Question 1:

a)
i.

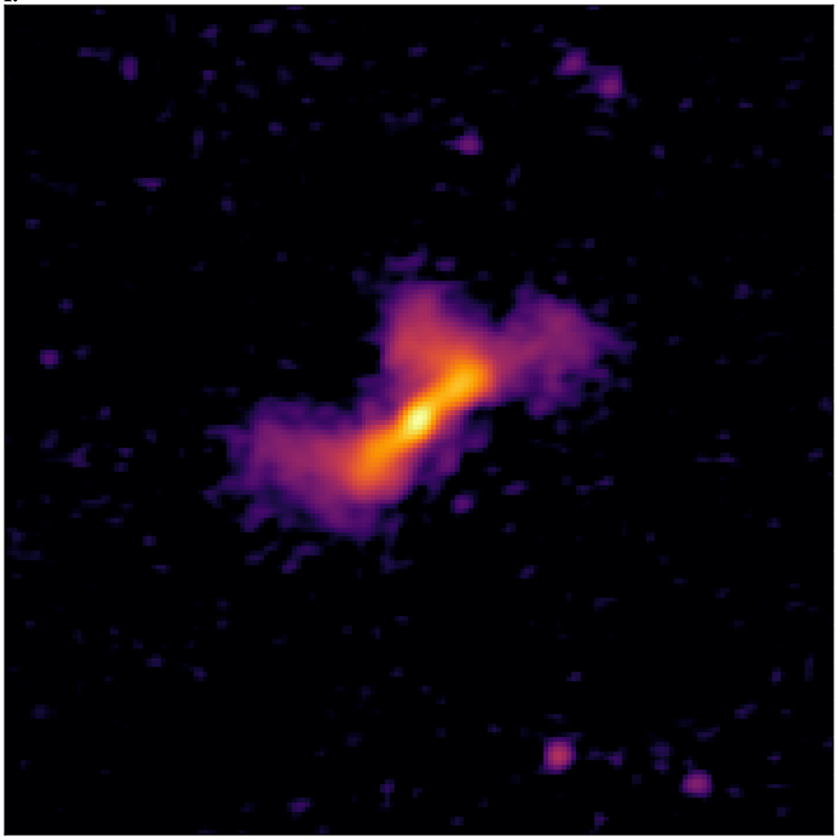

Figure 1: Example of Fanaroff-Riley type I radio source
Bright jets in the centre and fading outwards.

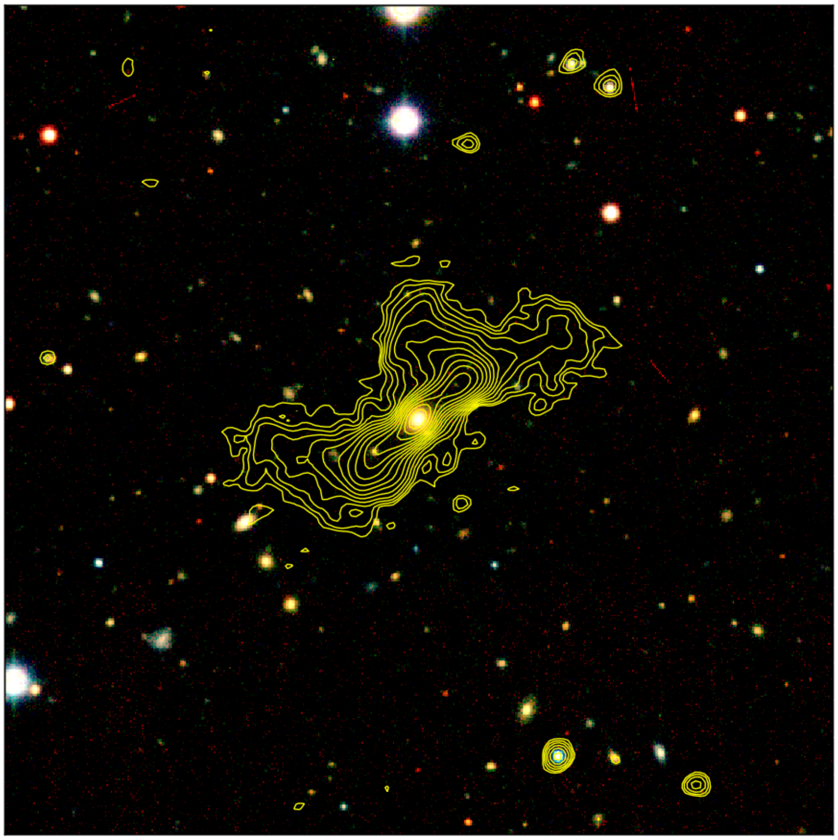

Figure 2: Example of Fanaroff-Riley type I optical source

Big elipse with no real extension.

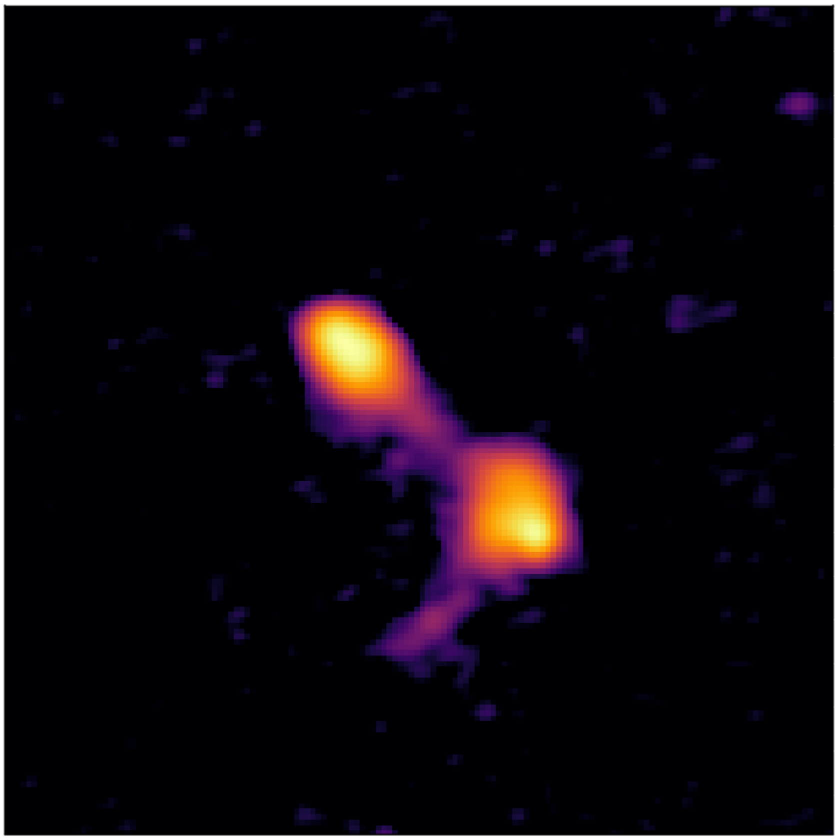

Figure 3: Example of Fanaroff-Riley type II radio source
Bright lobes with a weak core.

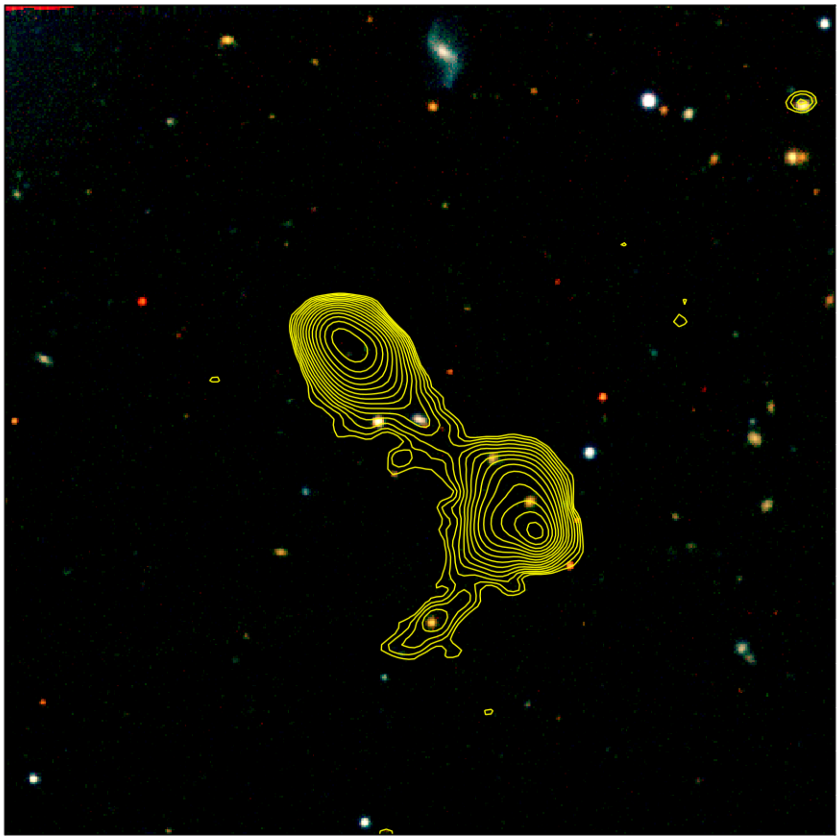

Figure 4: Example of Fanaroff-Riley type II optical source
Distict bright lobes with narrow line radio emissions.

ii.

In an FR I the peak surface-brightness occurs within the inner half of the source, giving an FR ratio < 0.5, whereas in an FR II the hot-spots are at the extremities so the ratio > 0.5. Visual inspection of Figs 1 3 shows the bright knots are (respectively) near the core and at the lobe edges, so Fig 1 must have FR ratio < 0.5 (type I) and Fig 3 > 0.5 (type II).

b)

i.

$$L = \frac{GM\dot{M}}{R}$$

$$L_{Edd} = \frac{4\pi GMm_p c}{\sigma_T}$$

hence

$$\frac{GM\dot{M}}{R} = \frac{4\pi GMm_p c}{\sigma_T}$$

$$\frac{GM\dot{M}}{4\pi GMm_p c} = \frac{R}{\sigma_T}$$

$$\frac{\dot{M}}{4\pi m_p c} = \frac{R}{\sigma_T}$$

$$\dot{M}_{\text{Edd}} = \left(\frac{4\pi m_p c}{\sigma_T}\right) R$$

As π, m_p, c, σ_T are all constants this shows that maximum accretion rate depends only on the radius of the accreting object

And as

$$R = \frac{2GM}{c^2}$$

$$\frac{2GM}{c^2} \implies \dot{M}_{\text{Edd}} = \left(\frac{8\pi Gm_p}{\sigma_T c}\right) M$$

and thus the the maximum accretion rate of a black hole depends only on its mass

ii.

$$\dot{M}_{\text{Edd}} = \left(\frac{8\pi G m_p}{\sigma_T c}\right) M$$

$$= \frac{8\pi\,(6.67\times10^{-11}\,\mathrm{N\cdot m^2/kg^2})(1.67\times10^{-27}\,\mathrm{kg})(1\times10^{9}\,\mathrm{M_\odot})}{(6.652\times10^{-29}\,\mathrm{m^2})(3.00\times10^{8}\,\mathrm{m\,s^{-1}})}$$

$$\approx 2.8\times10^{23}\,\mathrm{kg\,s^{-1}}$$

Divide by seconds in a year, and multiply by solar mass to give

$$\approx 4.4\,\mathrm{M_\odot}/\mathit{yr}$$

Question 2:

Slide 1: In May 2023, the LIGO-Virgo-KAGRA collaboration detected a gravitational-wave signal, GW230529, during the early part of its fourth observing run. The event was picked up by the LIGO Livingston detector while the other observatories were offline or not sensitive enough. This signal came from a binary merger involving a compact object with a mass between 2.5 and 4.5 times that of our Sun, and a neutron star between 1.2 and 2.0 solar masses. What makes GW230529 especially intriguing is that the more massive object sits in the so-called 'lower mass gap'—a previously underpopulated range between the heaviest known neutron stars and the lightest known black holes. This detection adds compelling new evidence to the growing case that nature might be more adventurous in populating this gap than previously believed.

Slide 2: GW230529 was detected on 29 May 2023 at 18:15 UTC by the LIGO Livingston detector. It was a strong signal, standing out from background noise and independently confirmed by three search pipelines using matched-filtering techniques. These pipelines compare real-time data to theoretical templates, and in this case, all three flagged GW230529 as highly significant. The signal's strength was such that even though only one detector was operational, the false alarm rate was estimated at less than one in a thousand years—making it an extraordinarily reliable detection. The waveform of the signal suggests a merger between two compact objects: one significantly heavier than the other, with the heavier component likely lying in the mass gap region between neutron stars and black holes. This event marks one of the most asymmetric mass ratios observed in neutron star–black hole mergers.

Slide 3: he binary system responsible for GW230529 had a primary object with an estimated mass between 2.5 and 4.5 solar masses, and a secondary object between 1.2 and 2.0 solar masses. This puts the heavier component squarely in the "lower mass gap," a region previously thought to be empty. The total mass of the system was around 5.1 solar masses, with a chirp mass, the effective mass of a binary system (black holes or neutron stars able to produce detectable gravitational waves), in the context of the Quadrupole Gravitational Radiation emitted by it.—one of the most precisely measurable properties of a gravitational-wave event—of about 1.94 solar masses. The spin of the primary was measured to be moderate, and the system as a whole showed no signs of precession. Although we can't be 100% sure of the nature of the heavier object, statistical analysis suggests it's more likely to be a low-mass black hole rather than a massive neutron star. Meanwhile, the lighter companion is almost certainly a neutron star, based on its mass and lack of strong spin evidence. The system was located roughly 200 million light-years away, based on its redshift.

Slide 4: Because GW230529 was only detected by a single observatory—LIGO Livingston—localising its position in the sky was challenging. Without input from the other detectors, the sky area where the signal could have originated remained broad. This poor localisation made it difficult for telescopes to follow up with electromagnetic observations. Despite this, several observatories attempted follow-up campaigns, including searches for gamma-ray bursts, neutrinos, and optical transients. No significant electromagnetic counterpart was identified. However, models suggest that tidal disruption of the neutron star—and thus visible emissions—is only likely under specific conditions, such as a high spin and favourable mass ratio. For GW230529, those conditions weren't definitively met, and the amount of matter expected to be left outside the black hole post-merger was likely too small to power a bright visible signal.

Slide 5: GW230529 is a landmark detection for several reasons. First, it adds weight to the growing evidence that the so-called ‘lower mass gap’—the region between the heaviest neutron stars and the lightest black holes—is not as empty as once thought. Previously, neutron stars were found through radio or X-ray emissions, typically under 2.5 solar masses, and black holes were seen in X-ray binaries, mostly above 5. This left a gap that may have simply reflected observational bias. Gravitational-wave detections, like GW230529, don’t rely on light and can reveal compact objects solely through their mass and motion. The discovery of a likely black hole with a mass in the 3–5 solar mass range challenges previous assumptions and could reshape our understanding of stellar collapse and compact object formation. It also nudges models of supernova physics and binary evolution toward accounting for lower-mass black holes and more diverse merger pathways.

Collaboration scientists say roughly 80 more strong candidates are already under study, and they expect the tally of gravitational-wave detections to top 200 by the end of O4.