Nuclear Physics in Astrophysics - X
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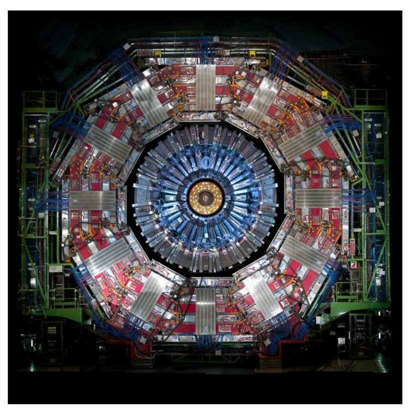

Observational and Astrophysical Study of Black Holes

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Abstract:

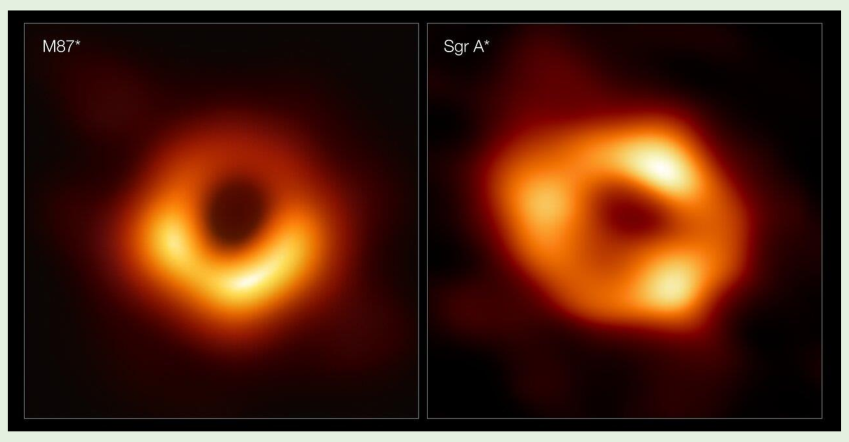
Black holes have ignited thought-provoking ideas for decades because of their peculiar origin of existence and very nature. Commending the expeditious advancement of the field, including the first ever images obtained, an introductory overview of black holes and Supermassive black holes has been given to understand the common trait that runs between nuclear physics and astrophysics. Different flavours of black holes ranging from 10^{-8} kg to 6.6×10^{10} $M_{\odot}$, keeping supermassive black holes as our main focus have been discussed. The study presents a simplified way for comprehending active galaxies and categorising them based on radio-loud and radio-quiet active galactic nuclei. Primary properties of black holes and a collection of the properties of 70 well-known supermassive black holes have been presented in tabular form, that will help our readers to understand the physics on which nuclear physics can be modelled.

Introduction:

A black hole is a physical entity with very strong gravitational pull of an extraordinarily concentrated mass from which nothing, not even light quanta, can escape. Considering G as the gravitational constant, r_s as the Schwarzschild Radius, M_{BH} as the mass of black hole and c as the speed of light, a black hole's escape velocity v_e is greater than the speed of light and is given as:

$$v_e = \sqrt{\frac{2GM_{BH}}{r_s}}$$

The only two black holes (M87 and Sgr A*) to be imaged till date



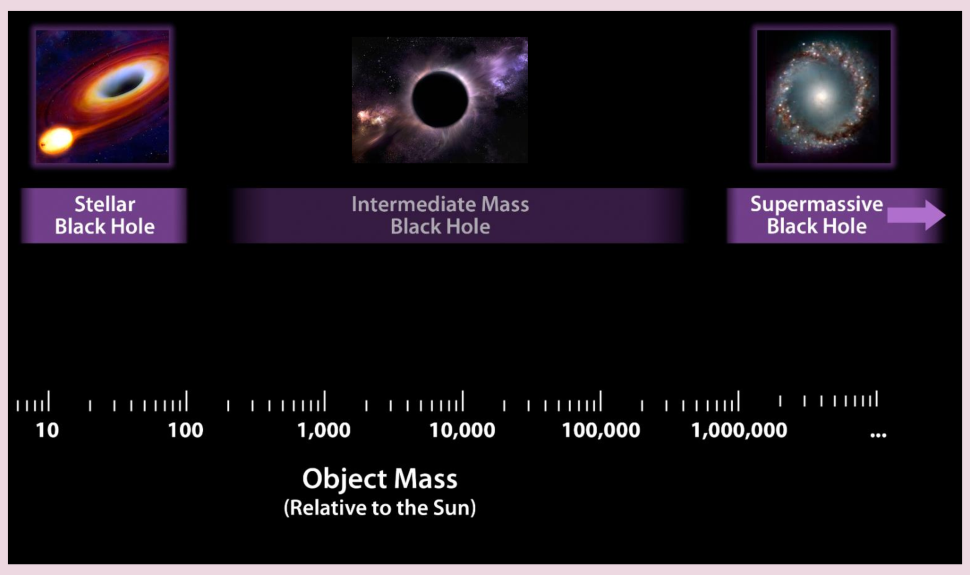
(Credit: EHT Collaboration)

Types of Black Holes:

- **Primordial Black Holes**: Mass ranging from Planck's relics (10^{-8} kg) to thousands of $M_{\odot}$
- **Stellar Black Holes**: Mass ranging from 3 - tens of $M_{\odot}$
- **Interstellar Black Holes**: Mass ranging from 10^2 - 10^5 $M_{\odot}$
- **Supermassive Black holes:** Mass ranging from 10^5 - 10^{10} $M_{\odot}$

$M_{\odot}$ or mass of the sun is 1.989×10^{30} Kg

Observed mass range of black holes

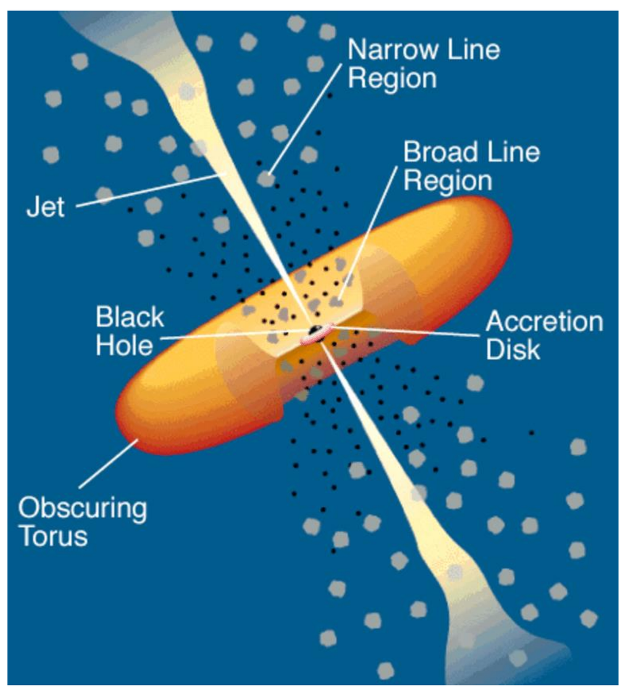


(Credit: NASA/JPL-Caltech)

Active Galactic Nuclei (AGN) and their classification:

The bright central region of galaxies comprising of scattered material or gas that orbits a black hole is called an Active Galactic Nuclei. Due to friction and gravity, this disk-like structure is rotating and falling towards the black hole. They have magnetic fields that twist at their poles and eject particles known as cosmic rays.

Type of Galaxy	RQ or RL	AGN	Emission lines
Normal	None	None	Weak Narrow
LINER	RQ	Undeter-mined	Weak Narrow and weak Broad
Seyfert 1 (Sy1)	RQ	Present	Both Narrow and Broad
Seyfert 2 (Sy2)	RQ	Present	Narrow
Quasar	Both	Present	Both Narrow and Broad
Blazar	RL	Present	Some Broad
BL Lac	RL	Present	Faint Broad
OVV	RL	Present	Strong Broad
RG	RL	Present	Some Weak and some Broad



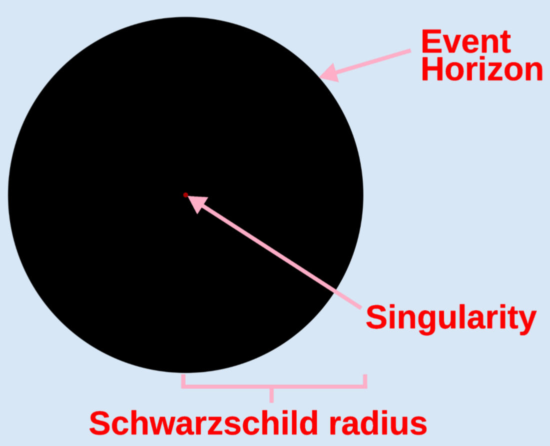
(Image Credit: C.M. Urry & P. Padovani)

Supermassive Black holes

Supermassive black holes are the biggest and most enormous type of black hole that can exist and has a size between 0.001 and 400 AU. The majority of galaxies, if not all of them, contain these enormous supermassive black holes.

Event Horizon and Singularity

- The 'point of no return' or the boundary beyond which all the radiations and matter are trapped is called event horizon.
- Beyond the event horizon, all the mass keeps on concentrating to a point called "Singularity", which is a point with intense gravity and density at which laws of physics are not applicable.



Primary Properties of Black Holes

1. **Schwarzschild Radius** : Schwarzschild Radius is defined as the distance between singularity and event horizon. It is the radial coordinate of the event horizon of a non-rotating BH in Schwarzschild coordinates and is given by

$$r_s = \frac{2GM_{BH}}{c^2}$$

2. **Mass**: Mass of a black hole can be calculated using Newtonian Physics and can be measured accurately via dynamical models, where we consider r as the radius of circular orbit, P_{orb} as the period of orbit and v is the speed of BH.

$$M = \frac{v^2 r}{G} = \frac{4\pi^2 r^3}{GP_{orb}}$$

3. **Density**: Density is the measure of the amount of mass concentrated per unit volume, which, for a Black hole, is enormous confined in a comparatively little space

$$\rho = \frac{3c^2}{8G\pi r_s^2}$$

4. **Eddington luminosity**: Eddington limit describes the maximum luminosity of a source, which is achieved by balancing the radiation pressure repulsion going outwards and the gravitational force acting inwards. Eddington luminosity is given as

$$L_{EDD} = \frac{4\pi GM_{BH} m_p c}{\sigma_{TH}}$$

5. **Eddington accretion rate** : The rate at which a BH radiates at Eddington limit is called Eddington accretion rate . Considering the accretion rate or the gas inflow rate is g s^{-1}, ε is the radiation efficiency i.e. fractions of rest mass energy of gas being radiated, we get:

$$\dot{M} = \dot{M}_{EDD} = \frac{4\pi GM_{BH} m_p}{\varepsilon \sigma_{TH} c}$$

Here G is the gravitational constant, M_{BH} is the mass of black hole and c is the speed of light, m_p is proton-mass, σ_{TH} is electron Thomson cross section, $M_{\odot}$ is the mass of Sun, $L_{\odot}$ is the luminosity of Sun, G- Normal Galaxy, Sy1- Seyfert 1 Galaxy, Sy2- Seyfert 2 Galaxy, QSO- Quasar, LINER- Low Ionization Nuclear Emission-line Regions, BCG- Brightest Cluster Galaxy and NLRG- Narrow Line radio Galaxy.

Galaxy	Type	RA	Dec	M_{BH} ($M_{\odot}$)	Distance D_L (Mpc)	Redshift z	Radial velocity (km/s)
Andromeda	G	00h42m43.3s	+41d16m9s	2.3×10^8	0.77	-0.001001	-300.09
Sagittarius A*	G	17h45m40s	-29d0m28.1s	4.3×10^6	0.008178	-	-
SDSS J0100+2802	QSO	01h00m13.0s	+28d02m25.8s	1.24×10^{10}	3900	6.3	288748
Messier 87	NLRG	12h30m49.5s	+12d23m28.1s	6.3×10^9	16.4	0.00428	1284.01
TON 618	QSO	12h28m24.9s	+31d28m38s	6.6×10^{10}	3180	2.219	665239.56
3C 273	Blazar	12h29m06.7s	+02d03m09s	8.86×10^8	749	0.158339	47468.84
Cygnus A	Sy2	19h59m28.4s	+40d44m02.1s	1×10^9	183.96	0.056075	16810.87
Messier 96	LINER	10h46m45.7s	+11d49m12s	4.8×10^7	9.59	0.00299	896.98
NGC 1097	Sy1	02h46m19.05s	-30d16m29.6s	1.40×10^8	13.78	0.00424	1271.12
Abell 1201	BCG	11h13m01.1s	+13d25m40s	$(1.3\pm0.6)\times10^{10}$	838.5	0.169	50604.98

Conclusion

- The largest SMBH ever observed is TON 618, which is a quasar located 3180 Mpc away.
- The closest black hole to us is in Andromeda galaxy located 0.77 Mpc away.
- The negative sign of Andromeda's redshift (and of several others) indicates that the galaxy is moving towards ours, unlike others moving away.
- In our data, the majority of SMBH are located in strong broad lines emitting Seyfert galaxies.
- In the collection of our data, most of the SMBH are located within a distance of 8000 Mpc.
- Majority of SMBHs in our data are in the mass range of 10^9 to 10^{10} $M_{\odot}$.