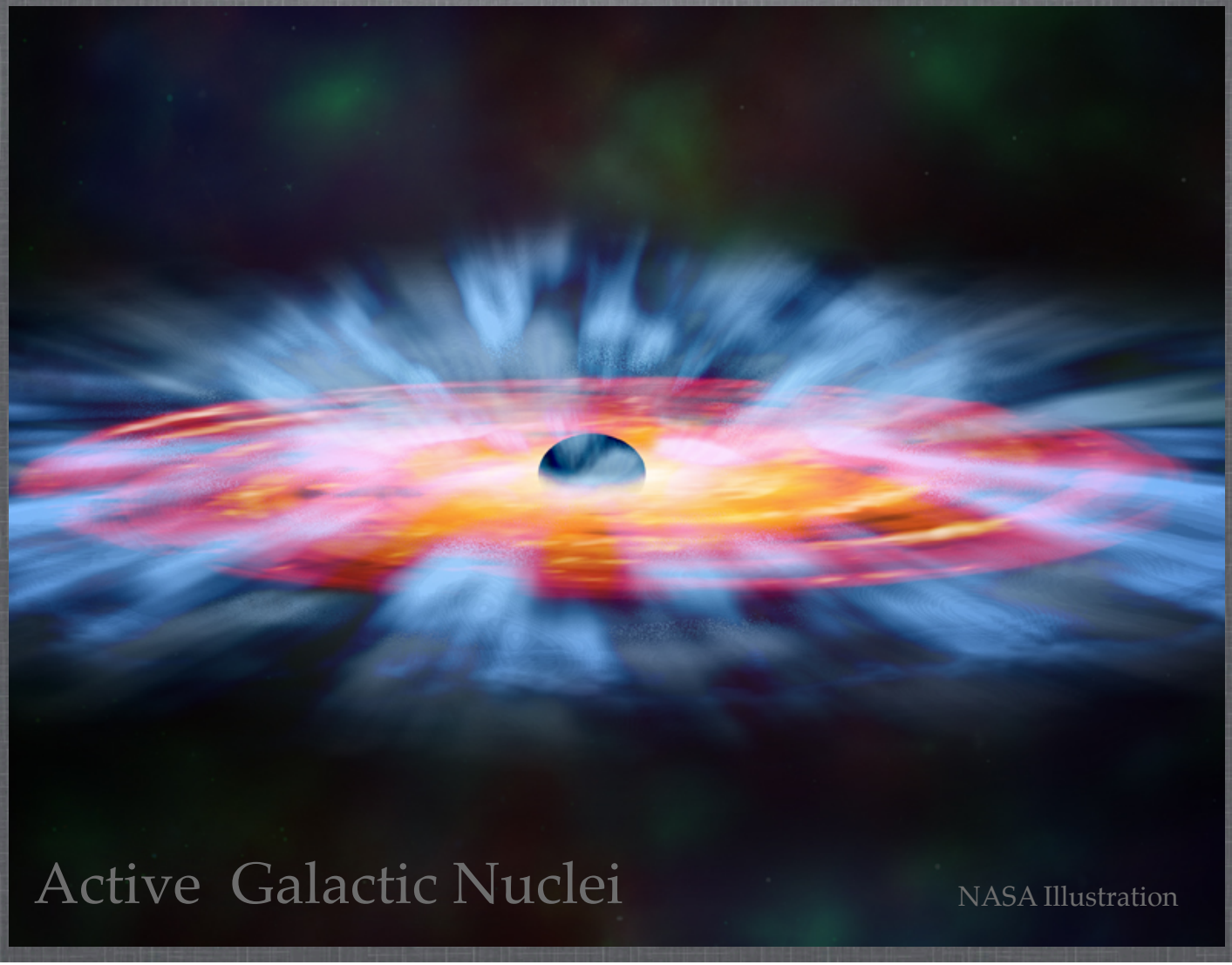
BLACK HOLES

JOE FRANCIS, RAC VP -- 10/25/10



Outline

- Introduction
- History
- Formation & Properties
- Evolution
- Event Horizon & Singularity
- Observational Evidence
- Alternatives
- Some Questions & Latest News

An artist's view of a black hole in a globular cluster is seen in this illustration.
HO/NASA/Space Telescope Science Institute/Reuters

Introduction

- A BLACK HOLE is a region with such great mass and gravity that nothing can escape, not even light
- A BLACK HOLE deforms space-time, as predicted by the general theory of relativity
- Black Holes can only be observed by the effect on light and/or other bodies of mass and/or electric charge
  - Bending light
  - Gravitational red shift
  - Attraction of other mass (just like normal)

Brief History

- 1784 John Michell writes about escape velocities greater than the speed of light = Dark Stars
- 1915 Karl Schwarzschild discovers solution for simplest Black Holes (mass only, no spin and no charge)
- 1915 Albert Einstein developed the theory of General Relativity that predicts Black Holes
- 1958 David Finkelstein identified the event horizon (Schwarzchild surface)
- 1974 Steven Hawkin predicts Black Holes should radiate, inversely proportional to mass (Hawkin Radiation)

Basic Formulas

- **Newton's law of universal gravitation** states that every massive particle in the universe attracts every other massive particle with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

$$F = G\frac{m_1 m_2}{r^2}$$

- **"Escape Velocity"** is the initial speed required to go from an initial point in a gravitational potential field to infinity with a residual velocity of zero.

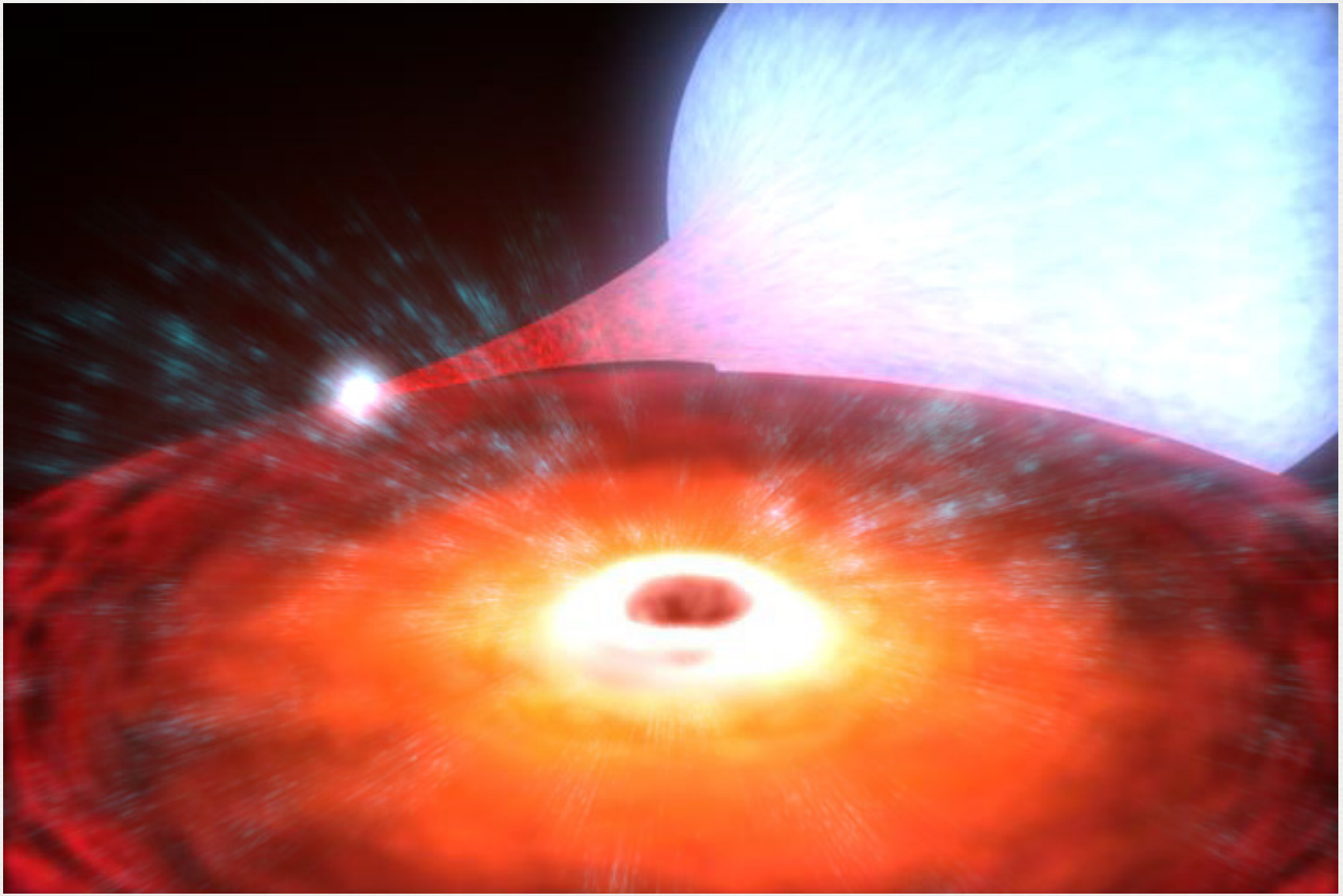
$$v_e = \sqrt{\frac{2GM}{r}}$$

- On the surface of the Earth, the escape velocity is about 11.2 kilometers per second (36,700 ft./sec)

Black Hole Formation

- Gravitational collapse of heavy objects like stars
- Neutron stars over 3-4 solar masses collapse to Black Holes
- Black Holes & Neutron Stars can be found in the center of a planetary nebula
- Black Holes grow and merge to form super-massive ones found in the center of galaxies
- Micro Black Holes can be formed by high energy collisions
    - (Large Hadron Collider is trying)

Binary Black Hole / Neutron Star



Artist Illustration

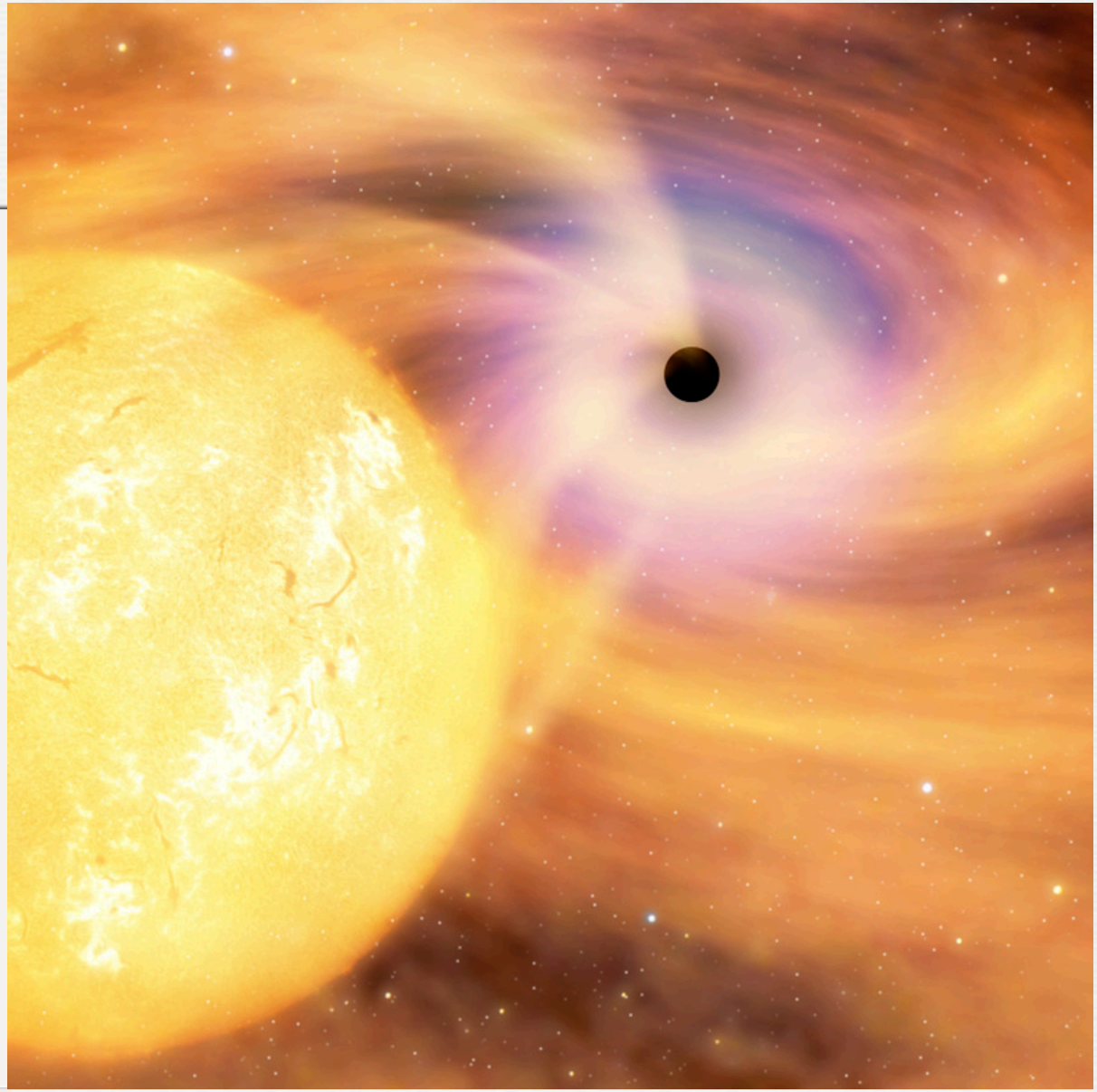
Basic Properties

- Mass, Angular Momentum (Spin) & Electric Charge
  - Charge and Spin are limited by size of Mass
- Black Hole Sizes in Mass (Event Horizon Radius)
  - Micro ~ up to mass of Moon (0.1mm)
  - Stellar = ~ 10 solar masses (30 km)
  - Intermediate ~ 1000 suns (1000 km)
  - Super-massive = 1 Million - Billions of Suns (<10 AU)

Evolution

- Micro Black Holes evaporate almost immediately
- Stellar Black Holes evaporate much slower than the cosmic radiation they absorb, so they grow, not shrink
- Stellar Black Holes absorb gas, dust, stars and other Black Holes to grow to intermediate and eventually super-massive size
- Black Holes are at the center of some star clusters and most galaxies
- Black Holes are scattered throughout galaxies (stellar and intermediate)
- The Black Holes, of merging galaxies, orbit around each other and create extreme velocities in the nearby matter (extreme red and blue shifts)

Black Hole taking a star



Artist Illustration

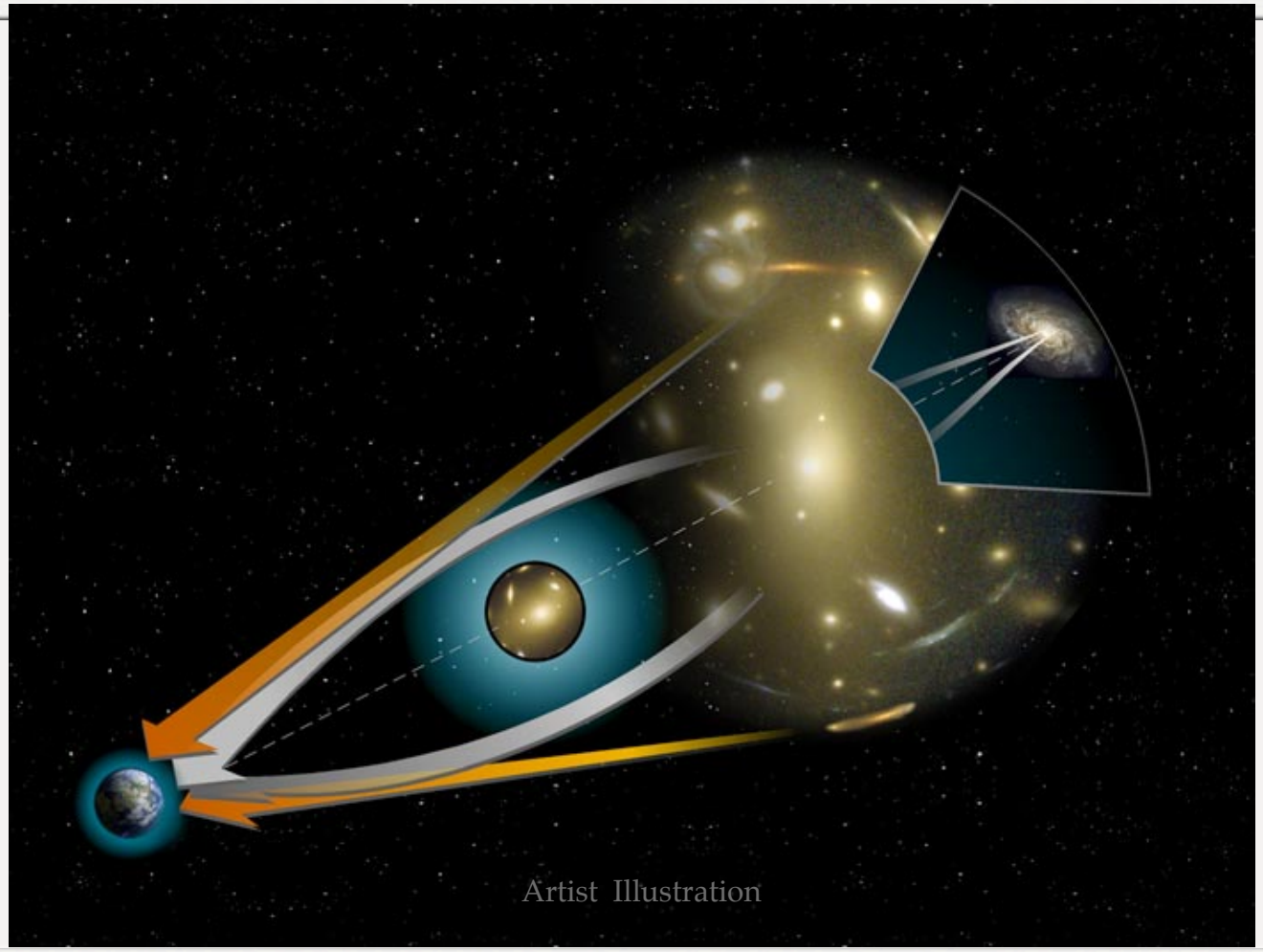
Galaxies merging

Artist Illustration

Event Horizon

- A boundary in spacetime through which light and matter cannot escape-- Schwartzschild radius
- For a distant observer, clocks appear to run more slowly near a Black Hole (Gravitational Time Dilation)
- Objects falling toward the event horizon appear to slow down and take infinite time to reach it AND all processes on the object slow down and cause emitted light to become redder and dimmer (Gravitational Redshift). Eventually, just before hitting the event horizon, the object becomes so dim it cannot be seen.
- However, to the falling observer, time seems normal, but he can't determine exactly when he crosses the event horizon

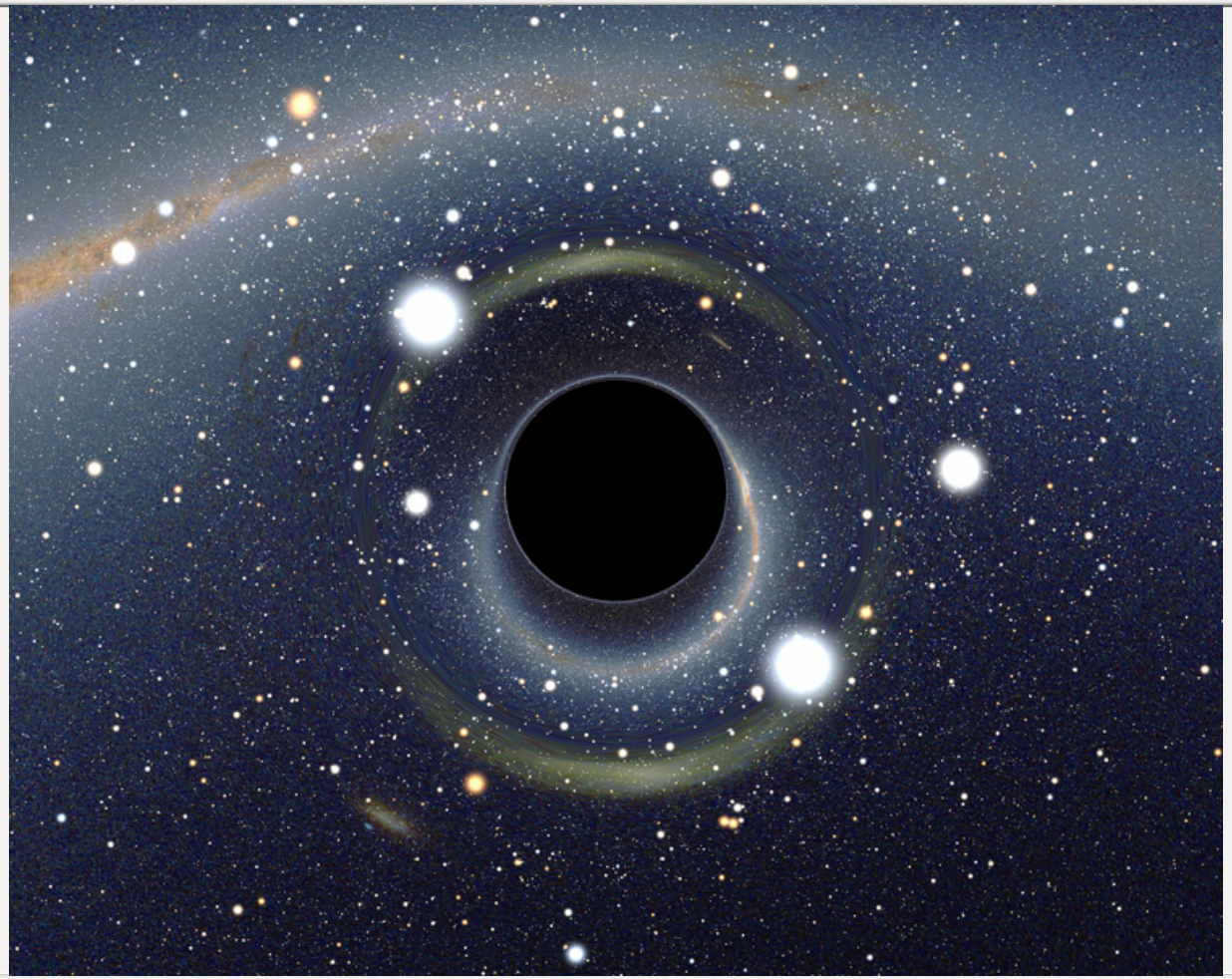
Gravitational Lensing
(Wikipedia Commons)

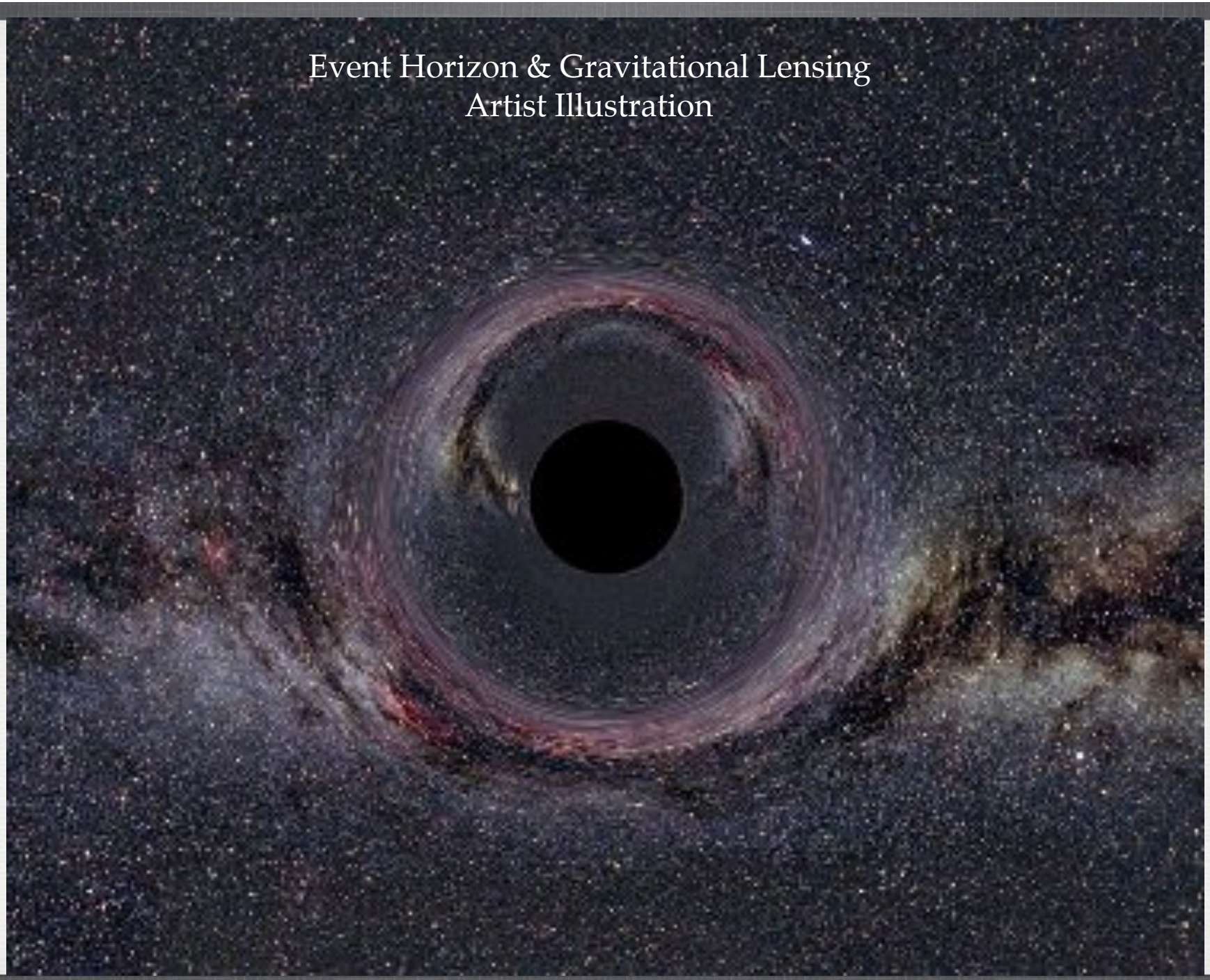


Artist Illustration

"Gravitational distortions caused by a black hole in front of the Large Magellanic Cloud"

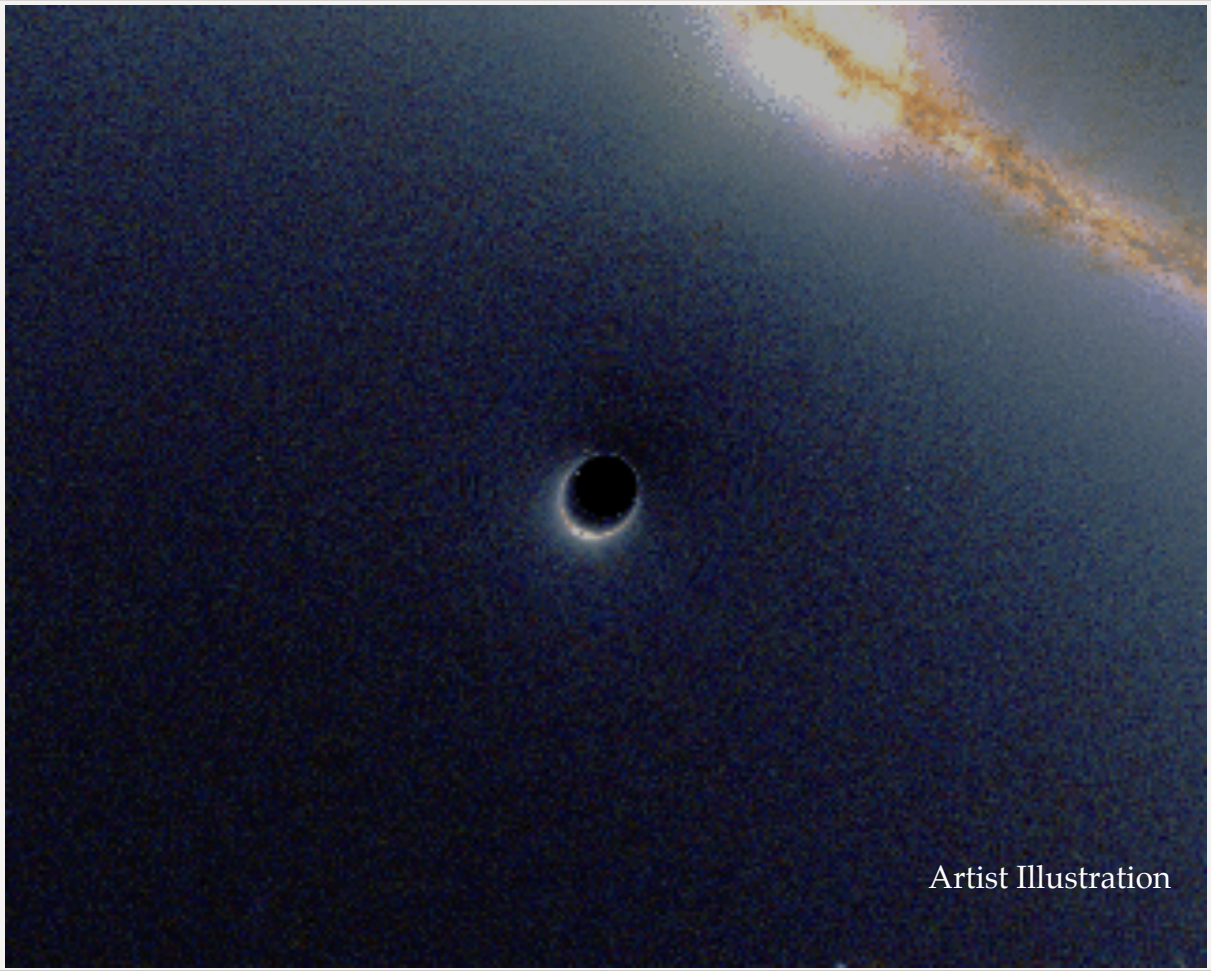
Ref: Wikipedia, Artist Illustration




Event Horizon & Gravitational Lensing
Artist Illustration

Black Hole Lensing

(Wikipedia)



Artist Illustration

Singularity

- The Gravitational Singularity at the center of a Black Hole is where density and spacetime curvature become infinite*
  - it is a POINT for a non-spinning Black Hole
  - it is a RING of zero volume for a spinning Black Hole
- *It is generally expected that a theory of quantum gravity will explain black holes without singularities.

Observational Evidence

Indirect Observations -- Black Holes are inherently invisible

- Gas falling into a Black Hole hole usually forms a hot disk of spinning material. This disk is heated so extremely by falling stars, neutron stars and other Black Holes that X-rays are emitted. The X-rays can be detected by telescopes. Up to 40% of mass in the accretion disk can be converted to radiation in this process.
- X-ray binaries are thought to be binaries of one Black Hole and one neutron star.
- Intense Gamma-ray Bursts (GRB) may indicate birth of Black Holes from collapse of giant stars or merger of neutron stars.
- Black Hole at center of Milky Way Galaxy is indicated by a bundle of extreme velocity star orbits observed with adaptive optics -- observations since 1998
- Similar observations for the center of Andromeda Galaxy, M32, M87, NGC 3115, NGC 3377, NGC 4258, and the Sombrero Galaxy

Black Hole characteristics have been observed sprinkled within some galaxies

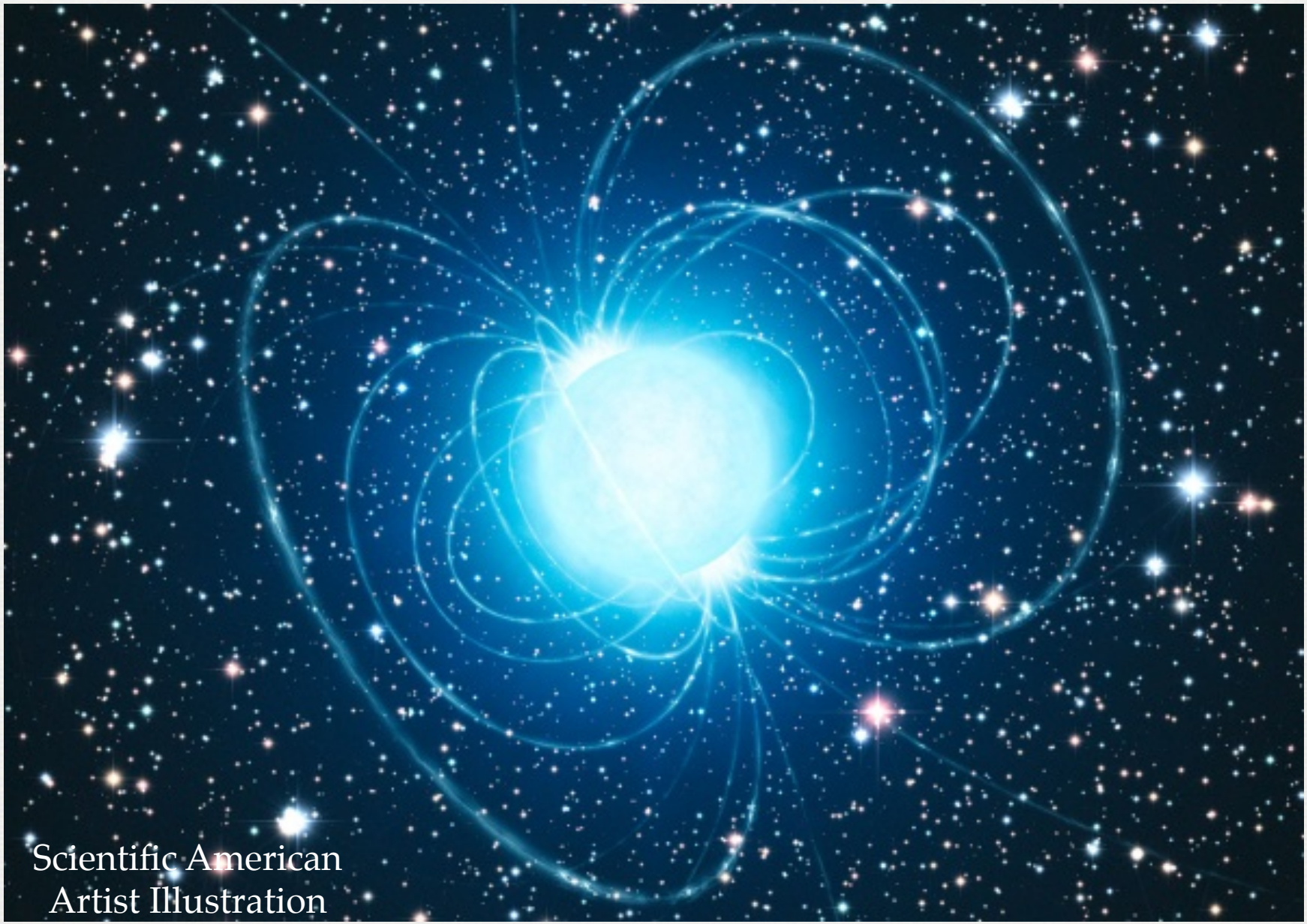
“This undated NASA image taken by the Spitzer Space Telescope shows an infrared view of the center of the Milky Way Galaxy. ... This detailed, false-color image shows older, cool stars in bluish hues. Reddish glowing dust clouds are associated with young, hot stars in stellar nurseries. The galactic center lies some 26,000 light-years away, toward the constellation Sagittarius. At that distance, this picture spans about 900 light-years.”

UPI/NASA/Newscom

Alternatives

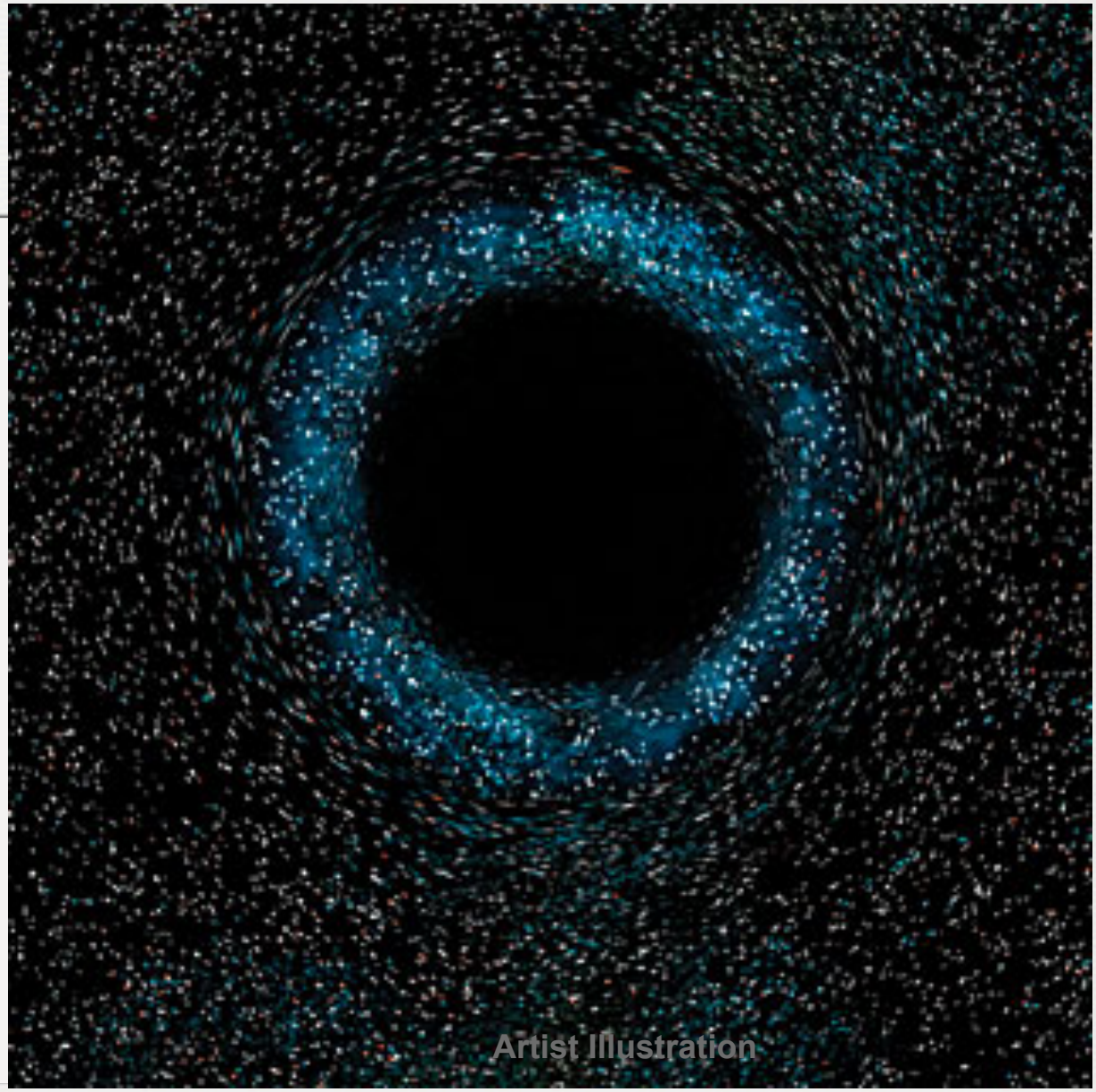
- Evidence for Black Holes relies on maximum calculated mass limit for neutron stars of about 3.4 solar masses – But, what if other high density forms of matter exist: Black Star?
- Quantum mechanics corrections to General Relativity may eliminate the singularity and define other forms of matter more dense than a neutron star.
- String theory indicates that both the singularity and the event horizon do not exist, so Black Holes per se may not be real--, but to an observer, they will look like Black Holes.

"Using ESO's Very Large Telescope, European astronomers have for the first time demonstrated that a **magnetar**, an unusual type of neutron star, was formed from a star with at least 40 times as much mass as the Sun."



Scientific American
Artist Illustration

Quantum theory predicts Black Stars



Some Questions

- Are Black holes the key to Galaxy formation? PROBABLY
- Are White Holes on the other side of Black Holes? POSSIBLY
- Can we detect the gravitational waves produced by merging super-massive "dancing" Black Holes in the center of merging galaxies? PROBABLY
- Are the characteristics of Peculiar Galaxies due to merging Black Holes (brightness and extreme redshift)? MAYBE
- Do Peculiar Galaxies have a corresponding blueshift that we have missed? MAYBE

NEWS

- Ohio State Simulation Results: Ref "onCampus", Ohio State publication, Sept 22, 2010--Quotes:

- Big galaxies formed much earlier in the universe's history than previously thought — within the first 1 billion years. These new computer simulations show that the first-ever super-massive black holes were likely born when those early galaxies collided and merged."

- First, gas and dust in the center of the galaxies condensed to form a tight nuclear disk. Then the disk became unstable, and the gas and dust contracted again to form an even denser cloud that eventually spawned a super-massive black hole.

- In our model, the black hole grows much faster than the galaxy. It could be that the galaxy is regulated by the growth of the black hole.

Black Hole being formed from gas

"Our result shows that big structures -- both galaxies and massive black holes -- build up quickly in the history of the Universe," said co-author Stelios Kazantzidis of Ohio State University.

Artist Illustration

More News

By *Denise Chow*, SPACE.com Staff Writer / May 25, 2010

- "In the first study, the erratic, unpredictable behavior of the super-massive black hole within the Andromeda galaxy ... They found that the black hole became 100 times brighter following an outburst on Jan. 6, 2006. After the outburst, however, the black hole entered another relatively dim state, but was still about ten times brighter on average than prior to 2006. The outburst suggests that a relatively high rate of matter had been falling onto the black hole, followed by a smaller, but still significant rate."

- " In another unexpected finding, a separate study demonstrated that a super-massive black hole previously thought to lurk in the core of a relatively nearby giant galaxy, called M87, is not actually located at the galaxy's center. Researchers used data from the Hubble Space Telescope to look more closely at the black hole, and found that the super-massive black hole in the M87 galaxy is, in fact, displaced from the center. The most likely cause for the black hole's position off center is a previous merger between two older, smaller super-massive black holes (SMBH)."

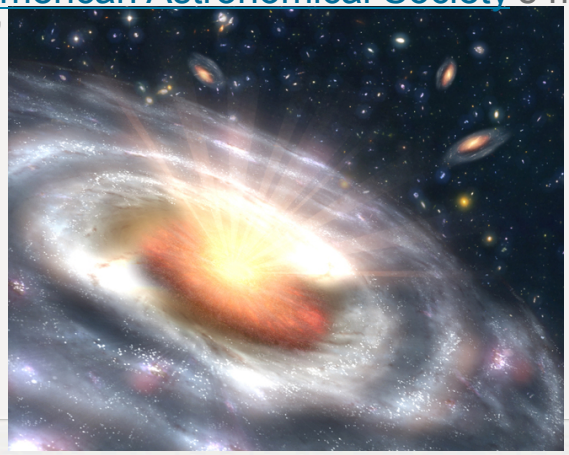
“It is the first time a quasar – the central region of a galaxy dominated by an energy-spewing black hole – has been discovered acting as a gravitational lens. The cosmic lens phenomenon was first predicted by Albert Einstein's theory of general relativity.” By *Clara Moskowitz*, SPACE.com Senior Writer / July 28, 2010

WIRED SCIENE
Yo Galaxy's Mama Is a Black Hole
By Clara Moskowitz January 7, 2009 | 11:52 am

"Lurking deep inside the center of almost all galaxies is a ravenous, super-massive black hole, and new research suggests the black hole may have given birth to its galaxy. ....By observing a series of galaxies and measuring the motions of swirling gas inside them, ... Black holes usually weigh about one one-thousandth of the mass of the galactic bulge.

But when the researchers looked at galaxies that were farther away, and thus effectively dating from earlier periods in the universe's history they found ... the black holes in the farthest away galaxies — the ones we are seeing in the youngest stage of development — were much larger than expected.

"The simplest conclusion is that the black holes come first and they somehow grow the galaxy around them," said astronomer Chris Carilli of the National Radio Astronomy Observatory during a briefing Wednesday at the American Astronomical Society's meeting in Long Beach, California."



Hundreds Of Rogue Black Holes May Roam The Milky Way, Swallowing Anything That Gets Too Close

ScienceDaily (Apr. 29, 2009) — It sounds like the plot of a sci-fi movie: rogue black holes roaming our galaxy, threatening to swallow anything that gets too close. In fact, new calculations by Ryan O'Leary and Avi Loeb (Harvard-Smithsonian Center for Astrophysics) suggest that hundreds of massive black holes, left over from the galaxy-building days of the early universe, may wander the Milky Way.

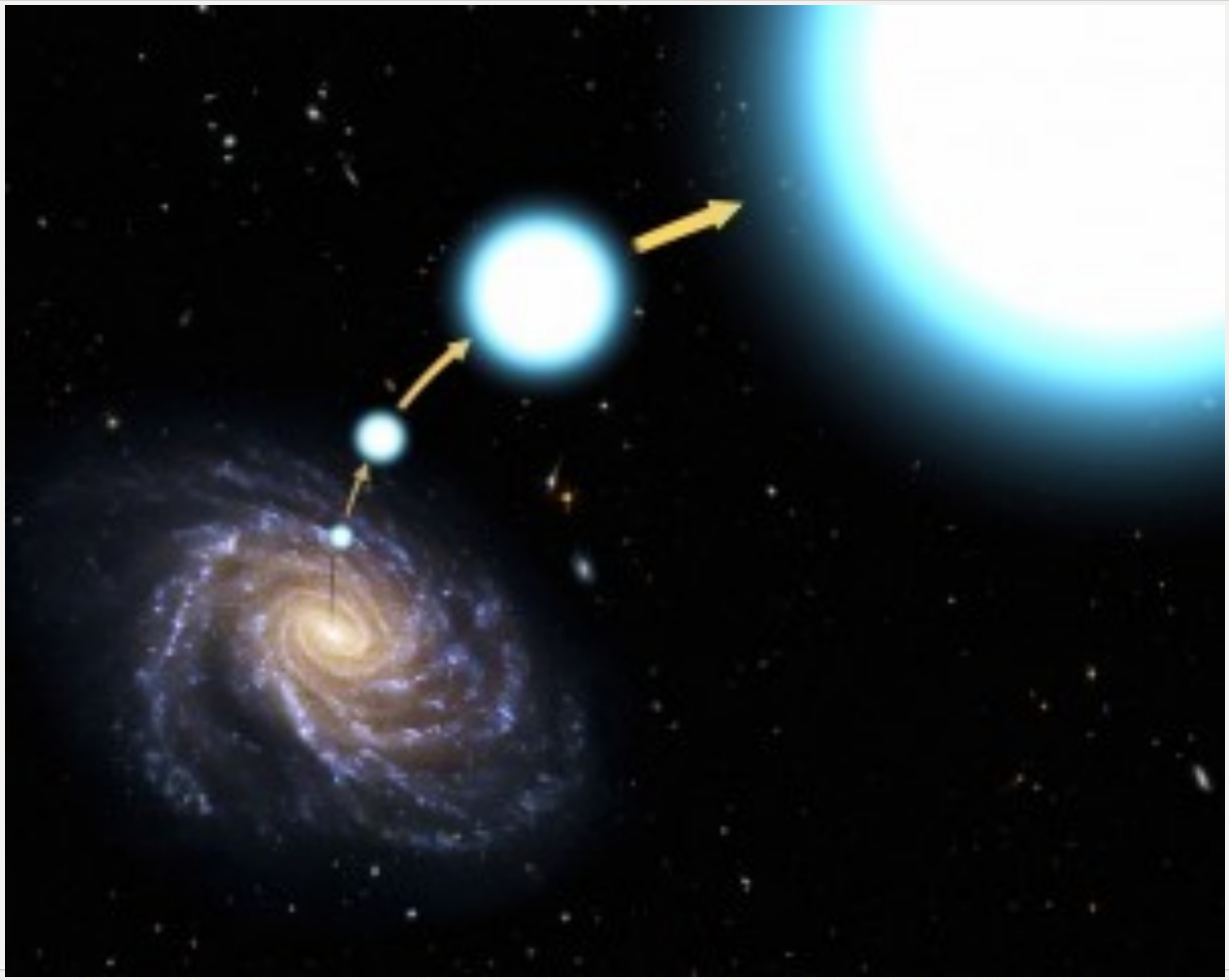
"Hundreds of rogue black holes should be traveling the Milky Way's outskirts, each containing the mass of 1,000 to 100,000 suns. They would be difficult to spot on their own because a black hole is visible only when it is swallowing, or accreting, matter."

http://www.sciencedaily.com/releases/2009/04/090429120851.html

Star kicked out by giant black hole

Posted on July 22nd, 2010

A runaway star found racing through space at an incredible 2.5 million km an hour (1.6 million mph), suffered a brush with a monster black hole at the heart of our galaxy, astronomers believe.



http://skymania.com/wp/2010/07/star-kicked-out-by-giant-black-hole.html

The Internet Encyclopedia of Science

- **"Arp, Halton Christian (1927–)** An American astronomer noted for challenging the theory that the large redshifts of quasars and other active galaxies are an indication of great distance. His *Atlas of Peculiar Galaxies*, published in 1966, contains photographs of 338 peculiar and interacting galaxies taken with the Hale Telescope, and was instrumental in raising the issue of discordant redshifts. Arp received a B.S. from Harvard (1949) and a Ph.D. from the California Institute of Technology (1953). "

- Maybe: Binary Central Black Holes, circling as a result of galaxy merger, produce the extreme redshift of some Peculiar Galaxies (rather than the velocity of the entire galaxy). Thus, Peculiar Galaxies may not be so far away as the redshift indicates.

Black holes 'do not exist' ???

Published online 31 March 2005 | Nature |
doi:10.1038/news050328-8

• George Chapline, an applied physicist at LLNL, "argues that a star doesn't simply collapse to form a black hole; instead, the space-time inside it becomes filled with dark energy and this has some intriguing gravitational effects."

• "Outside the 'surface' of a dark-energy star, it behaves much like a black hole, producing a strong gravitational tug. But inside, the 'negative' gravity of dark energy may cause matter to bounce back out again."

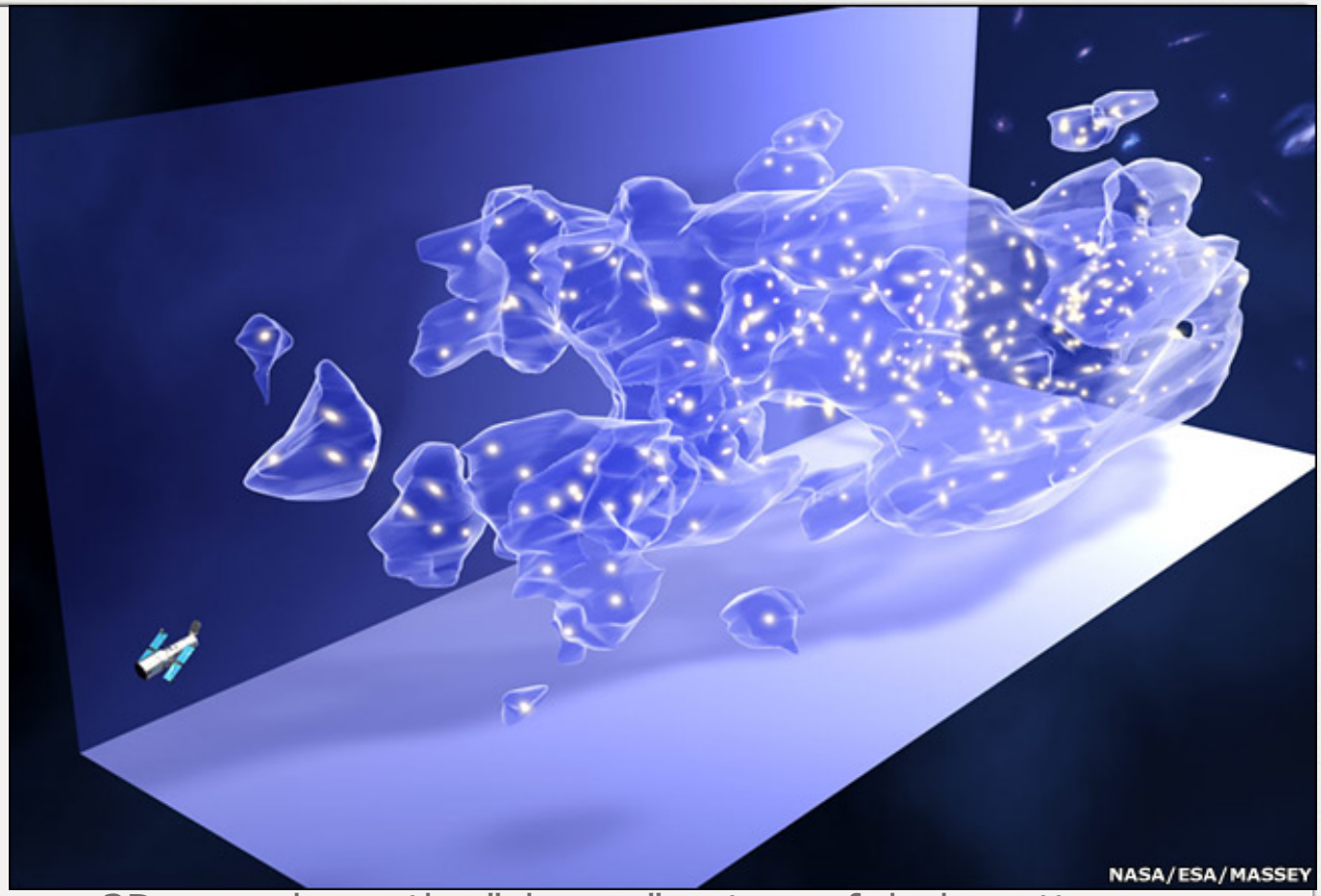
• "He also thinks that the Universe could be filled with 'primordial' dark-energy stars. These, he suggests, could be … the elusive substance known as dark matter."

Artist's conception of a black hole. *Credit: NASA*

No Singularity
No Event Horizon
Positron Release

Hubble makes 3D dark matter map

By Paul Rincon
Science reporter, BBC News, Seattle



- Hubble's new 3D map shows the "clumpy" nature of dark matter

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QUESTIONS?