Radio Emissions Of A Dormant Over-massive Black Hole: [GN 1146115] At Redshift Of z=6.68

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Abstract

James Webb Space Telescope have uncovered a number of previously hidden low-luminosity Active galactic Nuclei in the early universe. The recent discovery of GN-1146115 a supermassive black hole (SMBH) of 3.98 × 10^8 M⊙ at z = 6.68 challenges our understanding of BH formation and growth. The prime objective of this study is to determine if the existence of a SMBH in GN-1146115 can be confirmed by detection of radio flux. To achieve this goal, we employ a theoretical model to estimate the radio flux from a BH and its host galaxy. We found that radio emission from BH dominates over host galaxy and can be detected with current and upcoming radio observatories such as VLA, ngVLA and SKA. The detection of a radio flux above a few hundred nJy will validate the presence of SMBH in GN-1146115.

Terms: Flux radio density - Supermassive- black holes (SMBH) – Active galactic nuclei (AGN)- Fundamental planes(FPs) – Eddington limit

1.Introduction

Nowadays, the universe enigma remains unsolved. In the early stages subsequent to the cataclysmic event of the Big Bang explosion, the thermodynamics of the universe underwent significant alternatives. One of the extraordinary phenomena has been determined recently during this epoch is that SMBH (Super massive Black Hole) formation was ongoing, whereas star number was insufficient. Numerous theoretical models suggest that low-mass black holes can evolve to SMBHs in certain chronologies stage (Kovács et al. 2024). During the nascent stages of the universe, all the matter compacted indicates a cosmos redshift z > 10 (Latif, Aftab, and Whalen 2024). Seed-model theory is one model that posits super massive black holes (SMBHs) start forming due to massive stars collapsing with the dense materials in the surroundings at pre-galactic stage. At this particular phase, the black hole mass (M_{BH}) is relatively modest, where the evolution of BH's mass is due to the accumulation of matter over time and emerging with other BHs (Kovács et al. 2024). Through the accretion of observed galaxies, various Active Galactic Nucleis (AGNs) were witnessed in active galaxies. A highly immense energic region that is mostly powered by SMBH and other energetic celestial objects activities such as star formation and supernova. In the centre of the active galaxies, most AGN activities were witnessed with a total emissions from all spectral bands and referred to as bolometric luminosity. In space, black holes are invisible to telescopes since they do not emit or reflect light. Therefore, to detect them, the surrounding of a BH could indicates the presence of them by the way they affect it. The accretion disks consisting of gas and dust that surrounds the BH by rings emits light across different wavelengths, including x-rays and radio waves (NASA, 2024). More specifically, the formation of synchrotron radiation; In the centre of the active host galaxy jet, particles get accelerated in a spiral path emitting radio emission called (synchrotron emissions) due to profound magnetic field encounters. There are many empirical methods to observe radio activities. Multiple telescopes are utilized for radio studies, such as the ngVLG advanced radio telescope and SKA (square kilometres array) (Latif, Aftab, and

Whalen 2024). Utilizing the radio flux density provides an indication of SMBH growth evolution, where the flux is the amount of energy that is emitted from a celestial planet through a specific area at a certain time. Jansky (Jy) is a fundamental unit utilized to measure flux density per unit area per unit frequency, whereas luminosity is another significant intrinsic property and distance-independent that reflects the total amount of energy emitted per second. In order to differentiate the SMBH emissions from other galactic emissions, discarding the flux density of HII and SN is essential since the total potential contribution is involved (Latif, Aftab, and Whalen 2024). Furthermore, through utilizing fundamental plans (FPs), the mass of the black hole is theoretically detectable. FPs are mathematical relations that facilitate monitoring SMBH mass through radio and x-ray fluxes and luminosity data measurements. FPs demonstrate a proportional relation between the SMBHs and the radio flux density emissions. Larger black holes are most luminous and have a higher tendency to emit extreme flux. Nevertheless, these circumstances are not applied in all the cases in the universe. Recently, at redshift **$z \approx 7$,** which is about 13 billion years of universe age, the James Webb Space Telescope (JWST) witnessed an unactive SMBH black hole at the centre of JADES GN-1146115,the host galaxy. That rare model of SMBH suggests that galactic evaluations of SMBH vary and require further studies. In addition, gas motion dynamics surrounded the black hole indicate the strength of gravitational pull, which is directly proportional to SMBH mass. However, this case does not apply to all supermassive black holes (SMBHs). Despite that GN-1146115 black hole not actively accreting significant amounts of matter and exhibiting less active emissions than expected, it have been found as a massive black hole. (Juodžbalis, Maiolino, Baker, Tacchella, Scholtz, D'Eugenio, and Witstok 2024). Here we will study the black hole GN-1146115 in terms of its high redshift and the relationship with the emissions calculated and its mass. As we lay out our calculation of the X-ray and radio emission of SMBH in the host galaxy as the main source of AGN and compare it to emissions source of supernova and the HII regions.

2.Numerical Method

2.1 BH Radio Flux Density

-Table 1

FP	**A**	**B**	**C**
MER03	0.60	0.78	7.33
KOR06	0.71	0.62	3.55
PLT12	0.69	0.61	4.19
BON13	0.39	0.68	16.61
GUL09	0.67	0.78	4.80

We measured Black Hole (BH) in radio-luminosity and X-ray luminosity throughout the correlation with the black hole mass (M_{BH}). Utilizing the four essential fundamental planes in the Table(1) of BH accretion enabled us to determine the magnitude of radio, x-ray emissions luminosities .

To find the BH radio flux we utilize initially the fundamental planes to obtain the radio luminosity (Lr), which depends on X-ray luminosity (Lx) and M_{BH}. Lx is determined though the relation with bolometric luminosity (L_{bol}) which is $L_{bol} = 2 \times 10^{44}$ erg /s , which is a representation of summation energy's amount emitted per second per unit time. Utilizing the upcoming equation, we find Lx:

$$\log\left(\frac{L_{bol(L_0)}}{Lx_{(L_0)}}\right) = 1.54 + 0.24\mathcal{L}_{(L_0)} + 0.012\mathcal{L}^2{}_{(L_0)} - 0.0015\mathcal{L}^3{}_{(L_0)} \qquad (1)$$

Where $\mathcal{L} = \log(L_{bol}) - 12$ measured in solar unit(L_0). In this case unit conversion of L_{bol} from erg/s to L_0 is required. Through obtaining $Lx_{(L_0)}$then radio luminosity (Lr) is easily determined utilizing FPs correlation:

$$\log(Lr_{(erg/s)}) = A\ log\ Lx_{\left(\frac{erg}{s}\right)} + B \log M_{BH\,(M_\odot)} + C \qquad (2)$$

Hence radio luminosity will be quantified in erg/s unit, whereas Lx undergo conversion of (L_0) to (erg/s) unit's scale. The up-following step is calculating Lv, is luminosity that will be measured at specific portion of frequencies. where $\alpha = 0.3$.

$$Lv = \left(\frac{f_{(GHz)}\ (1+z)}{5_{(GHs)}}\right)^{-\alpha} \left(Lr_{\left(\frac{erg}{s}\right)}\right) \times \frac{1}{5\times10^9 Hz} \qquad (3)$$

The obtained Lv is in unit of (erg/s Hz). Utilizing this magnitude will lead to find radio flux density through:

$$Flux_{(Jy)} = \frac{Lv_{(erg/s.Hz)}\ (1+z)}{4\pi {d_L}^2{}_{(cm)}} \times \frac{1\ Jy}{10^{-23}{}_{(erg/s.Hz.cm^2)}} \qquad (4)$$

Where d_L is the luminosity distance that is calculated from second-year Plank cosmological parameters (Whalen, Latif, and Mezcua, 2023). The following equation demonstrates the Flux in unit of **jansky (Jy).** These calculations were applied to calculate the flux in various ranges of frequencies (0.1-10 GHz). **Note: no gravitational factor is applied.**

2.2 Supernova And The H_{II} Region Radio Flux Densities

In active galaxies AGNs are not applied for SMBH as the only source. Indeed, several active celestial objects radiate radio emissions. Supernova (SN) is a star that undergoes cataclysmic explosion creating a very dense object that spins upon itself at incredible speed radiating and emitting Synchrotron emission. Meanwhile, in interstellar medium an immense amount of high temperature is available due to star-formation process. Ultraviolet highly energetic emission radiated from the ionized gases such hydrogen two particles are accelerating due to massive magnetic field generated producing (Bremsstrahlung radiation) (Latif, Aftab, and Whalen 2024). It is crucial to while measuring radio flux of the black hole discard the emissions of Supernova and H_2. Calculation of the radio flux of supernova and HII enable us to distinguish flux spectra range from SMBH radio emissions.

$$L_{N\,(W/Hz)} = 5.3 \times 10^{21}\,[\,f_{(GHz)}(1+z)]^{-\beta}\,(SFR_{(M\odot/yr})\qquad (5)$$

Supernova luminosity indicated through star formation rate (SFR) and specifying the frequency range, where the SFR= $1.38\,M_{\odot}yr^{-1}$. In this case $\beta = 0.8$ is the nonthermal spectral index. And then finding the radio flux from the same equation (4) taking distance in meters.

Whereas H_{II} region the luminosity is primarily depending on temperature involved and Q_{Lyc} , since luminosity is generated due to thermal bremsstrahlung emission where ionized photons produce continuum spectrum of radio emissions.

$$L_H = \left(\frac{Q_{Lyc}}{6.3 \times 10^{52}}\right)\left(\frac{T_{eK}}{10^4{}_K}\right)^{0.45}\left[\,f_{(GHz)}(1+z)\right]^{-0.1} \times 10^{20}\left(\frac{W}{Hz}\right)\quad , \qquad (6)$$

$$where\ Q_{Lyc} = \frac{SFR(M_{\odot}\,yr{-}1\,)/}{1{\times}10^{-53}}\qquad (7)$$

The next step is calculating the radio flux density of supernova and H_{II} region using equation (4), taking distance in meters and the temperature of electrons $T_e = 10^4\ K$.

3.Results

We compute the theoretical values of the radio flux densities emitted by the overmassive black hole JADES GN 1146115 over the main five FPs at the redshift of $z = 6.68$. We calculate the faint radio emissions activites from the SN and the HII regions at the host galaxy for comparsion. Figure 1. shows the radio flux densities (in nJy), where the spectral lensing $\alpha = 0.3$ for all five FPs combined with the flux densities of the H_{II} and SN regions of the host galaxy at a frequency range (v) from 0.1-10GHz. As JADES GN-1146115 has a mass of $3.98\times 10^{8} M_{\circ}$, therefore, the results from the 5 fundamental planes (models) of the BH radio fluxes, are demeonstrate higher values compared to the SN and H_{II} region.

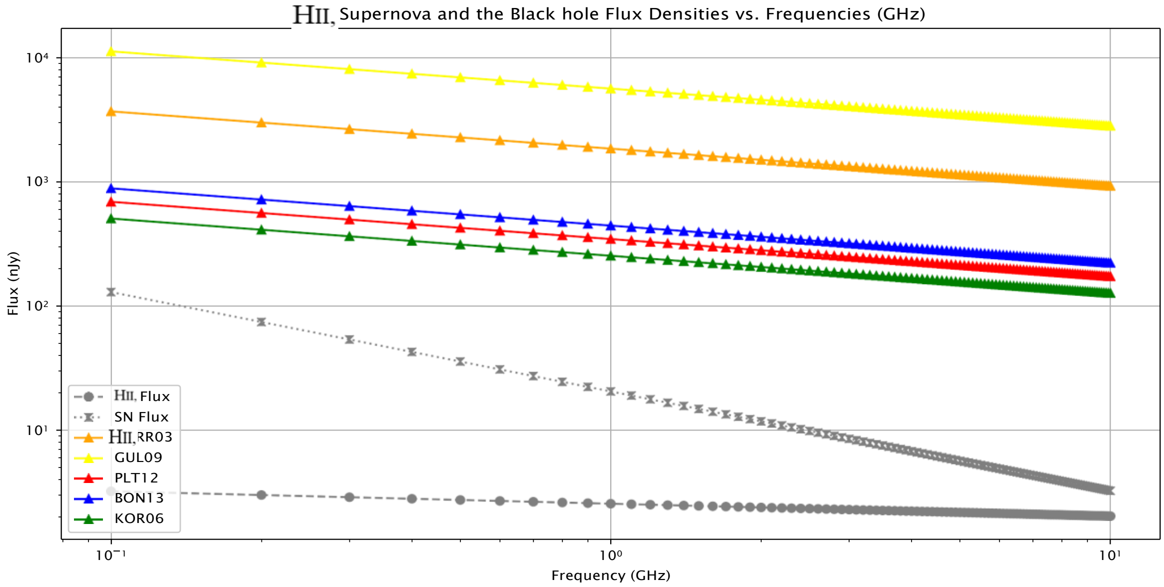

Figure 1 includes all 5 fundamental planes, H_{II} region and SN radio flux densities in (nJy) at $\alpha = 0.3$, Flux magnitudes are unaffected by gravitational lensing factor.

The computed radio flux densities of the black hole FPs at 0.1GHz, vary from ~11µJy – 0.51µJy, where at 10 GHz the flux extended from the range of ~2.8µJy – 0.13µJy. In contrast, flux densities theoretical magnitudes of H_{II} regions found to be < 4 n-Jy. For supernova (SN), the radio fluxes at [0.1-1-10 GHz] have been estimated as ~ 129.198 n-Jy , 2.496 n-Jy , 3.245 n-Jy respectively. The theoretical model indicates that GN-1146115 (SMBH) is creating the dominant radio activities for the host galaxy, while H_{II} region and SN have an insignificant contribution of AGN radio emissions. The observed signals of AGN sources vary depending on time integration times, listed in Table 2 (see Table 3 of Braun et al. 2019) and Table 3 (Plotkin & Reines 2018) respectively.

Table 2

Telescope limits for SKA for different integration time				
Frequency range	500 MHz	1.5 GHz	6.5 GHz	12.5 GHz
Radio Flux (nJy) 1 hr integration time	4400	2000	1300	1200
Radio Flux (nJy) 10 hr integration time	1391	632	411	379
Radio Flux (nJy) 100 hr integration time	440	200	130	120

Telescope limits for ngVLA for different integration time				
Frequency range	500 MHz	1.5 GHz	6.5 GHz	12.5 GHz
Radio Flux (nJy) 1 hr integration time	-	382	220	220
Radio Flux (nJy) 10 hr integration time	-	121	70	70
Radio Flux (nJy) 100 hr integration time	-	38	22	22

We find that for the SKA telescope, the resulting radio flux densities, for a range frequency (0.3-10GHz), indicate that only the top FP (GUL09) can be detected with a 1-hour integration time. In addition, the radio fluxes of FP (MER03) in the frequency range (1-10GHz) can be detected with a 10-hour integration rate by the telescope, while (GUL09) can be detected at all frequencies. To continue (MER03 & GUL09) can be detected from (0.1-10GHz) by a 100-hour integration time. While all the FPs, except for (KOR06), can be easily detected with a 100-hour integration time at frequencies from (1-10GHz). These estimations are made based on the currently known limitations of the SKA telescope as of the current time. In terms of the ngVLA telescope, it is expected that the new generation telescope will be able to detect even the smallest flux densities at only a 1-hour integration time, besides (KOR06)'s low flux densities, which can be detected, alongside all the other FPs, at a 10-hour integration time over the telescope's bandwidth of 1.2–3.5 and 3.5–10 GHz.

Next, analyzing the HII region radio emission; we find that it is far below even the most pessimistic of FPs, while the radio emissions from the SN region were found to be larger compared the HII region and by a factor of 5 lower than the lowest FP at 0.1GHz. At higher frequencies up to 10 GHz a significant decline is showing. Consequently, if radio emissions were to be detected at the higher frequencies, such as 10GHz, it would further confirm the existence of JADES GN-1146115, as even ngVLA, the upcoming most sensitive radio telescope, will be unable to detect emissions that low (>38 nJy) over its frequency range in any integration time from 1-100 hours.

4.Discussion & Conclusion

Theoretical radio flux densities of GN-1146115 (SMBH) were estimated using fundamental planes of BH accretion with the comparison of the radio emissions from the H_{II} regions and SN at 0.1-10 GHz . The radio fluxes vary from a range of hundred nJy at 10 GHz up to 10^4 nJy at 0.1 GHz. The maximum flux from H_{II} regions was ~ < 5 nJy, and SN radio flux span from ~ > 3 nJy to ~ >100 nJy. The radio flux conducted from GN-1146115 is higher in radio emissions than of its host galaxy even for the most pessimistic FPs. Furthermore, utilizing the detection limits of SKA and ngVLA are shown in Tables 1 and 2, we find that for the ngVLA able to detect the radio fluxes with a 1-hour integration time, but SKA will require integration times about 10 hrs. GN-1146115 is under-luminous compared to its size, while it is accreting at only 2% of the Eddington limit, making its radio emissions difficult to detect with current technology. However, upcoming evolution in telescopes like ngVLA and SKA will be vital, as their improved sensitivity will help to detect low, faint emission signals of BHs as GN-1146115 and will open synergies between NIR and radio observations

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