Astronomy

Distant black-hole pair spotted in galaxy merger

Cristiana Spingola

Observations from five telescopes have revealed a pair of supermassive black holes in coalescing galaxies, farther from Earth than any such pair detected previously. This feat offers key insight into how galaxies form. **See p.45**

When the Universe was roughly two billion to three billion years old, its galaxies underwent intense growth and formed stars at high rates during a period known as cosmic noon. Galaxy formation is thought to be hierarchical, with low-mass structures assembling first, before merging to form more-massive objects. And because nearly all galaxies host a supermassive black hole, an intermediate stage of this merging process should have given rise to galaxies hosting pairs of these black holes[1]. Such pairs have never been confirmed in the part of the Universe hosting galaxies that formed at cosmic noon – until now. On page 45, Chen *et al.*[2] report such a pair using observations at X-ray, optical, infrared and radio wavelengths in a huge effort involving several major telescopes.

Most supermassive black holes are quiescent, which means that they emit no radiation and so can be observed only indirectly (for instance, by studying the orbits of stars around the black hole)[3]. But galaxy mergers lead to inflows of gas that can feed a supermassive black hole and turn it into an object known as an active galactic nucleus (AGN). AGNs are the brightest sources of radiation in the Universe, and currently offer the only way of finding pairs of supermassive black holes located far from Earth, such as those at cosmic noon. It is precisely this type of supermassive black hole that Chen *et al.* found – specifically, an AGN pair known as SDSS J0749+2255, which is the most distant pair from Earth observed so far. The authors' analysis suggests that these AGNs are hosted by two galaxies that interacted during cosmic noon.

Radiation from AGNs covers the entire electromagnetic spectrum because the components of these objects emit light at various frequencies (Fig. 1). The central supermassive black hole of an AGN is powered by a disk of matter that spirals into the black hole, emitting light at ultraviolet and X-ray frequencies. Clouds of gas around this disk emit radiation that shows up as broad lines on the optical spectrum, but can be obscured by a torus of dust that radiates on infrared wavelengths, depending on the line of sight. Gas clouds lying outside the torus are ionized by strong radiation from the central black hole to produce emission that can be detected as narrow lines on the optical spectrum. And particles that avoid being accreted can form two jets that move away from the black hole at speeds close to that of light, emitting radiation at radio wavelengths[4].

Chen *et al.* observed all these features in radiation from SDSS J0749+2255 – and they observed them twice. Their observations were made across the spectrum using the Hubble Space Telescope and the Chandra X-ray Observatory, as well as Earth-based telescopes in the United States. From the broad lines detected at optical frequencies, the authors estimated that the two black holes have similar masses, which are around 300 billion times the mass of our Sun. But their observations at X-ray frequencies indicate that the black holes have very different properties. The authors interpret these differences as evidence that one of the black holes is experiencing a high accretion event, probably induced by the merger.

Dual AGN systems are ideal 'laboratories' for testing models of the evolution of supermassive black holes[5] and for understanding the role of mergers in converting these black holes into AGNs[6]. In particular, AGNs that are very close to each other are fascinating systems because they are bound gravitationally. This means that they are precursors of coalescing supermassive black holes. Observations of these pairs can therefore be used to refine models of the time it takes these objects to spiral towards each other before they coalesce.

So far, there has been only a handful of observations of AGNs that are as close to each other as are those in SDSS J0749+2255 – and these have all been located relatively close to Earth[7]. This is mainly because such observations require high-resolution telescopes to distinguish between the two supermassive black holes. Although Chen and colleagues' observation is only one confirmation of a dual AGN at cosmic noon, the discovery fills a crucial gap: at similar distances from Earth, the dual-AGN candidates consist of supermassive black holes that are much farther from each

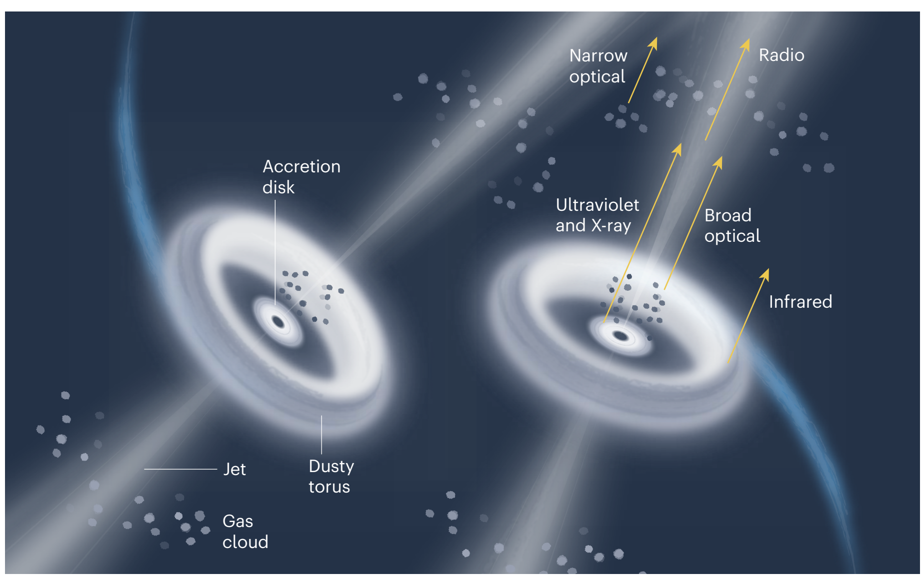

Figure 1 | A pair of active supermassive black holes in a galaxy merger. When galaxies merge, the supermassive black hole at each galaxy centre can be fed by an accretion disk that can convert it into an object known as active galactic nucleus (AGN). The disk radiates at ultraviolet and X-ray frequencies; gas clouds around the disk produce broad lines on the optical spectrum; and a dusty torus around the clouds radiates at infrared frequencies. Other gas clouds outside the torus produce narrow lines on the optical spectrum, and particles that are not accreted form collimated jets that emit radiation at radio frequencies. Chen *et al.*[2] observed all these features – twice – in radiation from a distant galaxy merger, marking the detection of an AGN pair called SDSS J0749+2255, which is the farthest from Earth observed so far. The black holes illustrated here are spiralling towards each other and will eventually coalesce.

other than are those in SDSS J0749+2255. Confirming that such close pairs existed at cosmic noon is particularly useful for understanding how long the final stages of merging and coalescence took during this period. For SDSS J0749+2255, the authors estimated this duration to be hundreds of millions of years.

Detailed multi-instrument studies such as that of Chen and colleagues are particularly welcome in the current era of 'multi-messenger' astrophysics, in which discoveries are made using observations from several sources. One such source will come from the gravitational waves that supermassive black holes produce when they finally merge, and that will be detectable with the Laser Interferometer Space Antenna[8] and Pulsar Timing Arrays[9,10] that are under construction. It is crucial that the black holes that generate these waves are characterized at all evolutionary stages so that the detections can be interpreted properly. Similarly, the rate at which these waves are generated, which will also soon be measurable, will directly test current astrophysical models, potentially revolutionizing what is known about the formation and evolution of supermassive black holes.

Forthcoming surveys with the Vera C. Rubin Observatory in Chile and the Square Kilometre Array in Australia and South Africa will offer a better depth and sky coverage than is possible with current telescopes. These surveys will allow the detection of supermassive black holes with a range of masses that are at various phases of galaxy merger, and at all cosmological distances. However, as long as these systems are observed only in a single survey (covering a limited band of frequencies), they will remain candidate dual AGNs, rather than confirmed pairs. Chen *et al.* have defined a clear method for confirming these candidates. And although the authors' approach is observationally expensive, it shows that sharp multi-wavelength observations are indispensable for understanding galaxy formation.

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Forum: Climate change

The medieval Moon unveils volcanic secrets

Innovative use of medieval musings about the Moon has revealed that volcanic eruptions coincided with abrupt, global-scale cooling events. The approach is exciting from the perspective of climate scientists and historians alike. **See p.90**

The paper in brief

- **Volcanic eruptions inject large volumes of sulfur dioxide into the atmosphere that are converted into aerosols in the stratosphere[1].**
- **These aerosols produce volcanic dust that can reduce incoming solar radiation, altering Earth's surface temperatures, precipitation and atmospheric circulation[2].**
- **Identifying past volcanic eruptions can therefore help to clarify the timing and nature of climate events, but current methods produce conflicting results.**
- **On page 90, Guillet *et al.*[3] report an approach that interprets medieval accounts of lunar eclipses to date volcanic eruptions that could have shaped a key climatic transition.**

Andrea Seim & Eduardo Zorita
A fresh take on an old challenge

Climate scientists usually identify past volcanic eruptions by measuring the acidity and amount of volcanic ash in cores drilled from polar ice, or by inferring abrupt temperature changes in tree-ring records. However, these sources sometimes disagree, because the location, intensity and timing of eruptions can produce varying results, as can circulation of the atmosphere. Guillet and colleagues' approach offers an independent — and perhaps even more direct — source of information about the timing of volcanic eruptions, which could resolve some of these disagreements.

> **"Dark lunar eclipses were observable for 3–20 months after an eruption."**

During a total lunar eclipse, the Moon is fully in Earth's shadow. A dark Moon indicates that volcanic aerosols are highly abundant in the stratosphere, whereas a reddish Moon suggests that they are scarce (Fig. 1). Guillet *et al.* examined historical accounts of lunar eclipses from the High Medieval Period (1100–1300), and estimated the abundance of volcanic aerosols from the descriptions of the colour and luminosity of the Moon. They used this information to refine the timing of a cluster of volcanic eruptions that occurred during this period, and which had previously been identified using ice-core measurements[4]. The authors found that seven of these eruptions generated aerosols that could have had a role in the transition from the Medieval Climate Anomaly (around 850–1250) to the Little Ice Age (around 1300–1850).

The strength of Guillet and co-workers' study lies in the precision with which the authors estimated the timing of volcanic eruptions — pinpointing the year, and even in some cases the month, of the event. The authors compared their findings with modern global aerosol measurements, climate model simulations and satellite observations to link five dark and two reddish lunar eclipses to major eruptions during the High Medieval Period. They found that the dark lunar eclipses were observable for 3–20 months after an eruption.

They then examined tree-ring records sensitive to summer temperatures in the Northern Hemisphere, in which an unusually cold summer is indicated by reduced wood formation. By combining these records with climate simulations, the authors further refined the timing of five eruptions and showed that they had a pronounced impact on the climate. The remaining eruptions