Astronomy

Bright black holes and neutron stars beat alike

Emrah Kalemci & Sara Elisa Motta

Multi-wavelength observations of radiation from a bright neutron-star system show signatures similar to that of a black-hole binary, suggesting that the accretion mechanism is the same for all such sources at high luminosities. **See p.45**

X-ray binaries are systems comprising a normal star and a collapsed star — a neutron star or a black hole. Matter falling from the normal star to the collapsed star becomes so hot that it emits copious X-rays. When the luminosity of these X-rays is high, the instabilities that occur can help us to understand the extreme conditions found in the vicinity of collapsed stars. One such high-luminosity source is the black hole GRS 1915+105, which shows curious variations in signals at X-ray and radio frequencies[1]. Similar behaviours have been identified in other black holes[2], but it has not been clear whether they exist in neutron stars as well. On page 45, Vincentelli *et al.*[3] report variability patterns in the neutron-star system Swift J1858.6−0814 that have so far been considered unique to GRS 1915+105.

The pattern of X-rays emanating from GRS 1915+105 strongly resembles a recording of a heart's electrical activity — it exhibits a characteristic called the β-type variability or, more commonly, the 'heartbeat'. The signal varies, and this variability is a direct result of the black hole accreting matter at a rate that fluctuates. This causes rapid depletion and replenishment of the inner accretion disk, which is a few tens to hundreds of kilometres from the black hole. These repeated variations lead to the marked changes in X-ray emission, and can be described by a dynamical instability known as a limit cycle.

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In simple terms, a limit cycle describes a defined set of behaviours through which a dynamical system cycles, without sampling any other possibilities. In the case of GRS 1915+105, the limit cycle can be thought of in terms of changes in the radius of the inner disk, which varies between a minimum and a maximum as the disk becomes depleted and refills. These changes occur as a result of the interplay between gravity and the radiation pressure that develops in the accretion flow. This pressure inflates the inner disk, thereby emptying its centre, and then gravity draws material from the outer edge of the disk to refill the inner region.

During the depletion phase of the cycle, material is expelled from the system in the form of a jet of particles moving at relativistic speeds (close to the speed of light) and can be observed at infrared and radio frequencies. As the disk refills, this jet rapidly loses energy, until it can form again once the disk is fully replenished. The only way to study this limit cycle properly is to observe high-luminosity sources simultaneously at X-ray, infrared and radio frequencies.

Vincentelli *et al.* undertook an ambitious campaign to obtain such multi-wavelength observations of the neutron star X-ray binary Swift J1858.6−0814. Discovered in October 2018 (ref. 4), this system was an excellent choice for the study, being very bright[5] (at 40% of the maximum possible luminosity) and showing highly variable emission. Indeed, previous studies reported emission characterized by flashes of light from the neutron star's surface[6], variability patterns that resemble those of GRS 915+105, and outflows

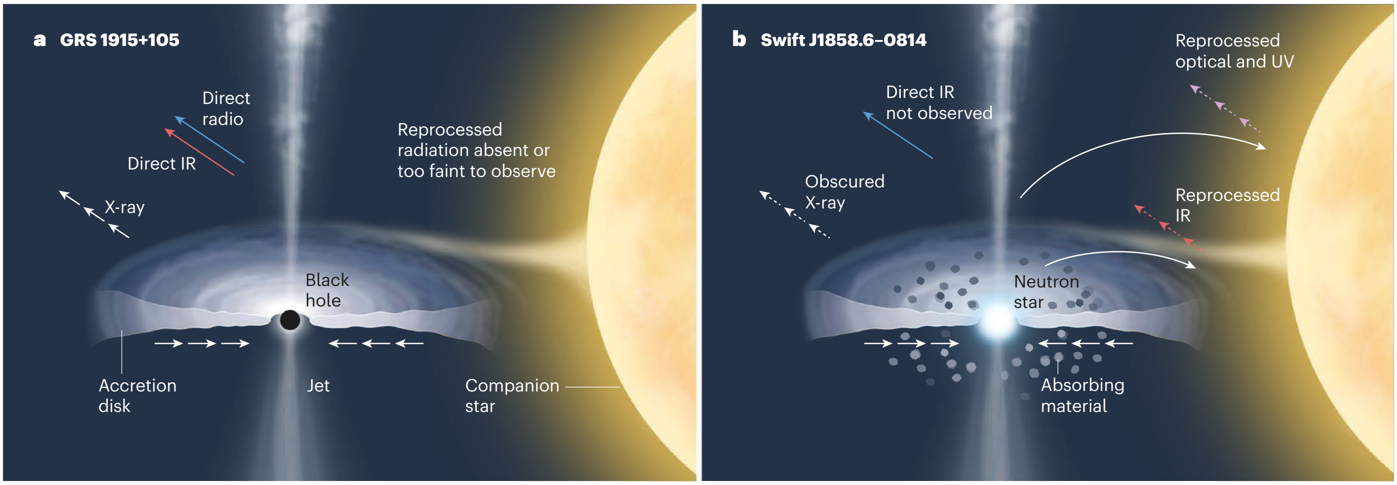

Figure 1 | A shared accretion mechanism for black holes and neutron stars. a, The black-hole binary system GRS 1915+105 emits X-rays that show a heartbeat-like signal because matter is accreted by the black hole at a fluctuating rate, resulting in rapid depletion and replenishment of the inner accretion disk, and therefore a 'beating' emission. Particle jets that form when the disk is depleted are observed as infrared- (IR-) and radio-frequency emission without beats. **b**, Vincentelli *et al.*[3] observed multi-wavelength radiation from the neutron-star binary system Swift J1858.6−0814 and recorded beating at X-ray, infrared, optical and ultraviolet (UV) frequencies. The authors' model holds that X-rays from the inner disk are intercepted by the outer disk and the companion star, then later re-emitted as infrared radiation. Radiation from the jets is re-emitted as beating signals at optical and ultraviolet frequencies. Such beating emission is not observed at these frequencies for GRS 1915+105 because of the system's geometry and inclination, and because it does not contain the absorbing material present in Swift J1858.6−0814. The black-hole system has a much larger accretion disk than the neutron-star system. The black hole's companion star is also larger, and the pair orbit each other at a larger distance than do the neutron star and its companion.

in X-ray, optical and ultraviolet frequencies[7] – the X-ray signals suggesting the presence of material near the neutron star[2]. The inner region of accretion flow and its emission were also obscured, indicating the presence of material above and below the disk, and shielding regions of the disk itself from the observer.

The authors observed the system for roughly four hours, using several instruments to access many wavelengths simultaneously. NASA's Nuclear Spectroscopic Telescope Array was used to obtain high-resolution X-ray signals; the Hubble Space Telescope accessed ultraviolet frequencies; the Liverpool Telescope in Spain was used for optical frequencies; the European Southern Observatory's Very Large Telescope in Chile covered the near infrared; and the Karl G. Jansky Very Large Array in New Mexico observed radio-wavelength signals.

One of the key results of the campaign was the discovery of 'beats' in the X-ray, infrared, optical and ultraviolet emission from Swift J1858.6−0814. This characteristic variability pattern was very similar to the β-type variability observed in X-rays from GRS 1915+105. Vincentelli and colleagues' analysis indicates that the infrared emission from Swift J1858.6−0814 lags behind its X-ray emission by 2.5–5.5 seconds. This is consistent with the idea that X-rays from the inner disk are intercepted by both the outer disk and the companion star, then reprocessed and re-emitted as infrared radiation a few seconds later.

The authors propose a model to explain the observed multi-wavelength properties of both sources. The model holds that changes in the size of the accretion disk induce rapid variability in the X-rays from both GRS 1915+105 and Swift J1858.6−0814, but that this variability is less obvious in the neutron-star system because the inner disk is obscured. The jets that form during depletion of the GRS 1915+105 disk can be observed directly as infrared and radio emission, whereas those ejected from the Swift J1858.6−0814 disk are obscured and observed only as 'beating' re-emitted radiation at optical and ultraviolet frequencies.

Such beating emission is not observed for GRS 1915+105 because its accretion disk is larger than that of Swift J1858.6−0814, and it is oriented differently with respect to Earth. There is also absorbing material in the neutron-star system that is not present in the black-hole system (Fig. 1), although the reasons for this are unknown.

Vincentelli *et al.* argue that this physical scenario could be valid for all accreting black holes and neutron stars with high luminosity. Such a conclusion will require further support from other sources, but it's clear that accretion instabilities, jets and the presence of obscuring material are three things to look out for when studying objects accreting with high luminosity. And although the authors' proposal is plausible, computer simulations are still unable to reproduce such instability models in detail. More observations are needed, both to confirm the predictions of the model and – perhaps more importantly – to better constrain parameters of the model.

Vincentelli and colleagues' achievement was made possible by the use of five telescopes, at locations across Earth and in space, observing signals from the same source at different frequencies. Such coordinated campaigns are difficult to arrange, in part because visibility is determined by the position of a source with respect to Earth, and by the local weather conditions at each facility. But they are also complicated by scheduling – a factor determined by when and for how long a given facility can observe the source, and by the multiple peer-reviewer boards tasked with granting their observing time. Confirming that high-luminosity binaries share a common accretion mechanism will therefore be tricky. In the meantime, Swift J1858.6−0814 suggests they might, and such a possibility is certainly intriguing.

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Ecology

Rainfall affects interactions between plant neighbours

Meghna Krishnadas

Neighbouring plants affect the performance both of their own species and that of other species. How these interactions vary with rainfall might explain patterns of plant diversity and predict responses to global environmental change. **See p.100**

Does rainfall change the extent to which plants interact with their own species compared with their interactions with other species? On page 100, Lebrija-Trejos *et al.*[1] investigate this question for seedlings growing in a tropical forest.

Neighbouring plants affect a plant's survival and how well it grows. The nature of these interactions depends on whether the neighbour belongs to the same species (is conspecific) or a different one (heterospecific). The relative effects of conspecific and heterospecific neighbours on plant performance influence plant diversity. Theory suggests that, to maintain species diversity, conspecifics must compete more vigorously with each other than with heterospecifics[2,3]. At the scale of neighbourhood interactions, this manifests as a stronger decline in the performance of individual plants with increased conspecific density compared with the performance with increased heterospecific density[4], a phenomenon called negative conspecific density dependence (NCDD; also known as conspecific negative density dependence).

A key process underlying NCDD involves pests (for example, herbivorous insects and disease-causing microorganisms) that attack plants in a density-dependent manner[5,6]. When plant species are abundant, individuals are more likely to encounter their conspecifics and be exposed to the pests that affect them. Rare species, by comparison, have a better chance of escaping their pests[7]. In this way, pests mediate NCDD to slow population growth as species become more abundant, potentially helping rare species to avoid extinction in the community and so maintaining diversity.

However, these biotic interactions can change depending on other factors – for example, abiotic conditions such as rainfall. Pests can be more prevalent and damaging in wetter conditions[8]. Therefore, at a given site, relative to drier years, wetter years might enhance NCDD, with plant diversity following suit. Rainfall-driven trends in the diversifying effects of biotic interactions might be prominent among seedlings, which are highly vulnerable to pests and can experience rapid shifts in community structure[9].