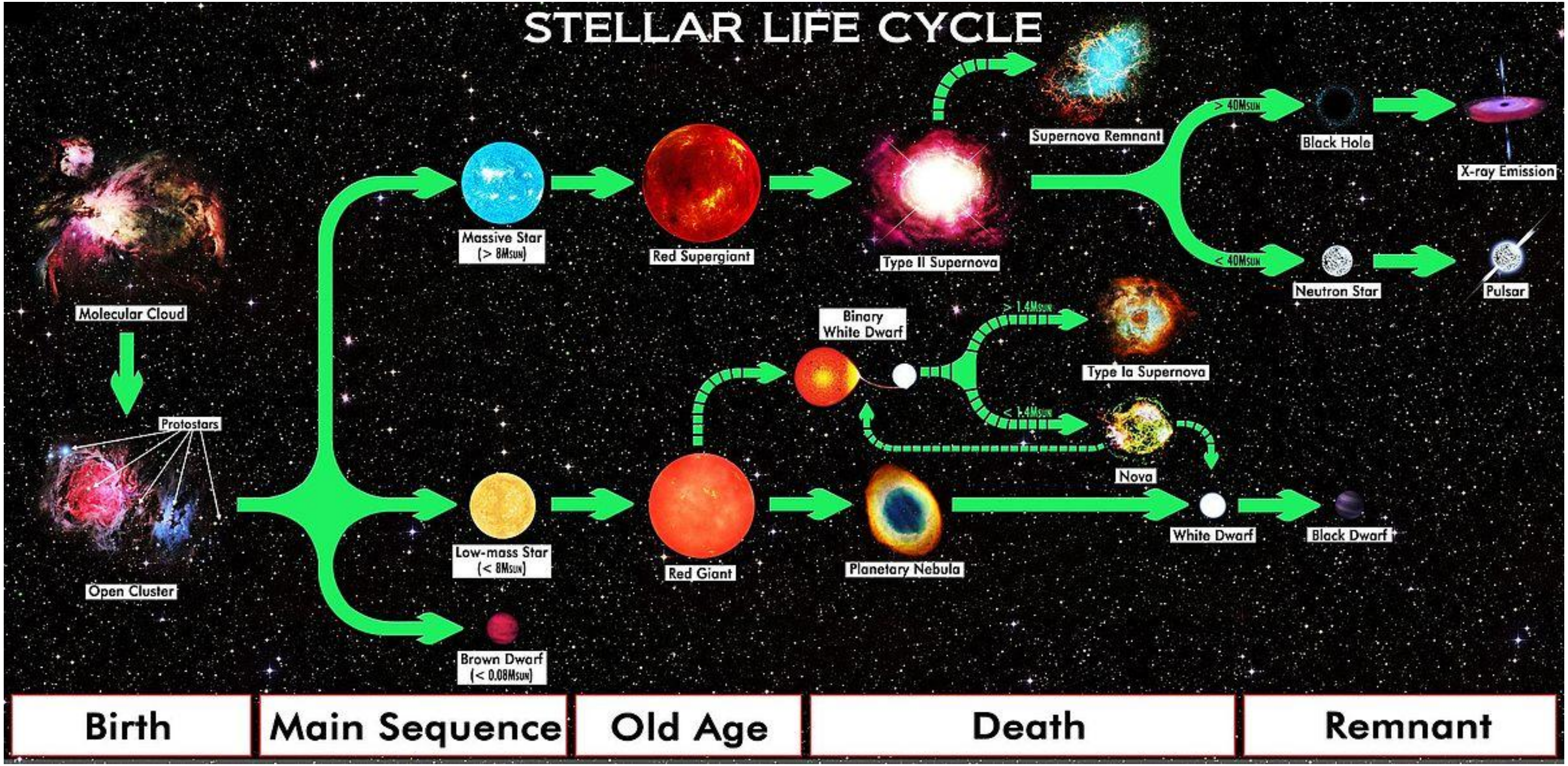
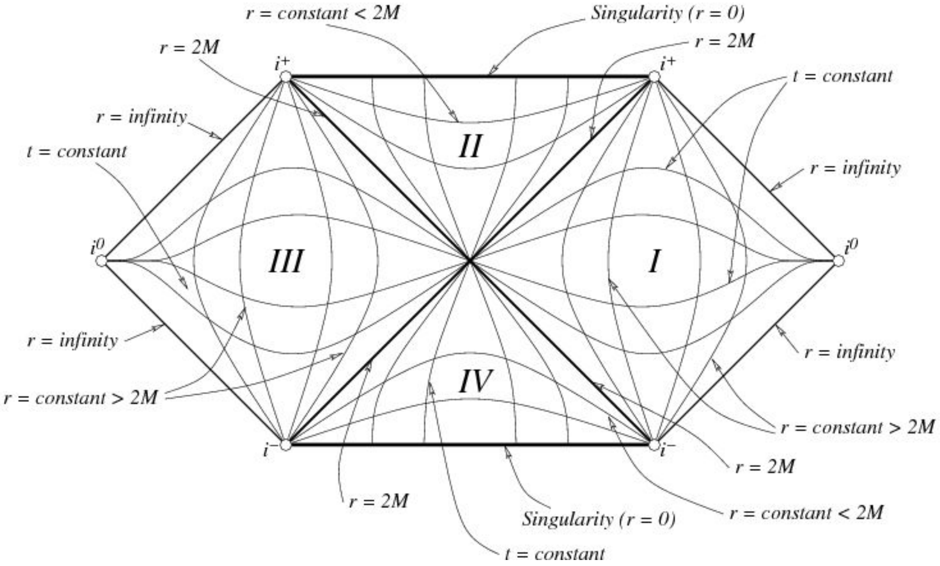
At the end of stellar evolution ...



... Black Holes

K.Schwarzschild 1916



ASTRONOMY

Science News Letter for January 18, 1964

"Black Holes" in Space

The heavy densely packed dying stars that speckle space may help determine how matter behaves when enclosed in its own gravitational field—By Ann Ewing

➤ SPACE may be peppered with "black holes."

This was suggested at the American Association for the Advancement of Science meeting in Cleveland by astronomers and physicists who are experts on what are called degenerate stars.

Degenerate stars are not Hollywood types with low morals. They are dying stars, or white dwarfs, and make up about 10% of all stars in the sky.

The faint light they emit comes from the little heat left in their last stages of life. It is not known how a star quietly declines to become a white dwarf.

Degenerate stars are made of densely packed electrons and nuclei, or cores of atoms. They are so dense that a thimbleful of their matter weighs a ton.

Some such stars are predicted in theory to have a density of one million tons per thimbleful. When this happens, the star is essentially made of neutrons and strange particles.

Because a degenerate star is so dense, its gravitational field is very strong. According to Einstein's general theory of relativity, as mass is added to a degenerate star a sudden collapse will take place and the intense gravitational field of the star will close in on itself.

Such a star then forms a "black hole" in the universe.

Modern tools, such as telescopes on an orbiting space platform, may be used to detect such black holes and to help determine how matter behaves when it is enclosed by its own gravitational field.

The light from the most famous white dwarf star, Sirius B, a companion to Sirius—which is the brightest star in the heavens visible from earth—has been captured using the 200-inch telescope atop Mt. Palomar. This was done as part of a program to study at least 20 white dwarfs.

Preliminary analysis of the light from Sirius B indicates that it has an effective temperature of 16,800 degrees Kelvin, or 30,000 degrees Fahrenheit. Its radius can be calculated from the temperature, and is only nine-thousandths that of the sun.

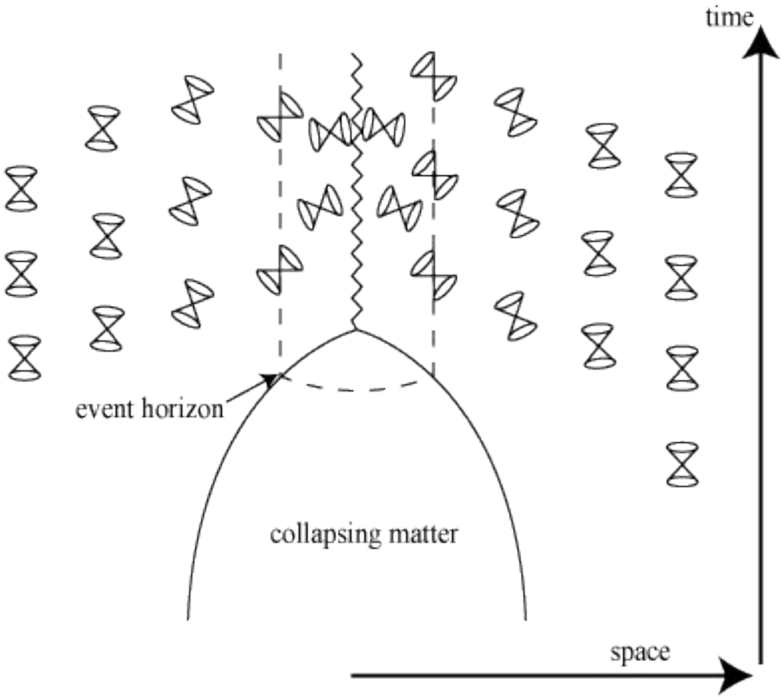
The star must therefore consist mainly of helium or heavier elements.

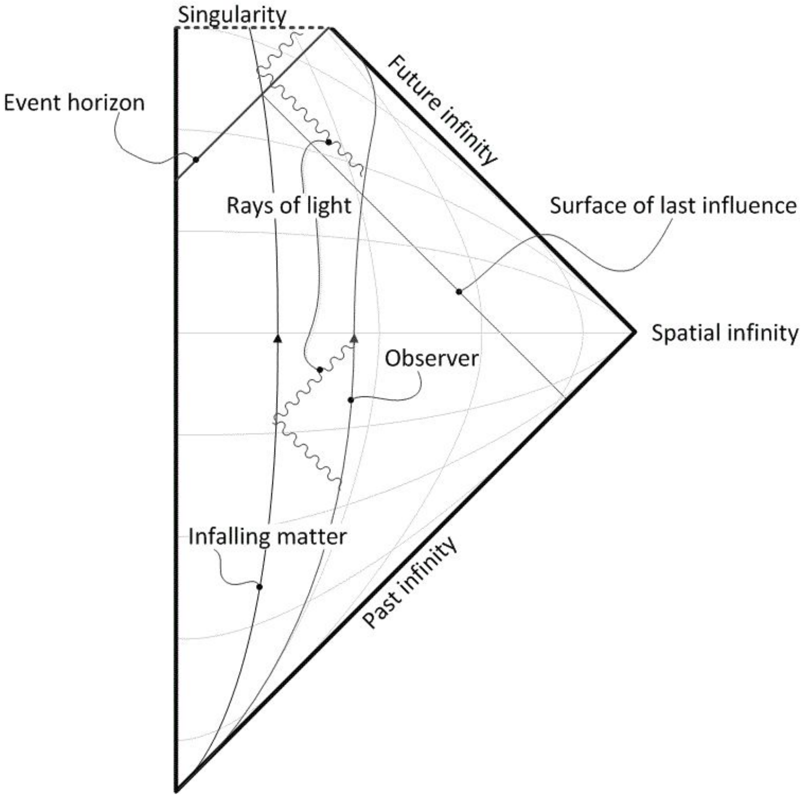
The speakers at the symposium were Drs. A. G. W. Cameron of the National Aeronautics and Space Administration's Goddard Institute for Space Studies, New York; Charles Misner of the University of Maryland; Volker Weidemann, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany, and J. B. Oke of California Institute of Technology. The symposium was arranged by Dr. Hong-yee Chiu of the Goddard Institute for Space Studies.

• Science News Letter, 85:39 Jan. 18, 1964

SPACE

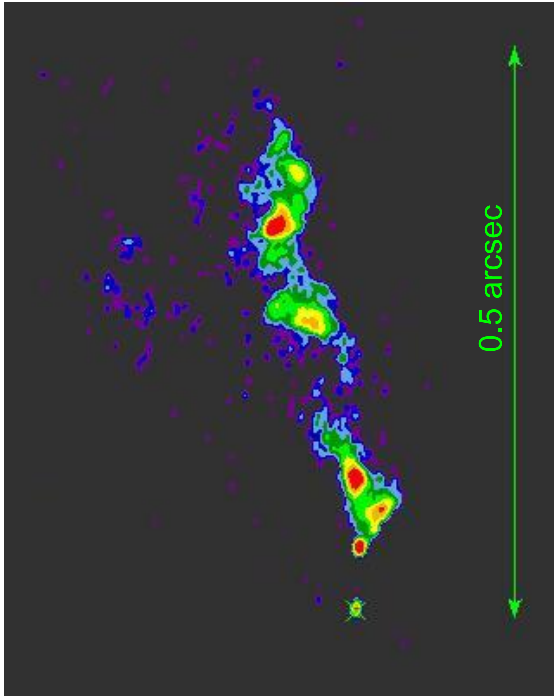
Gravitational collapse & black hole formation



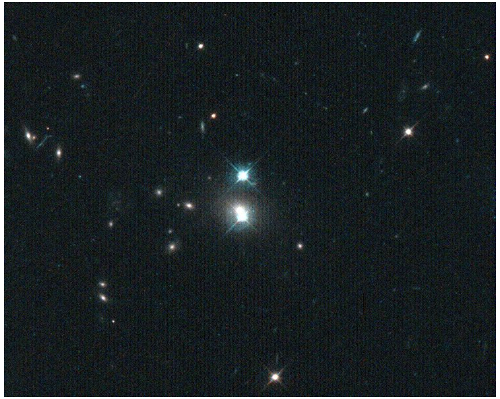


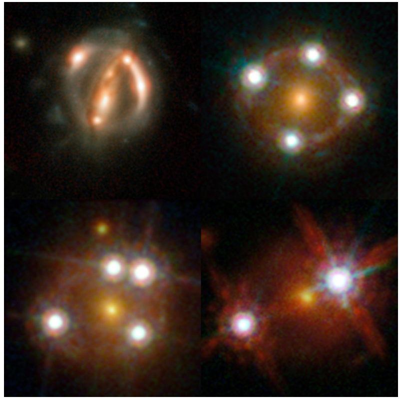
Quasars

C348 @ 1.4GHz



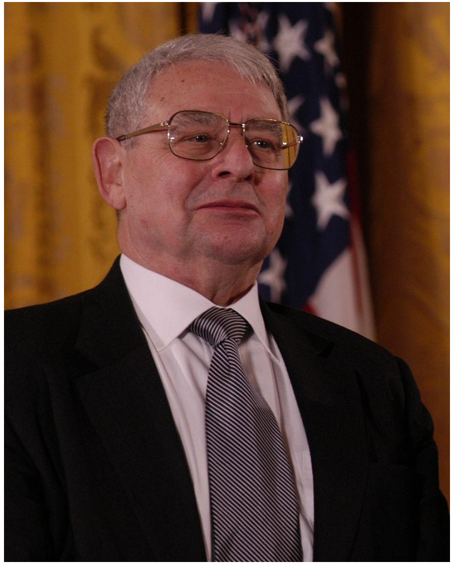
- 50s Radio sources of small size
- 60s Optical counterparts w\ High redshift (z ~ 7)
- Very luminous & extra-galactic? (> nuclear fusion, supernovae)
- 1964 Salpeter&Zeldovich: Supermassive BH + accretion disk
- Confirmed by
  - X ray observations of BH (*next slide*)
  - 1971 Peterson and Gunn: Galaxies containing quasars showed the same redshift as the quasars
  - 1979 Walsh,Carswell&Weyman: Grav. Lensing



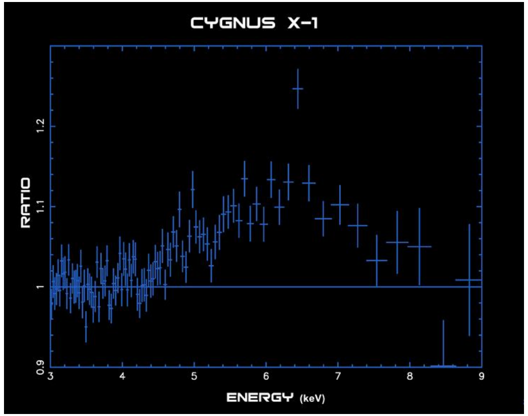


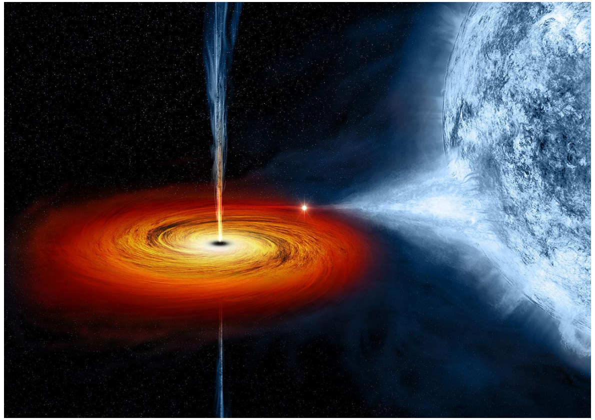
X-ray astronomy

- Hot gases at T ~ 1,000,000K emit X-ray
- 1962 Scorpius X-1
    - Strongest X-ray source together the Sun.
    - Low-Mass-X-ray binary
    - 1.4Mo NS + 0.42 star
- 1964 Cygnus X-1
    - High-Mass-X-ray binary
    - 14.8Mo BH + 20-40Mo supergiant star



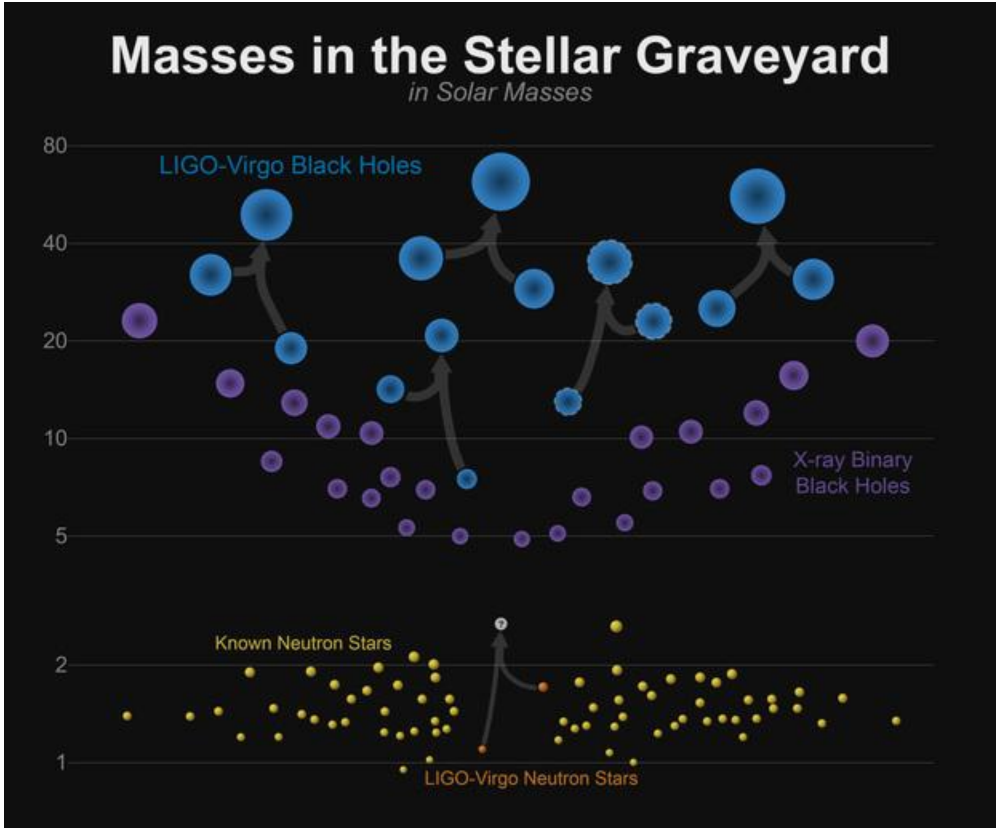
R.Giacconi Nobel Prize 2002

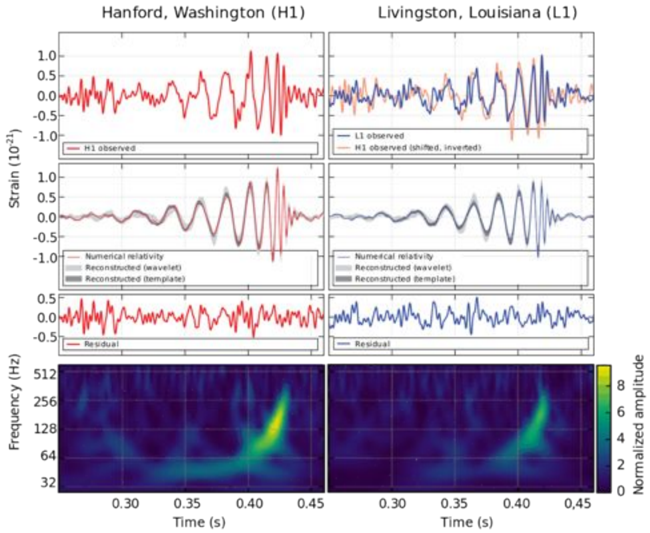


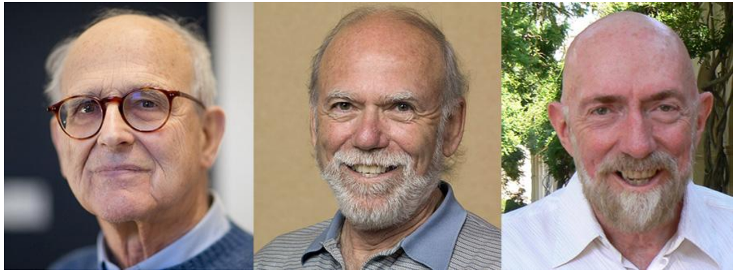


Gravitational waves from black hole collisions

since 2015, LIGO-Virgo observations

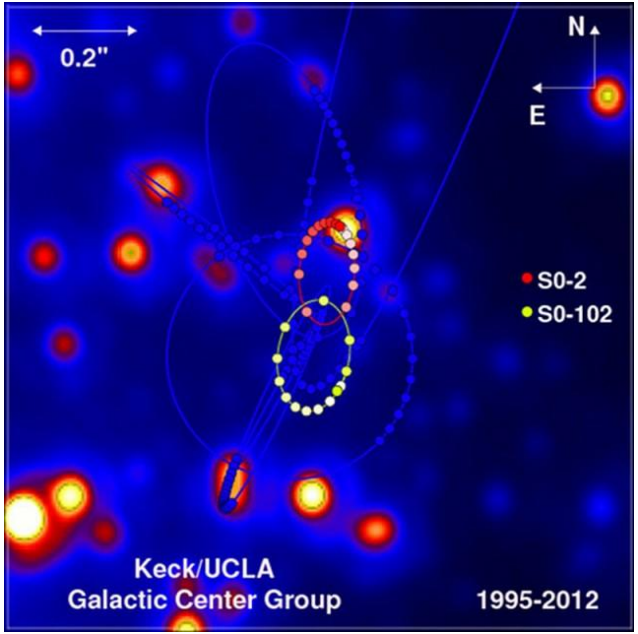


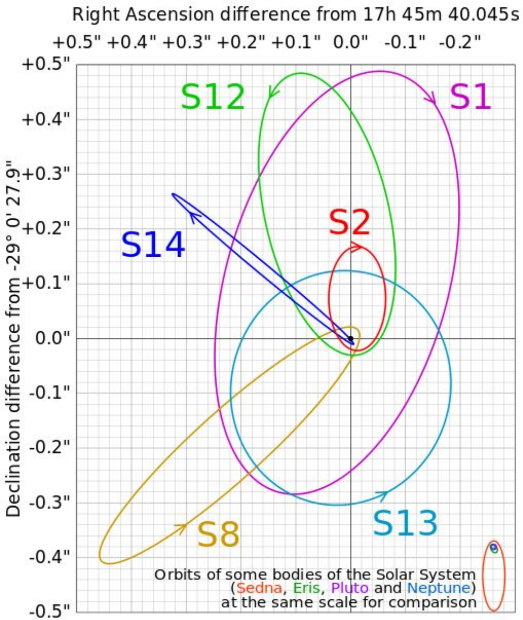




Weiss,Barish,Thorne Nobel Prize 2017

Sagittarius*A





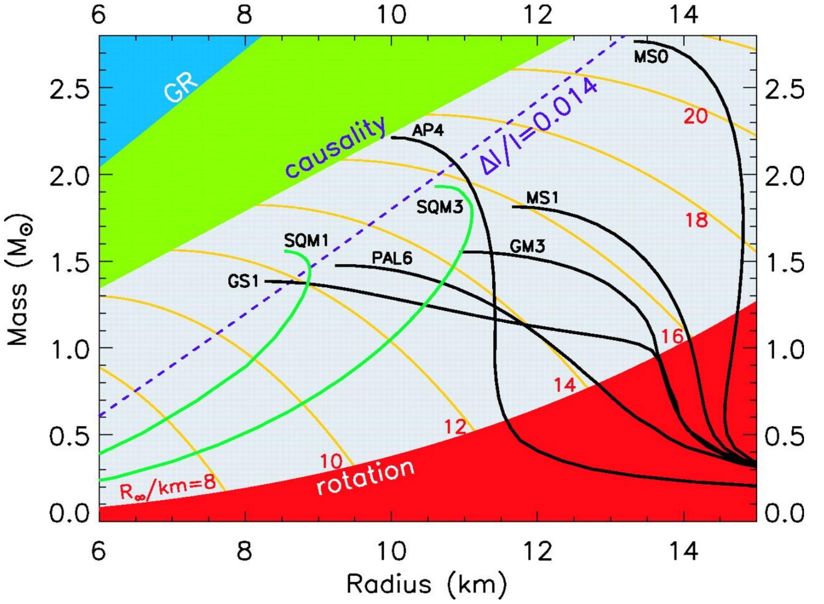
Galaxy center; Orbits' speed ~ 2% c

Mass ~ 4 million M_{Sun} ! => Supermassive BH

… Neutron stars

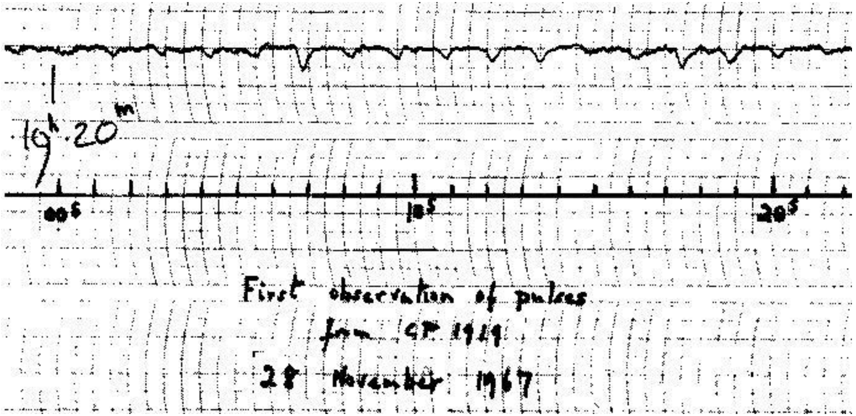
Baade / Zwicky 1933

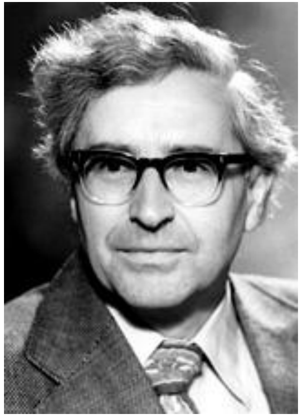
- Compact stars
  - $M \sim 1.5\, M_{sun}$, $R \sim 12$ km → $C = GM/(Rc^2) \sim 0.1$
  - $n \sim 0.3$ baryon/fm^3 (6-8 10^{14} g/cm3)
  - $T \sim 10^6$ K << $T_{Fermi} \sim 10^{12}$ K
- Formation: gravitational collapse of massive stars ($> 8M_{Sun}$, Type II SNCC)
- Extreme density matter
  → unknown composition and **equation of state** (**EOS**)
  P = P(n,T)
- Stellar models need to include GR effects
  - Tolmann–Oppenheimer–Volkoff equations
  - Spherical symmetry
  - EOS P=P(n) (in weak equilibrium)
- Maximum mass and stability



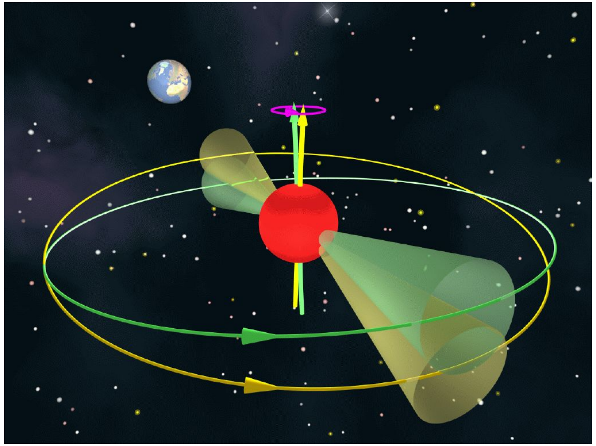
[Lattimer&Prakash 2004]

Pulsar observations

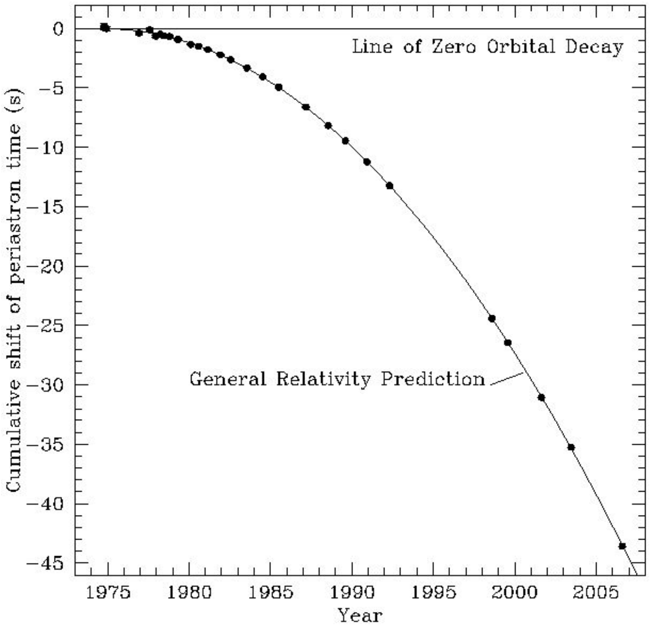




Bell / Hewish 1968
(Ryle & Hewish Nobel prize 1974)



Neutron stars in binary systems



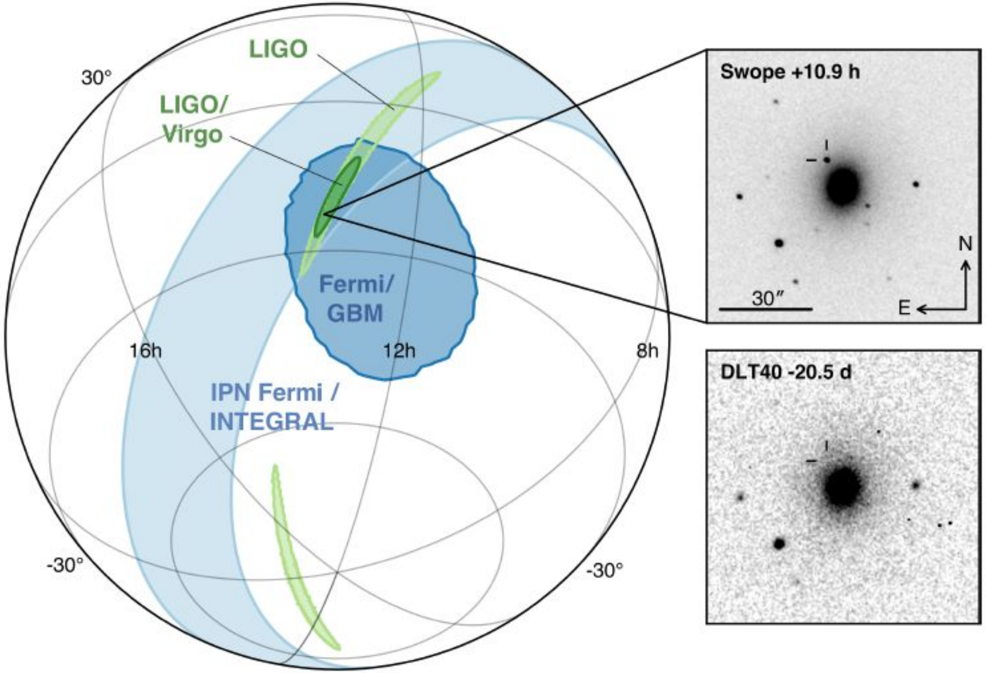
PSR B1913+16

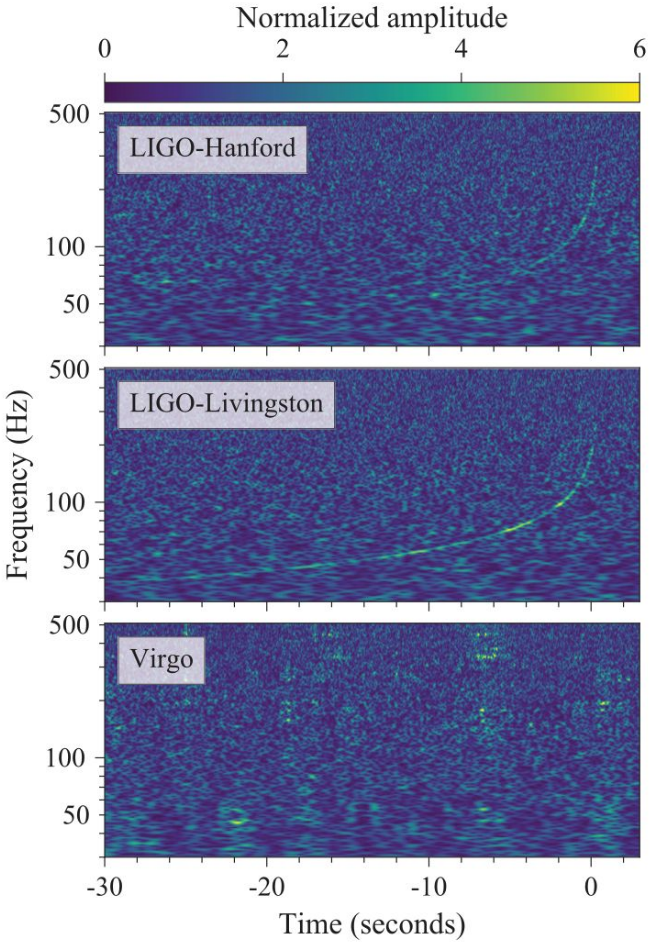
[Weisberg&Taylor 2004]

1993 Nobel prize: Hulse & Taylor

Gravitational and electromagnetic signals from a neutron star collision

August, 17th 2017, 12:41:01 UTC





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