hours, indicating a small and powerful source of energy. By 1965, Schmidt had extended the distance range of quasars to very high redshifts, $z > 2$.

Astronomers realized that quasars, rather than being isolated objects in our own galaxy, were in fact located at the centre of distant galaxies, with the rest of the distant galaxy often too faint to detect. The engines behind these "Active Galactic Nuclei " (or AGN) commonly produce 10^{39} W, more than two orders of magnitude larger than the luminosity of all stars in a typical galaxy. This mindboggling realization led to the idea that AGNs could be extremely massive stars, as heavy as several million solar masses, as first contemplated by Hoyle & Fowler (1963). However, it soon became clear that any such giant star would be extremely unstable and short-lived, and therefore could not explain the quasar observations.

The singularity theorem

Schmidt's discovery prompted Wheeler to reconsider the physics of gravitational collapse and he discussed this with Penrose, who began to think about the problem in late 1964.[2] Oppenheimer and Snyder had described the spherically symmetric case where an astronomical body contracts to within its Schwarzschild radius, forming a singularity of infinite density. However, it was far from clear that this could happen in the real world and whether the assumption of spherical symmetry was a prerequisite for gravitational collapse. Penrose was well aware of the rotating solution found by Kerr the year before (Kerr 1963). The solution retained a lot of symmetry and did not exclude the possibility that departures from symmetry could prevent singularities to form.

Penrose set out to analyse the situation *without* the assumption of spherical symmetry, assuming only that the collapsing matter had a positive energy density. To do this, he had to invent new mathematical methods and make use of topology. The key concept that Penrose introduced was that of a *trapped surface*. A trapped surface is a closed two-dimensional surface with the property that all light rays orthogonal to the surface converge when traced toward the future. This is contrary to a spherical surface in flat space, where outward-directed light-rays diverge.

It can be seen that in the spherically symmetric case, any spherical surface with a radius less than the Schwarzschild radius is a trapped surface, which provides a good way to understand the structure of a black hole. Examining the Schwarzschild metric, we find, as illustrated in figure 1, that the radial direction becomes time-like as one passes through the horizon. Time and space switch roles and the direction inwards, towards the origin of spherical coordinates, becomes time. Hence, it is as difficult to get back out of the black hole as it is to go backwards in time.

An even more dramatic consequence of the trapped surface is that the flow of time inevitably will bring any observer towards the origin of the radial coordinate, where time ends. All the matter that formed the black hole resides at this single moment in time, the singularity.

[2] Penrose relates the circumstances of his discovery in two books (Penrose 1989, 2010).