrument that sorted photons according to their polarization as well as their wavelength, in the hope that clues resided in that neglected aspect of quasar radiation. This really paid off: we used the instrument to isolate traces of light polarized by scattering near the heart of active galactic nuclei. We discovered that there is an extremely convenient natural periscopic mirror in many of the type 2 objects. This mirror allowed us to view a nucleus from a direction roughly perpendicular to our actual line of sight from Earth.

The polarized light spectra for the type 2 objects showed exactly the black-hole-related components seen previously only in the type 1 objects. Thus, we knew for certain that the type 2 objects possess the components relating to black holes, and that those components would be seen directly only along the axis of the active galactic nucleus. Our inference was that the other equatorial directions must be blocked by a torus. In fact, if astronomers are distributed randomly in the Universe, around half of them must classify our type 2 objects as type 1! As for the narrow region, it's too large to be obscured by the torus, and, in retrospect, this had hinted at black-hole activity in the nuclei even in the type 2 objects.

Many observations, especially those of radio-emitting jets of plasma, indicate that active galactic nuclei are approximately axisymmetric objects, and reveal their axes as projected on the plane of the sky. Given the polarization angles of the scattered light, we know that when the scattered photons first stream out of the nuclear region, they do so roughly along the jet direction. Apparently, those emitted near the equatorial plane are blocked: there must be some opaque structure that acts like an equatorial torus in its shadowing properties. We often refer to it as the active galactic nucleus torus, but this is shorthand for the shadowing geometry and doesn't provide any detail about the actual structure beyond its shadowing properties.

Emitted photons would spray out of this nuclear configuration in a broad bicone, which should be seen in polarization images, and also in the lines corresponding to highly excited gas in the narrow-line region. Although a range of morphologies has been seen, the overall picture has been amply verified by many astronomers[3–5].

All this work was the opposite of clever. The key inferences are deductive and thus very robust. It's also very natural for an accreting object to accumulate material in a plane set by its net angular momentum[6]. But this rotating equatorial matter is more than a passive structure casting a shadow: excellent early theory papers showed that cloud–cloud collisions

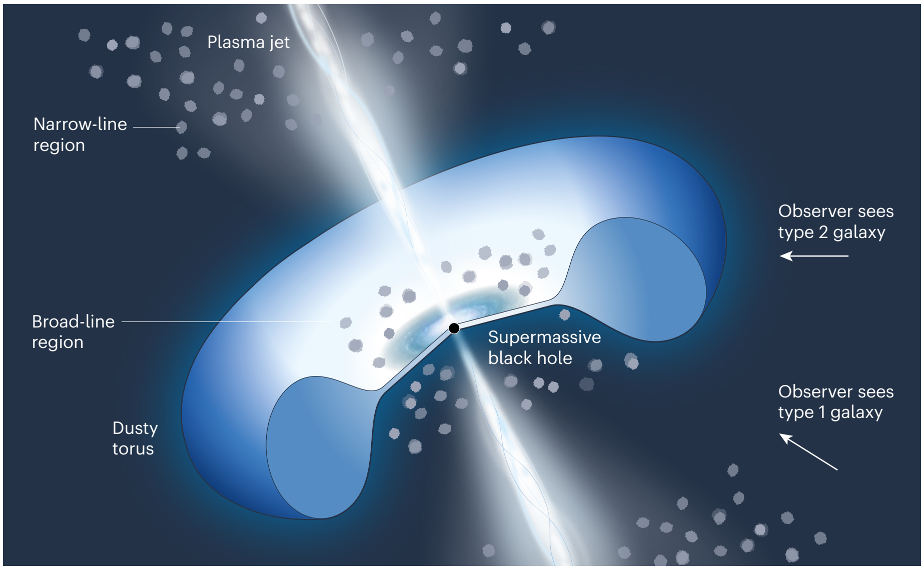

Figure 1 | Imaging the dust around an active galactic nucleus. Active galactic nuclei are the luminous centres of some galaxies, and are thought to be powered by supermassive black holes. The light emitted by such nuclei has key spectral features, including a broad-line region and a narrow-line region. Nuclei with spectra that show both regions are known as type 1 objects, whereas those that show only the narrow-line region are known as type 2 objects. The unified model suggests that this distinction arises because the line of sight to type 2 objects is obscured by a dusty torus of matter that feeds the black hole. This model is supported by observations of plasma jets emanating from the nuclei. Gámez Rosas *et al.*[1] imaged the dusty torus around an active galactic nucleus with very high sensitivity.

must lead to copious accretion onto the black hole, so the mass flow through the torus could power the whole magnificent edifice[7,8]. Better understanding requires imaging the torus.

Gámez Rosas and colleagues' data come from a powerful instrument called MATISSE, which combines data from the four units of the European Southern Observatory's Very Large Telescope Interferometer in Chile with sufficient angular resolution and sensitivity to identify the torus of an active galactic nucleus. The work also required great judgement, technical skill and astrophysical knowledge, because the dust is distributed in a complicated, weather-like way and it absorbs as well as emits.

In fact, similar data at slightly shorter wavelengths were previously presented by another group, who failed to identify the nuclear infrared source[9]. I disagreed strongly with their interpretation of their data, and the present authors rule it out. They do this in two principle ways, but we need to know a bit of physics first to understand how. As torus material works its way towards the black hole, it inevitably gets so hot that the dust evaporates, and the distance at which that occurs, the sublimation radius, is the inner edge of the dusty torus.

The present authors' dataset includes spectral channels that specifically measure foreground absorption towards each location on the image. This breaks a degeneracy (ambiguity) between temperature and obscuration, showing that the hottest innermost dust is far from the location proposed previously[9].

Gámez Rosas *et al.* decisively confirmed the location of the black hole on the infrared images in an independent and robust manner. Their new maps obtained using radio interferometry can persuasively be aligned with the maps of infrared emission obtained previously[9]. In my opinion, this does confirm that the positional registration adopted by the first group is incorrect. With the correct registration, Gámez Rosas *et al.* found a compact infrared source at the black-hole position, which, generally speaking, answers the requirements for the active galactic nucleus torus. This is great work!

There is, however, a little unfinished business. The unified model was derived from the shadowing properties inferred from polarization, and their relation to the radio jet. Both of these observations indicate a torus extended very close to the east–west direction[10]. The structure Gámez Rosas and colleagues identified as the torus is tilted by 30° to where it must be to produce the scattered light. But it is also not straight. I predict that, with improved resolution, imaging will reveal that the torus is oriented east–west on the smallest scales.

Furthermore, the resolution of the authors' data is still at least several times too poor to resolve the crucial region where the dust grains sublimate. There are both observational and theoretical reasons to think that the torus swells and controls the shadowing at this very location[11].

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Metrology

Atomic clouds stabilized to measure dilation of time

Ksenia Khabarova

Tests of relativity once required accurate clocks separated by thousands of kilometres. Optical techniques have now made such tests possible in an atomic cluster measuring no more than one millimetre in size. **See p.420 & p.425**

As Albert Einstein predicted in his theory of general relativity, the gravitational field of a massive object distorts space-time, which causes time to move more slowly as one gets closer to the object. This phenomenon is known as gravitational time dilation, and it is measurable — particularly in the vicinity of a very massive object such as Earth. The measurement requires a sufficiently accurate clock, and, today, the most accurate timekeepers are atomic clocks, which keep time by detecting the transition energy between two

Correction
The original version of this article incorrectly said that one parsec is 3.08 light years.