Summary of Theory Assignment: Week 1

Mansi

Accretion

Accretion is the process in which matter falls onto a compact astrophysical object such as a white dwarf, neutron star, or black hole. As the material spirals inward, it loses gravitational potential energy. This lost energy is converted into heat and radiation, making accretion one of the most powerful energy-release mechanisms in the universe.

Energy Released by Accretion

The energy released per unit mass depends on how compact the accreting object is. More compact objects (smaller radius for the same mass) release more energy when matter falls onto them.

White dwarfs release modest amounts of energy. Neutron stars release far more because of their extreme compactness. Black holes release the most, with efficiencies that can reach a significant fraction of the rest-mass energy of matter.

Accretion onto black holes is the most efficient known astrophysical process for converting mass into energy, surpassing even nuclear fusion.

Accretion Luminosity

The power output from accretion depends on both the compactness of the object and the rate at which mass is falling in.

Different astrophysical systems exhibit characteristic luminosities:

Quasars shine with enormous power, requiring roughly a solar mass of material per year to fall into a supermassive black hole. X-ray binaries involve a stellar-mass compact object accreting from a companion star, producing strong X-ray emission. Gamma-ray bursts represent extremely rapid and violent accretion episodes, briefly outshining the entire observable universe.

These systems demonstrate how accretion can drive a wide range of high-energy phenomena.

Radiation Pressure and the Eddington Limit

As accretion produces radiation, that radiation pushes outward on the infalling material. If the outward radiation force becomes too strong, it can halt further accretion.

This balance defines the Eddington limit, the maximum luminosity an object of a given mass can sustain while still allowing matter to fall inward. Objects radiating above this limit would blow material away rather than accrete it.

Salpeter Timescale

Because the Eddington limit restricts how fast mass can be accreted, it also limits how quickly black holes can grow.

Under Eddington-limited accretion, the mass of a black hole increases exponentially with time. The characteristic timescale for this growth is tens of millions of years. This timescale, known as the Salpeter time, sets the pace at which supermassive black holes can form in galaxies.

Emission Mechanisms

Accretion can produce radiation in two extreme ways:

(a) Thermalized Emission Energy released by infalling matter is fully converted into heat and radiated from the surface or inner disk.

Neutron stars produce temperatures typical of X-ray sources. White dwarfs produce ultraviolet and soft X-ray emission.

(b) Shock Heating If the infalling material impacts the surface or inner region violently, the energy can be converted directly into extremely high temperatures.

In reality, accreting systems often show a combination of these processes.

Comparing Different Accretors

White Dwarfs - Lower compactness. - Emit mainly ultraviolet and soft X-rays. - Found in systems like cataclysmic variables and dwarf novae, which show periodic outbursts.

Neutron Stars - Extremely compact. - Emit hard X-rays and sometimes gamma rays. - Often found in X-ray binaries.

Supermassive Black Holes - Enormous mass but large radius. - Surprisingly similar surface temperatures to white dwarfs for thermalized emission. - Produce ultraviolet, X-ray, and sometimes gamma-ray radiation. - Power quasars and active galactic nuclei.