



A close supermassive black hole binary in Centaurus A?

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Abstract

The Event Horizon Telescope (EHT) project has recently published a high-resolution picture of the Centaurus A galaxy core, where a supermassive black hole (SMBH) is supposed to be located. This picture has been accompanied with interpretation difficulties. In particular, the expected central SMBH and its accretion disk are not detected, the conical forward plasma jet seems hollow and its bended shape is difficult to explain. We argue that this image could in fact reveal the existence of two SMBHs, instead of one. Within this alternative interpretation, the black holes and their disks become visible on the image, the curved jet shapes may more easily be explained and the jets display no dark spine. The putative SMBH binary system shows a projected separation distance of $\sim 0.4\text{--}0.7$ milliparsec. This is 700 times narrower than the NGC 7674 SMBH binary, so far the visually-identified system with the shortest such distance (0.35 pc). The orbital period can be inferred to lie in the 10^1 to 10^{-1} yr magnitude range. The image suggests a double helical jet structure that, if real, would support the lower end of this estimation range. If confirmed by future observations, this close SMBH binary in Centaurus A will be of great interest as a testing ground for SMBH binary dynamics models and plasma jet studies.

Keywords Galaxies: jets · Galaxies: nuclei · Galaxies: quasars/supermassive black holes · Black hole physics · Stars: black holes

1 Introduction

The Event Horizon Telescope (EHT) project has recently published a high-resolution picture of the Centaurus A (Cen A), or NGC 5128, galaxy nucleus (Janssen et al. 2021). The EHT project aims at obtaining detailed 1.3 mm-wavelength-images of nearby supermassive black holes by relying on Earth-wide Very Long Baseline Interferometry (VLBI). They have famously published the first-ever detailed images of the two supermassive black holes with largest apparent sizes, namely the one hosted by the M87 elliptical galaxy (Akiyama et al. 2019) and the one sitting in our own galaxy, Sagittarius A* (Bower 2022). Only one project has attempted VLBI on larger scale, namely RadioAstron, that involved the space-based Russian radiotelescope Spektr-R, at 3, 6 and 18 cm wavelengths, reaching a resolution of 26 micro arcsec with a baseline of 171,000 km when observing the quasar 3C273 (Kovalev et al. 2016).

The EHT observed Cen A on 10 April 2017 for six hours. The resulting imaging was made available in two versions. The first picture displays a (nominal) resolution of 25 micro-arcsec (0.46 milliparsec locally or half a light-day). The second picture had a higher but sub-nominal resolution of ~ 4 micro-arcsec (0.07 milliparsec or 2 light-hrs). Furthermore, the authors estimate that their image reconstruction model offers a positional precision of about 5 micro arcsec for the robust image features.

Cen A is the nearest galaxy where an active galactic nucleus (AGN) has been observed to emit large relativistic plasma jets. The central, jet-generating engine is expected to be a supermassive black hole (SMBH), whose mass was estimated from stellar kinematics at $M = 5.5 \pm 3.0 \cdot 10^7 M_{\odot}$ (Neumayer 2010). The galaxy is located at a distance of 3.8 ± 0.1 Mpc (Harris 2010). Wide-field radio imaging shows that the northeastern approaching and the southwestern receding jets, including the large lobes at both extremities, extend over a total length of 530 kpc.

Plasma jets are observed in many active galaxies, but the jet creation mechanism is not fully understood (see e.g. Kim et al. 2018). In that context, the new EHT pictures of Cen A raised much hope of improving our understanding by giving us unprecedented insight into the jet-forming region – even

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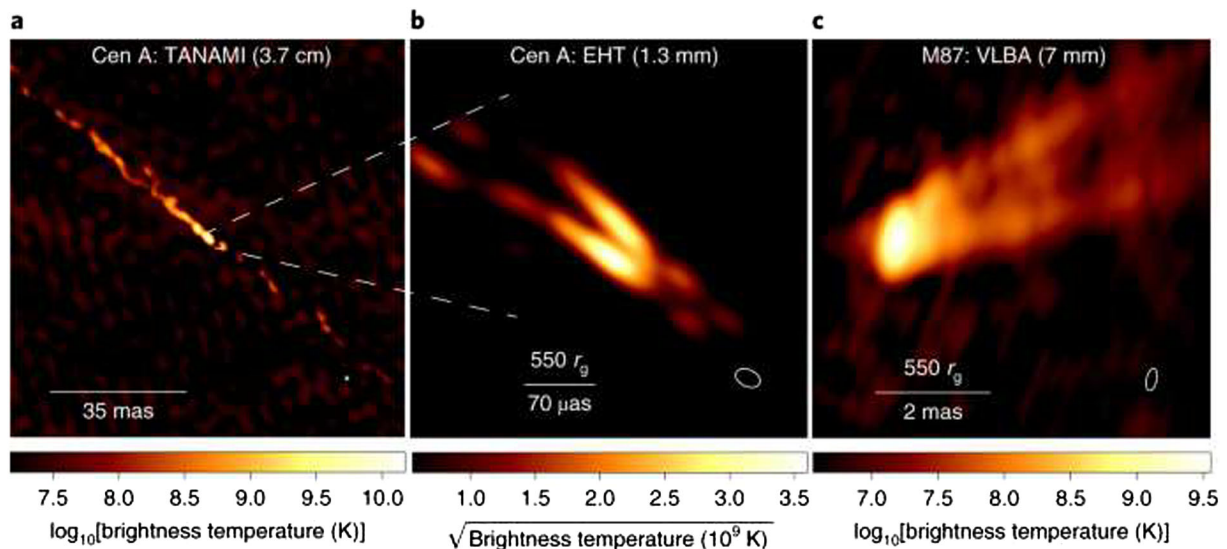


Fig. 1 The nominal resolution EHT picture of Centaurus A (center) reproduced from EHT2021 (their Fig. 1) which is licensed under CC-BY

as their resolutions remained respectively 43 times (nominal picture) and 7 times (over-resolved picture) too unsharp for making out the central SMBH (expected gravitational diameter of $3.3 \pm 1.8 \cdot 10^{11}$ meter, or 18 ± 10 light-minutes).

2 Initial interpretation

The new image has allowed the EHT project team to compute the intrinsic, unprojected opening angle of what they identified as the approaching (single) plasma jet. Moreover, the team noticed that both (approaching and receding) jets displayed much stronger luminosities along their “ridgelines”, the projected edges of their conical envelope, or sheath, than inside the cones, or spines (Fig. 1). Moreover, both ridgelines of the approaching jet seemed to contain, farther away from the expected jet base and expected SMBH & disk, a maximum luminosity spot, whose brightness temperatures were estimated in the $\sim 10^{10}$ K magnitude (Janssen et al. 2021).

Given the high expectations, the new EHT image of Cen A was well received and widely publicized in the secondary literature. However, some perplexity has emerged about the unexpected jet configuration and the surprising invisibility of the central SMBH.

The EHT pictures, in their current interpretation, raise principally five issues, that we discuss below.

2.1 Black hole invisibility

First and foremost problem, the central supermassive black hole (SMBH) and its accretion disk powering the kpc-long relativistic jets have remained invisible at the place where

it is supposed to be (Figs. 1 and 2). The authors have argued that a higher resolution would reveal them (Janssen et al. 2021). This would imply that the accretion disk is much darker than expected, implying a temperature or density much lower than the jets themselves. It is not fully clear how an accretion disk could generate jets of much higher temperature or density than itself. The Sun is known to heat up the corona to temperatures much higher than the photosphere via magnetic field line recombination and ion acceleration (as predicted by Parker 1988 with observational confirmation in Bahaud et al. 2021). Nevertheless, it is more reasonable to assume that the accretion disk should display similar or higher temperatures than the jets that it powers.

In M87, the SMBH disk and nascent jet have been measured to both reach temperatures in the $\sim 10^9$ - 10^{10} K range – both shining brightly on radio imaging (The VERITAS Collaboration et al. 2009; Kim et al. 2016, 2018). If the Cen A SMBH&disk were very dark, this would imply that on the milli-arcsec image (Müller et al. 2014), the luminous spot at the middle of the jet line was in fact some part of the jet itself.

As an alternative explanation for the undetectability of the central SMBH & disk, the authors have argued that an obstacle could lie in the way, along the line of sight, hiding the central SMBH (Janssen et al. 2021). However, gas clouds are usually transparent at the chosen 1.3 mm observation wavelength. An object obstructing the entire accretion disk, assuming the latter has a radius of 5 R_s , should be located, if as large as for example the star Zeta Puppis (radius = 15-25 R_\odot) no farther than 80,000 pc from us. A sun-like star should be no farther than 3,200 pc and a red dwarf like Proxima Centauri within 500 pc from us. All of them should have been detected. A dark, compact object would

need to be even closer to us to be able to hide the Cen A SMBH & disk from our view. A black hole (BH) of $55 M_{\odot}$ would have to lie at 0.74 pc away from us or closer (and be perfectly aligned by chance), i.e. nearer than the nearest star Proxima Centauri. Although not impossible, the existence of such a big compact object in our immediate vicinity seems rather unlikely. An unseen $70 M_{\odot}$ BH has recently been discovered, at 4,600 pc from us (Liu et al. 2019), but that was much farther away. It must be added that, with the right distances and masses, a foreground object might in fact produce the opposite effect, i.e. magnify the background image by microlensing.

Finally, the ionized environment of the SMBH might filter some of the light emitted by the accretion disk by free-free absorption or synchrotron self-absorption. However, this surrounding cloud should be quite dense, given that, in the 1-10 GHz frequency range, such absorption mechanisms are observed to only partially reduce emissions from the central black hole and accretion disk of quasars (see e.g. Tingay and de Kool 2003) and given that free-free absorption decreases for higher frequencies like $\sim 1/\nu^2$, whereas the EHT observation was done at 228 GHz.

Interstellar dust might have produced such a darkening effect, as, in the radio to far-infrared ranges, dust absorption increases with higher frequencies. Dust grains with sizes between 10^{-3} cm and 10 cm are estimated to achieve, at 1.3 mm, absorption coefficients from 0 to $1 \text{ cm}^2 \text{ g}^{-1}$ (Pavlyuchenkov et al. 2019). Numerical simulations by the same authors suggest that optical depths of 1 to 10 may be achieved at 1.3 mm in the central regions of protoplanetary disks surrounding young stars. The high density along the line of sight, just in front of the SMBH, would be associated with a sharp density gradient around the SMBH, since there seems to be very little absorption along the ridgelines, in the EHT picture, at distances of over 10 micro-arcsec (or 80 gravitational radii) from the apex. This would imply a compact and dense isolated protoplanetary disk core, with little external diffuse disk. Its radius should reach (and should not exceed) 50-80 gravitational radii (or 60-90 UA) if located in the Cen A galaxy. While not impossible, such a configuration does not seem very probable.

In short, while it is not strictly impossible for some obstacle to stand precisely along the line of sight by chance, so as to prevent us from observing the single SMBH & disk supposed to be located at the apex of the 4 ridgelines in the EHT picture, the most straightforward explanation for this non-detection remains the absence of any object at this place.

2.2 Jets non connected to their sources

The (northeastern) approaching jet and the (southwestern) receding counterjet ridgelines appear not to connect to the

alleged central SMBH in the image, at the apex of the 4 lines. An empty zone of 1-2 light hours in diameter seems to separate them. It is difficult to imagine a physical process causally linking the central SMBH to the jets, while allowing the temperature to remain much lower at the jet base, although a fast-changing or rotating extreme magnetic field could be a possibility, as mentioned above.

2.3 Broad luminous spots in the middle of the “ridgelines”

The forward jet ridgelines appear to increase in temperature in their edges when getting away from the alleged central black hole. They reach a hottest spot (along their edges) at about 20-30 micro-arcsec distance from the apex. Further away, the jets seem to turn back to decreasing in temperature.

The authors of Janssen et al. (2021) associate these two brightest features, or blobs, with the radio-shifted core of the Cen A SMBH. We argue that there is little chance for this hypothesis to hold.

It is known that, in the case of quasars observed in the 1-10 GHz range, the exact position of the core seems to be shifted along the forward jet, by a distance increasing with lower frequencies like $\sim 1/\nu$. This is believed to be due to synchrotron self-absorption within the plasma jet. Shabala et al. (2012), for example, build on this relation between the apparent AGN core shift and observational frequency to obtain the intrinsic kinetic power of distant AGN jets.

Voitsik et al. (2018) have measured the radio core shift with typically 1 milli arcsec precision, or lower, in the 1.7 to 8.4 GHz frequency range for 24 quasars. Translated for the Cen A galaxy imaged at 228 GHz (distance 500 times shorter and frequency over 60 times higher), this implies that we might expect an apparent core shift of at most 0.03 micro arcsec, which remains several orders of magnitude below both EHT picture resolutions.

Well aware of this $\sim 1/\nu$ dependence of the core radio-shifting effect, the authors of Janssen et al. (2021) finally suggest that those two blobs could be caused by a shock in the jet. As the authors explicitly notice, this second explanation is not very satisfactory either.

Inhomogeneities are definitely a frequent feature of AGN relativistic jets. In particular, higher density zones or “knots” are often observed, resolution permitting. However, in the EHT picture, both blobs turn out to be wider than the rest of the jet edges (ridgelines). Furthermore, it is unusual to observe just one knot along a jet, and even less usual to observe knots that are much brighter than their source. A configuration with a completely obscure central SMBH&disk and high-temperature, very luminous, mid-jet edges, would sound like an oddity.

2.4 Obscure spines within shining sheaths

On both EHT images, the zones corresponding to the “spines”, or interiors of the jet cones, seem empty. They appear totally obscure. A hollow jet structure runs counter to current models and remains unexplained. The authors themselves are at pain of explaining this weirdness (Janssen et al. 2021).

Comparing with the well-resolved forward jet structure of the M87 galaxy may bring some insight. Within the M87 jet, luminosities per unit surface have been precisely measured by Walker et al. (2018) working on the USA-wide VLBA network. The authors have defined several slices transversely to the jet direction, at distances from 0.47 to 7.62 milli arcsec (mas) from the SMBH. They have measured luminosities per surface unit along these slices. In the projected space, 5 mas are equivalent to 0.4 pc or 700 gravitational radii of the central BH. In the unprojected space, along the jet, 5 mas are equivalent to 1.35 pc or 2,400 gravitational radii, assuming the jet points at us with an angle of 17 degree to the line of sight.

The luminosity contrast per unit surface from the darkest place of the interior to the most luminous zones in the edges of the jet cone, summarized across all slices, is found to lay in a ratio of 1 to 3 (Walker et al. 2018). That is, there is a spine to sheath luminosity differential, but the interior is never completely dark.

It may be counter-argued that these latter values were measured in pictures averaged over 23 time intervals, in 2007 and 2008, whereas the EHT picture was taken in a single 6-hour time interval. It may not be excluded that the EHT photographing took place at an exceptional time of very obscure spine for Cen A. Conversely, some more obscure phases could have been averaged out in the VLBA pictures. Also, it is thought that the M87 jet makes an angle of 14 to 18 degree to the line of sight (Walker et al. 2018), whereas Cen A is thought to be oriented at 50-80 degree (Israel 1998). This should make the Cen A forward jet appear optically less luminous than the M87 one. Nevertheless, the spine absolute darkness on the EHT picture tend to suggest much more an empty space than a plasma jet interior.

2.5 Bended conical jets

The approaching conical jet edges seem curved, both on the nominal resolution and on the sub-nominal, over-resolved images. The forward jet extends over 210 micro-arcsec in the EHT picture. This represents (with 0.46 milliparsec / 25 micro arcsec) a projected length of 3.6 mpc, or 4.3 light-days, which implies that the part of the forward jet visible on the picture has been produced during a time window of at most 15-20 days, given an angle of the jets of 50-80 degrees to the line of sight.

Such jet bending may be explained by projection effects or by a precession of the source. Projection-induced bending may be compatible with the observation of fat lobes and rectilinear jets at large scales, as discussed in Horton et al. (2020). However, the bending amplitude observed in the EHT picture, with an angle in excess of 10 degrees over an unprojected distance of maximum 6 mpc, generated by a single source, seems difficult to reconcile kinematically with jets remaining straight over hundreds of kpc, as observed in the wide-field pictures of Cen A.

On the other hand, jet curvature may be produced by a precession of the jet emission axis (most probably aligned with the SMBH spin axis). However, in the case of a single giant black hole, it comes out as a challenge to explain a precession period of a few years at most – like needed to explain a significant directional change taking place in 15-20 days. Indeed, a possible mechanism for generating a single SMBH spin axis precession involves the misalignment of the black hole spin axis with the accretion disk axis. However, this is believed to induce precession periods in the magnitude of Myr. Alternatively, a dense nuclear star cluster may produce a precession in the Gyr range (Krause et al. 2019).

Alternatively, jets might be shaped and curved by interstellar medium (ISM) turbulences or winds. If short-lived, such an effect could be reconciled with the large-scale rectilinearity observed in the Cen A jets.

3 New interpretation

On the other hand, if we conjecture that we are contemplating not one, but two SMBHs in the EHT imaging of Cen A, then these five issues become easier to solve.

In that binary system interpretation, the first black hole, that we shall call SMBH1, is found in the south-eastern sector IV of the EHT image (Fig. 2), inside the lower “ridgeline”, at the point of maximal luminosity. The second black hole, SMBH2, less luminous, is to be found in the north-eastern sector I (Fig. 2), inside the upper “ridgeline”, at the place of maximal luminosity. The 4 “ridgelines” are now interpreted as being the approaching and receding jets emitted by SMBH1 and SMBH2.

This new hypothesis explains away why the expected unique central BH and his accretion disk remain invisible at the apex of the “ridgelines”. Indeed, in that case, there is nothing there at all. Within the new interpretation, we notice that both SMBH1 and SMBH2 and their accretion disks are perfectly visible – like they should, since they are expected to reach extreme temperatures. Their brightness temperatures may be quoted from Janssen et al. (2021). SMBH1 in sector IV is observed to reach $32 (\pm 8) \times 10^9$ K and SMBH2 in sector I reaches $20 (\pm 4) \times 10^9$ K.

Furthermore, there is no need to calculate any photon trajectory to make sense of this image, at this stage, since both

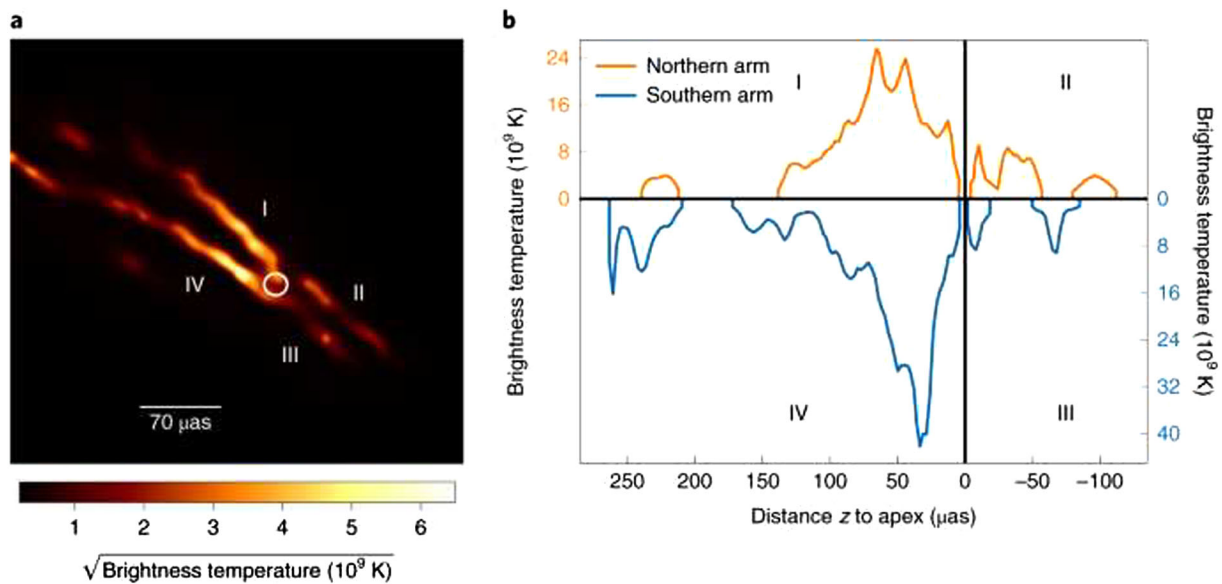


Fig. 2 The sub-nominal, over-resolved EHT image divided in 4 sectors reproduced from EHT2021 (their Fig. 2) which is licensed under CC-BY

EHT image resolutions remain too low (between 40 and 80 times, resp. 8 and 16 times) to resolve any of both black holes.

This alternative hypothesis enlightens equally well why the two ridgelines do not join at the apex. Around the “apex”, the lower parts of the “ridgelines” are in fact the counterjets of SMBH1 and SMBH2, which may or may not intersect.

Finally, there is no longer any jet-source connection problem. Both sets of jet and counterjet do visibly connect to their sources SMBH1 and SMBH2 on the picture. The jets and counterjets show temperatures similar in magnitudes to the accretion disk temperatures, like expected. They decrease in temperature when getting farther away from their sources, as can be seen in Fig. 1.

3.1 Bended jets

The two approaching jets clearly display a curved shape. This jet bending is observed on both the over-resolved and the nominally-resolved images. In a binary system, it may be caused by the movements of the sources revolving around each other.

Within the double black hole hypothesis, this bended shape becomes less of a problem to reconcile with the large-scale jet rectilinearity observed on wide-field images. Indeed, across their revolutions, the two SMBHs may aggregate their individual jets into a single “braided jet” that could in principle keep a rectilinear structure at larger scales.

We shall discuss further under Sect. 4 what physical information can be extracted or not from these bended jets.

3.2 Blobs along both forward jets

Within the unconvolved, super-resolved (sub-nominal) image, we observe, along each jet line, two most luminous spots, separated by about 15–20 micro-arcsec, instead of just one that should mark each black hole location. One of those spots could be the black hole itself, and the other one could be a knot in the jet. Such knots have been observed in other supermassive BH jets, like in M87 (The VERITAS Collaboration et al. 2009) and in Pictor A (Hardcastle et al. 2016). On the other hand, these blobs could be artefacts of the suboptimal resolution. They fully disappear in the nominal-resolution picture.

3.3 Are the 2 SMBHs inherited from pre-merger galaxies?

The existence of two SMBHs at the center of the Cen A galaxy may be considered plausible. Indeed, this object is believed to be the result of a merger between two smaller galaxies. Each of both initial, pre-merger galaxies might have hosted its own central SMBH. Indeed, it is widely believed that most galaxies harbour a SMBH at their center, as reminded in Kollatschny et al. (2020).

Relying on hydrodynamical simulations to reconstruct the history of Cen A, Wang et al. (2020) found that the scenario best fitting the present galaxy configuration implied a merger completion date ~ 2 Gyr ago. This scenario involved two initial galaxies with mass ratios of 1.5 and gas densities of 20% and 40%.

We do not know precisely how long it takes for two SMBHs to inspiral and coalesce. Numerical models wildly

vary in timescales (Mannerkoski et al. 2019). It is broadly estimated that SMBH binaries resulting from galaxy mergers are driven to sub-parsec separations within 10^{7-8} yr, and then into their final merger during another 10^{7-9} yr (Krause et al. 2019). These different timescale estimations are compatible with the hypothesis that the Cen A core is currently hosting a sub-parsec SMBH binary.

4 Physical determination of the SMBH binary system

4.1 SMBH masses

At this stage, with only the EHT pictures at hand, it is not possible to reliably estimate the individual SMBH masses in the binary system. We may only assume that their total mass is equal to that of the (previously considered single) central SMBH, as inferred from stellar dynamics (that is, $M=5.5 \pm 3.0 \times 10^7 M_{\odot}$), since the regions observed by Neumayer (2010) are located far enough from the tightly bound SMBH binary.

If we assume, in a first step, a linear relation between brightness temperature and mass, we obtain $34 (\pm 19) \times 10^6 M_{\odot}$ for the southern SMBH1 and $21 (\pm 12) \times 10^6 M_{\odot}$ for the northern SMBH2. From this, we may infer diameters of 11 ± 6 light-minutes and 7 ± 4 light-minutes.

However, this calculation is only indicative. For a binary SMBH with $0.1 < q < 1.0$ (with $q=M1/M2$), the mass-luminosity ratio might be far from linear, as the smaller binary system component might become the more luminous one, due to its orbiting closer to the dense part of the circumbinary gas disk and due to its greater velocity (De Rosa et al. 2019). For the general case of the link between active galactic nuclei luminosities and their central SMBH masses, some studies have found very little or no correlation at all (see e.g. Woo and Urry 2002). It shall become possible to build reliable estimates of the respective SMBH masses when more orbital data has become available from further observations.

4.2 Jet width

On the convolved, nominal resolution, image, the two approaching jets appear to be 12 to 24 microarcsec wide (i.e. 0.2 to 0.4 milliparsec). This means, each jet would be as broad as ~ 60 -220 times its source. This is found to be comparable with the approaching jet of M87, where the jet basis was observed to reach a width of ~ 170 gravitational radii (The VERITAS Collaboration et al. 2009). That is, if we assume that the four jets are resolved at all on the optimal resolution image. There is still some doubt about this. The two available EHT pictures deliver conflicting evidence about

the jet widths. The sub-optimal picture suggest a jet width of 5 micro-arcsecs at most. More data is needed to settle this issue.

4.3 Distance between both SMBHs

The projected separation distance between SMBH1 and SMBH2 is ≈ 25 -35 micro arcsec, depending of where exactly the SMBHs are supposed to be located in the two bright blobs. This means 0.45-0.64 milliparsec in the local frame (~ 7 -10 light-hours). An upper limit for the unprojected separation distance is provided by the TANAMI 8.4 GHz radio pictures, that show a single, unified plasma jet and a single source at the scale of ~ 5 milliarcsec (100 milliparsec) (Ojha et al. 2010).

From the similar luminosity gradients of both approaching jets, we may infer that these approaching jets are essentially aligned in real space, and not just in the projected space. On the super-resolved (sub-nominal) picture, the two counterjets show signs of a direct interference with each other. This intermingling is neither confirmed nor disproved in the nominal picture. If this intermingling between both counterjets is real, it could be taking place at 30-50 micro-arcsec south-west of both BHs. In such a case, both SMBHs should be remarkably close to each other. On the basis of these assumptions, we may infer that both SMBHs could be separated from each other (unprojected) by between 0.5 and 1.6 milliparsec distance (0.6 to 1.9 light-days).

The tightest SMBH binary presently known by direct identification (omitting the candidates from quasar spectra with Doppler-shifted emission lines or periodic variability) was detected in the Seyfert galaxy NGC7674 at $z=0.0289$, with a projected separation of 0.35 pc (Kharb et al. 2017). The next narrowest binary is hosted by the radio galaxy 0402+379, at $z=0.055$, with a projected separation distance of 7.3 pc. The orbital period was estimated at $P \approx 3 \times 10^4$ yr and the total mass at $M \approx 15 \times 10^9 M_{\odot}$ (Rodriguez et al. 2006; Bansal et al. 2017). The other known, visually identified SMBH binaries have separation distances in excess of 100 pc (Kollatschny et al. 2020; Koss et al. 2018).

Hence, if confirmed, the SMBH binary system at the center of Cen A would display the shortest known projected separation distance, at ~ 0.45 -0.64 milliparsec. It would also be the binary SMBH that sits nearest to us. This is good news, since “of these [binary SMBH] systems, the most interesting ones are those in an advanced state of merging (i.e., those with the smallest distances between their SMBHs)” (Kollatschny et al. 2020).

4.4 Revolution period

The exact orbital parameters of the binary may only be determined by direct, repeated observation. In any case, the orbital period should be much shorter than that of any other known binary SMBH.

4.4.1 Conservative approach with no helical pattern

If we assume (conservative separation distance approach) that the maximum separation distance in real space is 1 milliparsec, we would obtain, relying on Newtonian dynamics, a revolution period of between 0.3 and 0.6 yr (taking into account the total mass uncertainty). With a maximum separation of 3 milliparsecs, we obtain a period between 1.7 and 3.2 yr.

Generally, a binary associating two jetted SMBHs should exhibit a double helical jet structure, with: wavelength $\lambda =$ binary period \times jet speed. In the case of parallel jets, the double helix wave amplitude, as measured in the system rest frame, should be similar to the maximum distance between both SMBHs along their orbit (i.e. their major axis). More precisely, the wave amplitude should be equal to the major axis at the jet base, and grow larger further away from the source. Deriving the exact jet geometry shall however require sophisticated numerical simulations. We assume the Cen A binary's barycenter to be essentially motionless in the Cen A rest frame.

With regard to the eventual helical structure of the Cen A core, there are two possible approaches.

In a first approach (the "conservative separation distance approach", we may assume a revolution period of 10.3 to 3 yr, like hypothesized above. Given that the speed of the aggregated jet is estimated at half the speed of light (Israel 1998), this implies a λ of 0.5 to 2 light-years / in the 0.1 to 1 pc scale.

This wavelength is too long to be detected within the EHT pictures, that shows a 7 mpc-wide region. Thus, in that approach, we should conclude that there are and can be no visible helical jet structure on the EHT picture. The fact that no double helical structure was either seen on larger-scale pictures, like the ones of the TANAMI project, may then clearly be explained by the very narrow helix width and wave amplitude (from 0.1 to 1 milliparsec), much tinier than the 1.7 pc resolution of the best non-EHT pictures.

Last but not least, it is even possible that the helical jet structure would never show up on future, better resolved pictures, because the two jets may possibly interfere with each other and mix into a single "braid" jet, instead of double helix, at an early stage, i.e. before their sources have completed a full revolution.

4.4.2 Helical pattern-based approach

In a second approach, we may take inspiration from the 43 GHz (7 mm) image of the central SMBH of Cygnus A obtained by Boccardi et al. (2015). This picture shows a SMBH forward jet with a bended shape that seems strikingly similar to the Cen A jets in the EHT picture. This shape was one of the reasons for Krause et al. (2019) to argue that the

Cygnus A core may harbor a SMBH binary. The bended jet was interpreted by the same authors as the early part of a helical jet structure with wavelength $\lambda = 4$ pc, implying an orbital period of roughly 18 yr and a binary separation of 0.05 pc.

This image realized with global VLBI on 43 GHz (7 mm) had achieved a resolution of 90 micro-arcsec, the best so far for this object. This resolution was equivalent to 400 gravitational radii, assuming a total SMBH binary mass of $2.5 \times 10^9 M_{\odot}$, and a distance of 250 Mpc (redshift $z=0.056$).

If we apply the same lecture grid onto the Cen A curved jets of the EHT picture, we may indeed interpret the bended shape of the 2 forward jets as the early portion of a double helical jet structure. Even more so as they look like bending back when reaching the edges of the image. By visual inspection, we may estimate that the parts of the 2 forward jets that are visible on the EHT picture, i.e. of 210 micro arcsec, should represent about half a wavelength of the double helix (Figs. 1 and 2). However, since the projected images of the two jets do not cross each other, and since this intersecting should happen twice every wavelength, we might infer that the portion visible on the picture remains slightly below half a wavelength. Thus, we might estimate the helical total wavelength at ≈ 420 -500 micro arcsec. This is equivalent to 7.7 to 9.2 mpc in projected space (with 0.46 milliparsec / 25 micro arcsec), i.e. 7.8 to 12.0 mpc in unprojected space (i.e. 9.3 to 14.3 light-days) given the uncertainty in the projection angle (50 to 80 degree).

Such a helical jet wavelength, assuming a nascent jet velocity of 0.45 c, would imply for the SMBH binary an orbital period of 20.8 to 31.8 d. This seems extremely short. However, at this stage, with the available data so far, it is not possible to eliminate this second approach.

Such an orbital period would imply a unprojected maximal separation distance of 0.21 to 0.42 milliparsec, relying on Kepler's third law and taking into account the uncertainties in the total SMBH binary mass (25 to 85 mln Ms). This result turns out to be slightly smaller than the *projected* distances directly inferred from the EHT pictures (0.45-0.64 milliparsec). However, these estimations remain compatible with each other, given that the EHT pictures resolutions do not allow yet to locate the two SMBH binary components very reliably, and given that significant uncertainties remain in the nascent jet velocity, in the helical wavelength, in the Newtonian approximation and in the Centaurus A galaxy distance. In fact, we could argue that this relatively good agreement between the two very different evaluation methods rather speaks in favor of the helical interpretation of the bended jets in the EHT picture-

Basically, we would be facing two objects with Earth orbit-radius diameters (1 UA), in case of equal masses, revolving around each other at a distance of 1.5 to 3 Neptune

Table 1 Strengths and weaknesses of both models

Single SMBH interpretation	SMBH binary interpretation
The cone aperture of the 2 jets (forward jet and counterjet) is measured with precision.	Cone aperture of the 4 jets is not precisely assessed.
The SMBH&accretion disk do not appear at the place where they are supposed to be (at the apex of the 4 ridgelines).	Both SMBH&disks are clearly located and visible.
No connection visible between jet source and jets, or between jet and counterjet (at the apex of the 4 ridgelines).	Jet-to-source connections are found and clearly visible.
Extremely luminous blobs appear along the 2 ridgelines of the forward jet. These bright features are interpreted as either the radio-shifted core or as the effect of shocks in the forward jet. Both explanations remain unsatisfactory.	The two blobs receive a logical explanation: they are the two SMBHs&disks.
The spine (inner part) of both the approaching and receding jets remain totally obscure, like if it was empty space.	The entirely dark zone is effectively empty space.
The significantly bended ridgelines cannot be explained well by projection effects or SMBH spin axis precession. An interstellar medium “storm” would be necessary.	The strong bending of the four jets can be explained by the orbital motion of their two SMBH sources.

orbit radii (43 to 87 UA). Assuming circular orbits, these SMBH1 would dart along their orbits at speeds of 3.3 to 5.7 percent of the speed of light.

If valid, the helical jet structure-based calculations would suggest that the total SMBH binary mass should rather lay in the upper end of the mass estimation bracket, i.e. closer to 85 than to $25 \cdot 10^6$ Ms. Indeed, in Kepler’s 3rd law, with a constant period, a larger mass implies a longer major axis. This would make the helical-pattern estimated unprojected distance (0.21–0.42 milliparsec) easier to reconcile, after the other error sources are factored in, with the projected distance (0.45–0.64 mpc) directly estimated from the EHT image.

From both methods to estimate the separation distance, we may infer that the SMBH binary stands closer to its final merger than any other known similar system.

In SMBH binary evolutions, three phases are usually identified (Begelman et al. 1980): bounding (through dynamical friction, mostly with stellar population), tightening (dissipating energy mostly via circumbinary gas disk friction) and uniting (dissipating energy mostly via gravitational wave (GW) emission). This latest phase is subdivided into inspiraling, merger and ringdown. When the orbital parameters of the Cen A SMBH binary are known with more precision, it shall be possible to assess how close this system is from entering into the third, GW-dominated final phase or if it has already entered this third phase.

5 Summary

We provide Table 1 summarizing the strengths and weaknesses of both models for interpreting the EHT pictures of the Cen A core.

6 Experimental verification and outlook

How can we discern which interpretation of the EHT picture is correct? The most promising approach in the future shall be for astrophysicists, in particular the EHT project, to regularly image the Cen A core. Any change in the relative positions of the two most luminous spots, the would-be SMBH1 and SMBH1, would be the telltale sign of a binary system. That could occur relatively fast, due to the quite short expected orbital period of the binary, between 20 d and 3 yr.

If confirmed, this binary system at the center of the Centaurus A galaxy shall undoubtedly become the binary Supermassive Black Hole with the shortest separation distance, and also the closest to Earth, that we know of. This will open a wide field for research, since, as Michael Eracleous puts it, “The first confirmed binary supermassive black hole will be like the Rosetta Stone. It will tell us which of our models were right and which were wrong. It will allow us to refine our next searches and we should be able to find more.” (Sholtis 2021).

The Cen A SMBH binary, if confirmed, shall in particular help solve the “final parsec problem” (see for example Tillman 2020). The system sheer existence would prove that SMBH binaries may inspiral down to milliparsec separations. The Cen A core circumbinary disk must have been dense enough to bring the binary system continuously closer, while emitting powerful jets. It would help answer modelling questions, like estimating the viscosity torque (De Rosa et al. 2019).

Last but not least, this Cen A SMBH binary system, because it emits two distinct jets, will help to model the complex interactions between jets, between jets and neighbouring black holes, as well as between jets and the circumbinary gas disk.

Because the Cen A SMBH binary could have entered the GW-dominated energy dissipation phase already, it should become a natural target for space-based GW detectors, like ESA's Laser Interferometer Space Antenna (LISA), due to launch in the 2030s. Even more so as SMBH binaries with $0.5 < q < 1.0$ are supposed to emit the loudest GW sources (De Rosa et al. 2019).

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