# 12 ZERO TO ZILLIONS and BLACK HOLE

## SYNOPSIS

**ZERO TO ZILLIONS – Theory of the Big Bang**
How the Universe exploded from an infinitesimal speck to create matter, radiation, time and space. In the first trillion-trillion-trillionth of a second, the cosmos grew a hundred million times to less than the size of an atom. Then, in another instant, the Universe was the size of a galaxy. Now, 14-billion years later and strung along vast filaments, the Universe has some 50-billion galaxies that continue to expand as stars within them are born, live and die.

**BLACK HOLES – Cosmic Vanishing Acts**
Black holes occur when a massive star dies. As its outer layers cascade into space, the core collapses to beyond the visible. It becomes a voracious gravitational trap from which nothing, not even light, escapes. Black holes can be detected by bright surrounding disks – material swirling to the event horizon and oblivion. But at the brink, some material hits a shockwave and shoots at right angles from the disk blasting out vast jets and plumes.

## BACKGROUND

From Earth to the depths of the cosmos, the same 92 naturally occurring elements are scattered. Common matter forms everything and all of us. Once there was nothing – no matter, no radiation, no time. Some reject the theory, but most cosmologists agree that the Universe was born of a Big Bang. From an infinitesimal speck the Universe exploded – not into space, because there was none, but inflating within itself.

The Big Bang was some 14-billion years ago. In the first trillion-trillion-trillionth of a second, time, space and matter grew 100-million times to less than the size of an atom. Then, in another instance, they were as big as a galaxy. The Universe was a soup – so hot that energy generated matter and antimatter as massive particles.

As they decayed into lighter ones, matter triumphed over antimatter by one part in a billion – but enough to yield us the cosmos. By now, the temperature had dropped to a trillion degrees Celsius. When the era ended, the Universe was just ten-millionths of a second old.

At one thousandth of a second, sub-atomic particles like quarks and gluons formed protons and neutrons. Then, at one-second, as the temperature dropped to one billion degrees, protons and neutrons made atomic nuclei. At three minutes the first elements formed – hydrogen, helium and a little lithium. Through the next 350-thousand years, electrons were captured in closed orbits around nuclei. The temperature was down to 3,000 degrees.

When electrons were locked into atoms, they no longer blocked the passage of light-bearing photons. Suddenly, the fog cleared and the Universe became transparent. So began the matter-dominated era. From gassy clouds of hydrogen and helium galaxies condensed. Galaxies formed clusters and clusters formed filaments. To this day the process continues – the cosmos ever expanding and ever cooling.

Evidence for the evolution of the Universe came in 1965 with the discovery of cosmic background radiation, a hiss emanating from every direction in the sky. That hiss was a remnant of the time, 350-thousand years after the Big Bang, when the cosmos had cooled from near infinite heat to 3,000 degrees. Subsequently, the WMAP spacecraft has charted the early Universe in microwaves and revealed that expansion from the Big Bang was not smooth. Matter rippled and clumped.

Only after a billion years did the large-scale structure of the cosmos resolve. Galaxies clustered along frothy filaments. Between them, voids of space widened. Then, stars were born. Everywhere, gas was condensing and heating to initiate nuclear fusion. This first generation of stars was hotter, brighter and more massive than the supergiants of today.

Now, generations later, 50 billion or so galaxies swarm in superclusters where filaments intersect. This cellular structure was set by fluctuations in the density of matter in the early Universe. That fundamental discovery was through cosmic background radiation.

* * *

Like whirlpools in the ocean, the cosmos is shot through with black holes. But, unlike whirlpools, black holes are invisible. A black hole is an object so collapsed that nothing escapes its voracious gravity – not even light. Swirling inward, everything is trapped as it crosses the so-called event horizon.

And, even if we could see them in the vastness of space, a black hole with a mass equal to that of the Sun would have a diameter of just 3 kilometers. A black hole with a mass ten times that of the Sun would have a radius of 30 kilometers, and a million-solar-mass black hole at the center of a galaxy would have a radius of 3 million kilometers.

The smallest black holes are thought to evolve from extremely massive stars. In old age, as hydrogen runs out, the nuclear furnace at the stellar core fuses heavier and heavier elements. In the end, with nothing left to fuse, the core becomes solid iron and collapses. The result is a catastrophic supernova, blasting the outer layers far and wide and compressing the core still farther.

As the core swallows itself, a black hole is born. Crucially, such a collapse occurs only if the original iron core has more than three times the mass of our Sun. But, since they are invisible, how are black holes detected? Astronomers look for visible clues nearby.

In a binary system, for instance, if one star has collapsed into a black hole, the remaining companion continues to orbit a seemingly empty space. As material swirls into the black hole, some is saved at the brink and pitched outward at right angles by the shockwave around the central vortex of the visible accretion disk. Such jets can extend dozens of light years. In addition, the orbital motion of the remaining binary star allows astronomers to “weigh” the invisible black hole. Most have ten times the mass of the Sun.

A massive black hole is thought to lurk at the heart of our Galaxy, the Milky Way. It may well have the mass of three-million Suns. Andromeda, our nearest galactic neighbour, is believed to have twin black holes at its centre with a combined mass of at least 70-million Suns. The pivotal black hole of Centaurus A could have the mass of 200-million Suns. Quite probably, all galaxies have black holes at their centre.

When galaxies collide, their black holes fall quickly towards the hub of the newly merged galaxy. But instead of merging themselves, the black holes orbit each other for hundreds of millions of years. When they do combine, they form a supermassive black hole with perhaps one billion solar masses. They cause ripples in the fabric of space-time.

More powerful still, quasars are the brightest objects in the Universe. The largest are powered by black holes with the weight of ten-billion Suns. The glare of quasars out-shine their host galaxies. Black holes powering quasars have enormous appetites. They gobble the equivalent of 40 Earths an hour.

So what are quasars? They are thought to fire up when a supermassive black hole starts gorging on gas, dust and stars. Falling inward as an accretion disk, the cosmic debris emits prodigious radiation.

**Weblinks for ZERO TO ZILLIONS – Theory of the Big Bang**

http://en.wikipedia.org/wiki/Big_Bang - From Wikipedia, the free encyclopedia, an overview of the Big Bang theory for the origin of the Universe.

http://www.pbs.org/deepspace/timeline/ - From PBS, an interesting timeline of events from the Big Bang to the end of the Universe.

http://www.damtp.cam.ac.uk/user/gr/public/bb_home.html - From the University of Cambridge, England, an introduction to Big Bang cosmology and its successes. Also includes a discussion of problems with the standard Big Bang model.

http://cfa-www.harvard.edu/seuforum/bigbanglanding.htm - From the Harvard-Smithsonian Center for Astrophysics, a useful discussion of Big Bang cosmology, including questions such as: "What was the Big Bang?", What powered the Big Bang?" and "Where did the Universe come from?"

http://cosmology.berkeley.edu/Education/IUP/Big_Bang_Primer.html - From the University of California at Berkeley, a cosmology primer on the Big Bang theory.

http://www.sciam.com/article.cfm?chanID=sa006&articleID=0009F0CA-C523-1213-852383414B7F0147 – A thought-provoking feature article from the March 2005 issue of *Scientific American*, entitled "Misconceptions about the Big Bang".

http://en.wikipedia.org/wiki/Big_Bang_nucleosynthesis - From Wikipedia, the free encyclopedia, an introduction to the production of the first elements in the Big Bang.

http://www.bnl.gov/rhic/ - Home page for the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, used by scientists to study what the Universe may have looked like in the first few moments after the Big Bang.

http://www.sciam.com/article.cfm?chanID=sa006&articleID=0009A312-037F-1448-837F83414B7F014D – Feature article from the May 2006 issue of *Scientific American* entitled "The First Few Microseconds".

http://map.gsfc.nasa.gov/ - Home page for the Wilkinson Microwave Anisotropy Probe (WMAP) mission which has produced a new, more detailed picture of the infant Universe.

**Weblinks for BLACK HOLES – Cosmic Vanishing Acts**

http://en.wikipedia.org/wiki/Black_hole - From Wikipedia, the free encyclopedia, an introduction to black holes.

http://imagine.gsfc.nasa.gov/docs/science/know_l2/black_holes.html
and
http://heasarc.gsfc.nasa.gov/docs/blackhole.html - From NASA's Goddard Space Flight Center, two sites providing an introduction to black holes, intended for students age 14 and above.

http://www.damtp.cam.ac.uk/user/gr/public/bh_home.html - From the University of Cambridge, England, an overview of black holes and information on current research.

http://cosmology.berkeley.edu/Education/BHfaq.html - From the University of California at Berkeley, Ted Bunn's fascinating list of frequently asked questions about black holes with answers.

http://amazing-space.stsci.edu/resources/explorations/blackholes/lesson/index.html - The truth about black holes - an "Amazing Space" activity designed to teach students about black holes.

http://antwrp.gsfc.nasa.gov/htmltest/rjn_bht.html - Ever wondered what it would be like to travel to a black hole or a neutron star? If so, this exciting page – including MPEG movies – is a must.

http://hubblesite.org/explore_astronomy/black_holes/ - Award-winning interactive multimedia website about the physics and astronomy of black holes from NASA's Space Telescope Science Institute, with information on the properties, formation, and location of black holes. Includes an interactive voyage simulator and an encyclopedia of terms.

http://cassfos02.ucsd.edu/public/tutorial/MW.html - From the University of California, San Diego, Gene Smith's useful guide to the structure of our Milky Way, including a summary of the evidence for a massive black hole at its heart.

http://chandra.as.utexas.edu/~kormendy/stardate.html - A review article by John Kormendy and Gregory Shields' on supermassive black holes for the general public - from *Stardate* magazine.

http://chandra.as.utexas.edu/~kormendy/kormendy-ho/kormendy-ho.html - John Kormendy and Luis Ho's article on supermassive black holes in inactive galaxies for generalist scientists - from the *Encyclopedia of Astronomy and Astrophysics.*

http://chandra.harvard.edu/xray_sources/blackholes_sm.html - From the Chandra X-ray Observatory, a field guide to supermassive black holes.