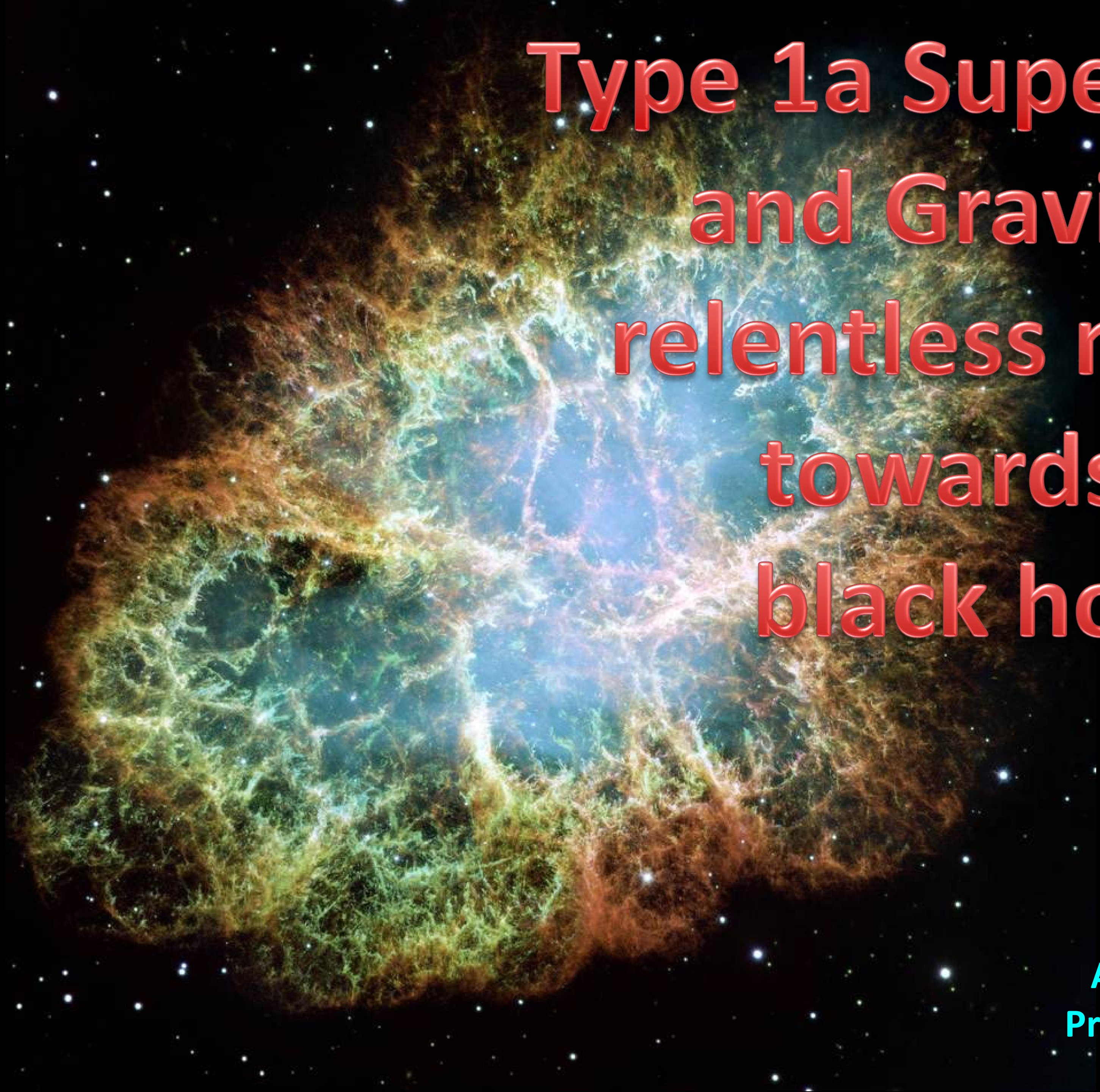
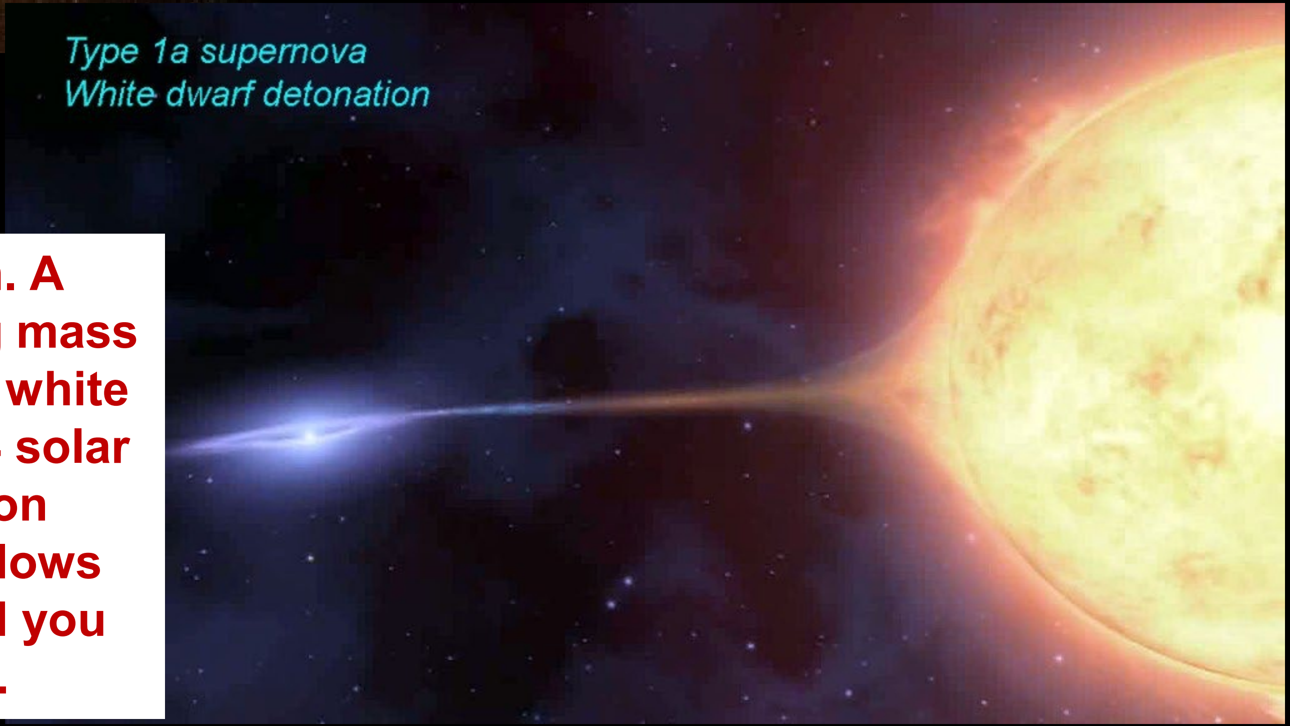


Type 1a Supernovae and Gravity’s relentless march towards a black hole

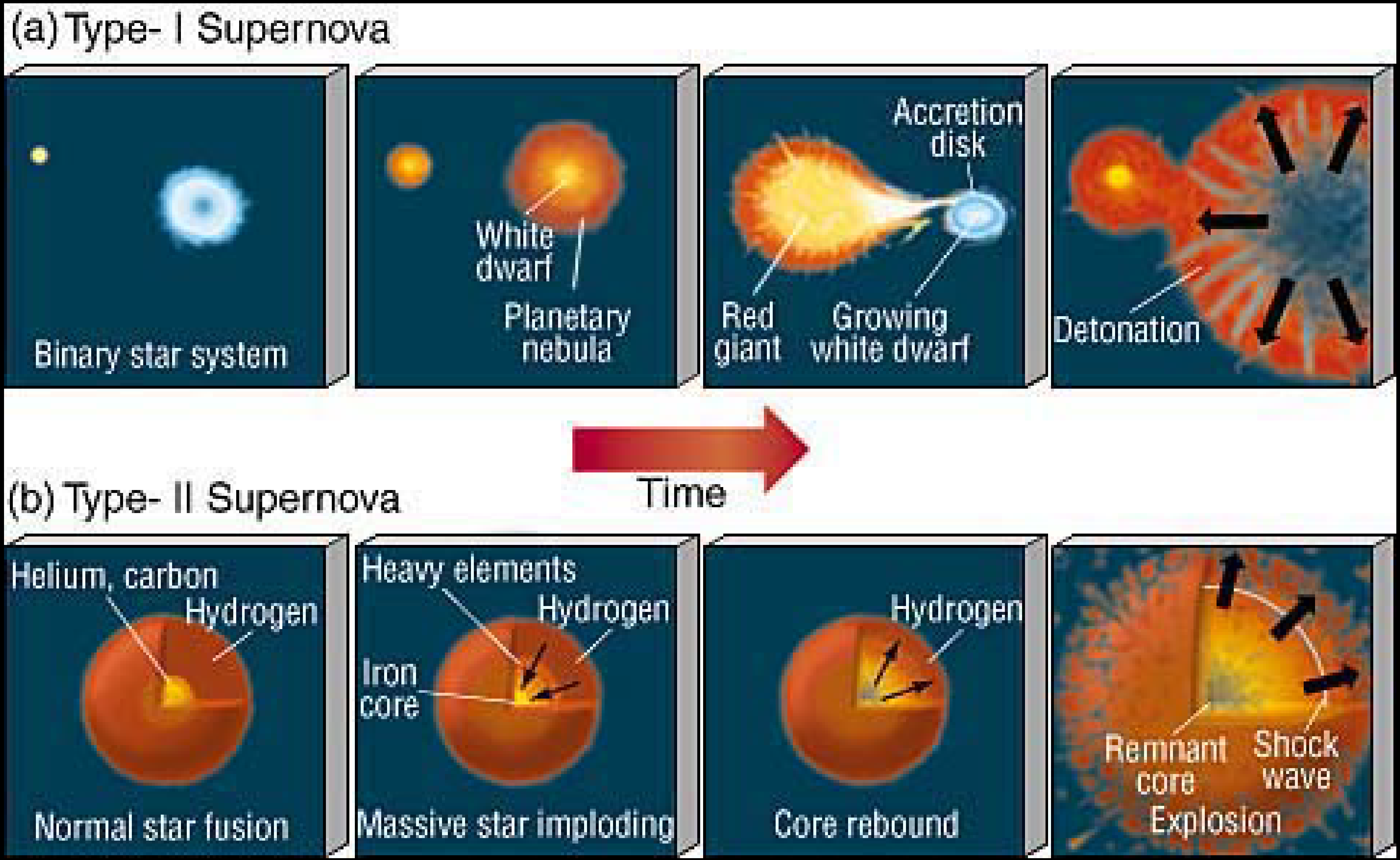
Astronomy 101
Prof. van der Veen

Type II Sn: When a massive star runs out of nuclear fuel, the iron core implodes under its own weight, the outer layers collapse, then rebound, blowing star apart, leaving behind a degenerate core of neutrons.

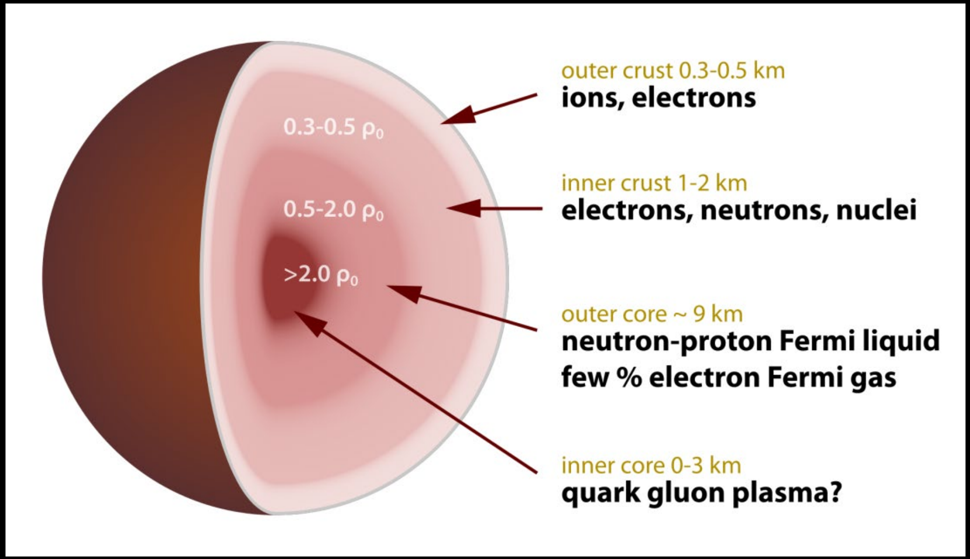


Type Ia Sn: binary system. A dense white dwarf pulling mass off larger companion; if a white dwarf's mass exceeds 1.4 solar masses, nuclear detonation happens on its surface, blows the white dwarf apart, and you have a Type Ia supernova.

Summary of the evolution of Type I and Type II supernovae:



Neutron stars – these extremely dense objects, a little more than a solar mass compressed into a ball with a radius of around 10 km, with density around 10^{17} grams/cm^3 (imagine a sugar cube weighing 10 million billion kg), in which protons and neutrons have been compressed together into neutrons by the star's enormous gravity.

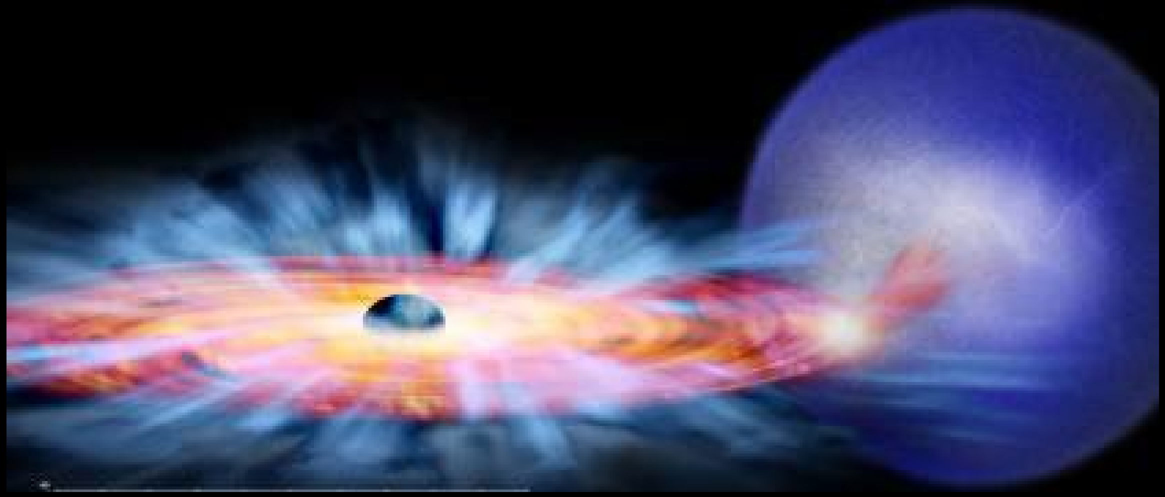


Theoretical models of what the interior of a neutron star could be made of are based on the laws of **QUANTUM MECHANICS**. At the surface, electrons and ions (nuclei with electrons stripped off) can co-exist, but deeper in the interior it is theorized that individual nuclei cannot exist, and what's left is a **quark**-**gluon** plasma.

In between the outer crust and the core of a neutron star, the pressure gradients and the competition between repulsive and attractive nuclear forces create states of matter that have been called **NUCLEAR PASTA**.

And be sure to watch this visualization of the phases of nuclear pasta HERE.

BUT…



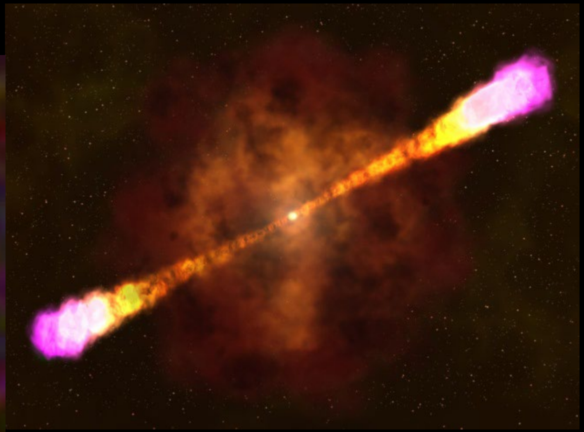
A neutron star greater than 2.16 or 2.17 SOLAR MASSES cannot hold itself up by neutron degeneracy pressure, and its gravity compresses it into a ...

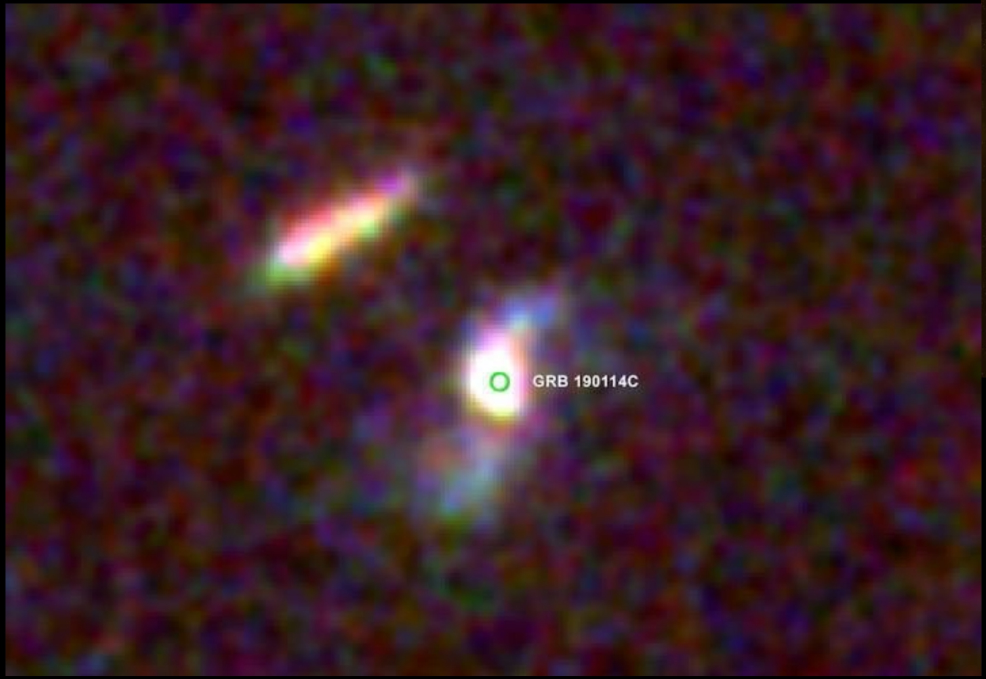

BLACK HOLE

Watch this video on the birth of a stellar black hole: http://www.youtube.com/watch?v=80HkL3EF2tc

gamma ray burst: announcing the birth of a black hole

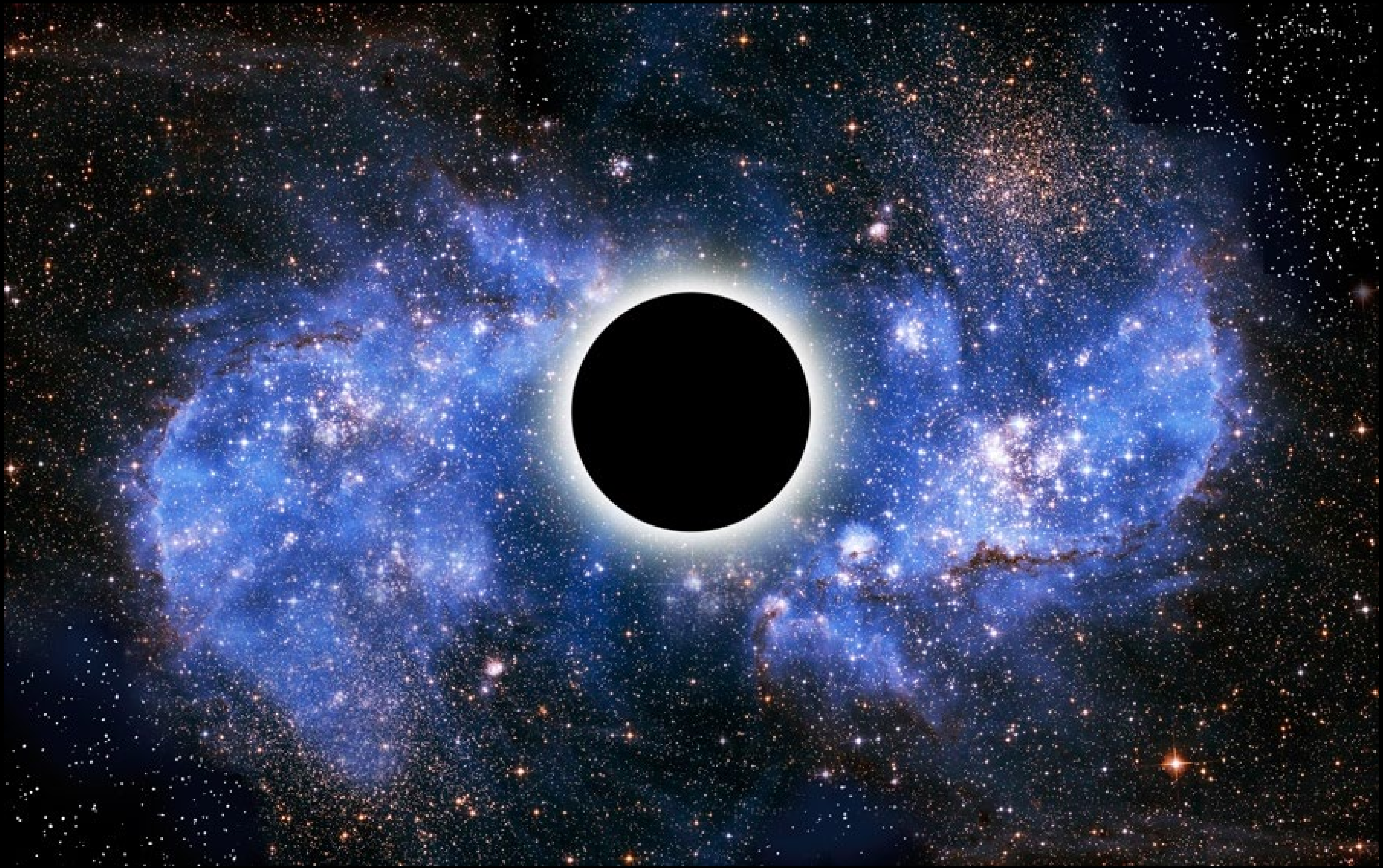
when a supermassive red giant becomes a black hole…





Gamma ray bursts - the most energetic radiation, which can be seen across the universe, indicates that a black hole is about to form!

The bending of spacetime inside a black hole is so extreme that spacetime is torn apart. Why?...



Einstein’s General Relativity Theory

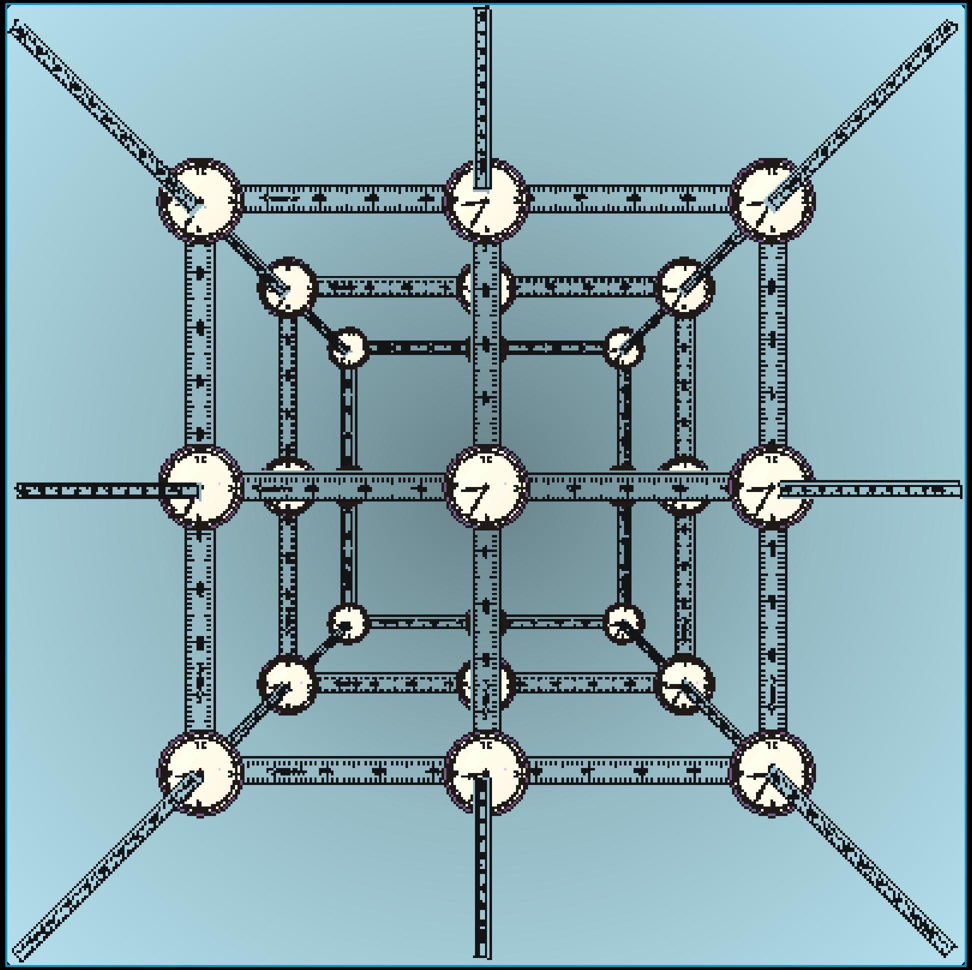
Mass and energy curve spacetime.

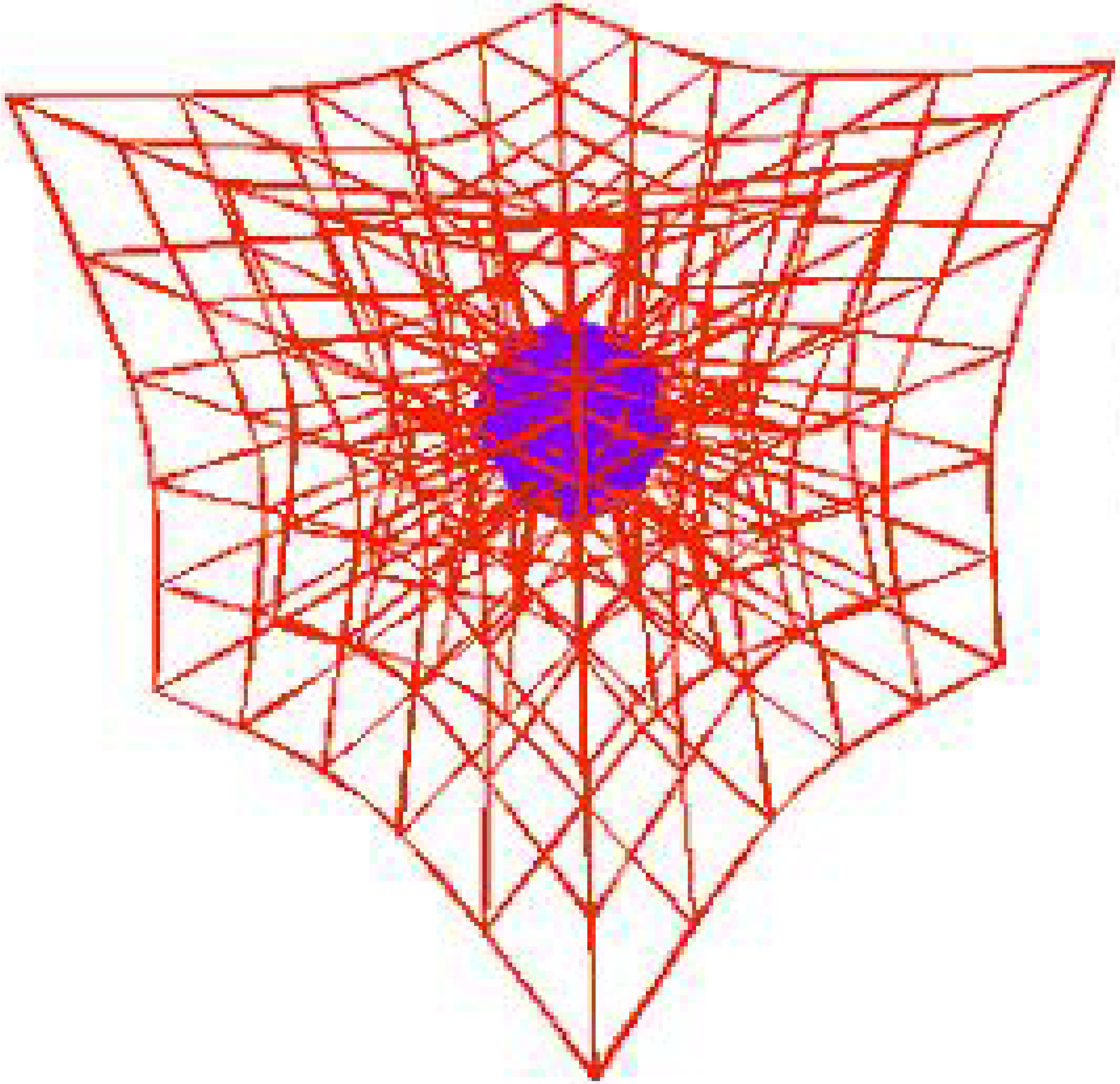
More details about Special and General Relativity and Quantum Mechanics in the next lecture!

THE EINSTEIN FIELD EQUATION

$$G_{\mu\nu} = 8\pi T_{\mu\nu}$$

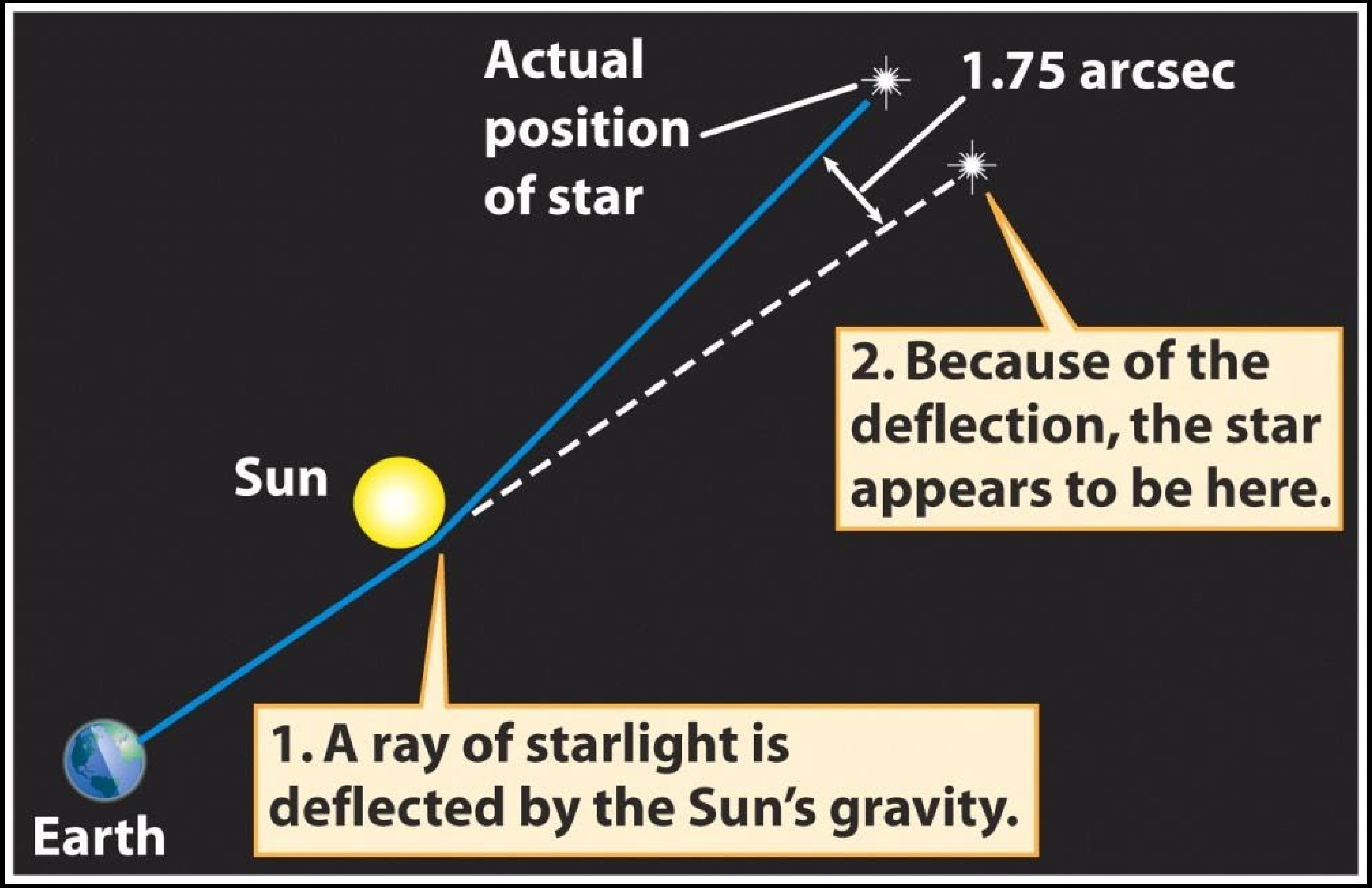
Curved spacetime is equivalent to a gravitational field, thus where ever you move your clock ('time ruler'), the curvature of spacetime is different, so the time ruler is stretched. Clocks tick at different rates due to the curvature of spacetime – i.e., the local gravitational field. The greater the gravity / curvature of spacetime, the slower the clocks run.

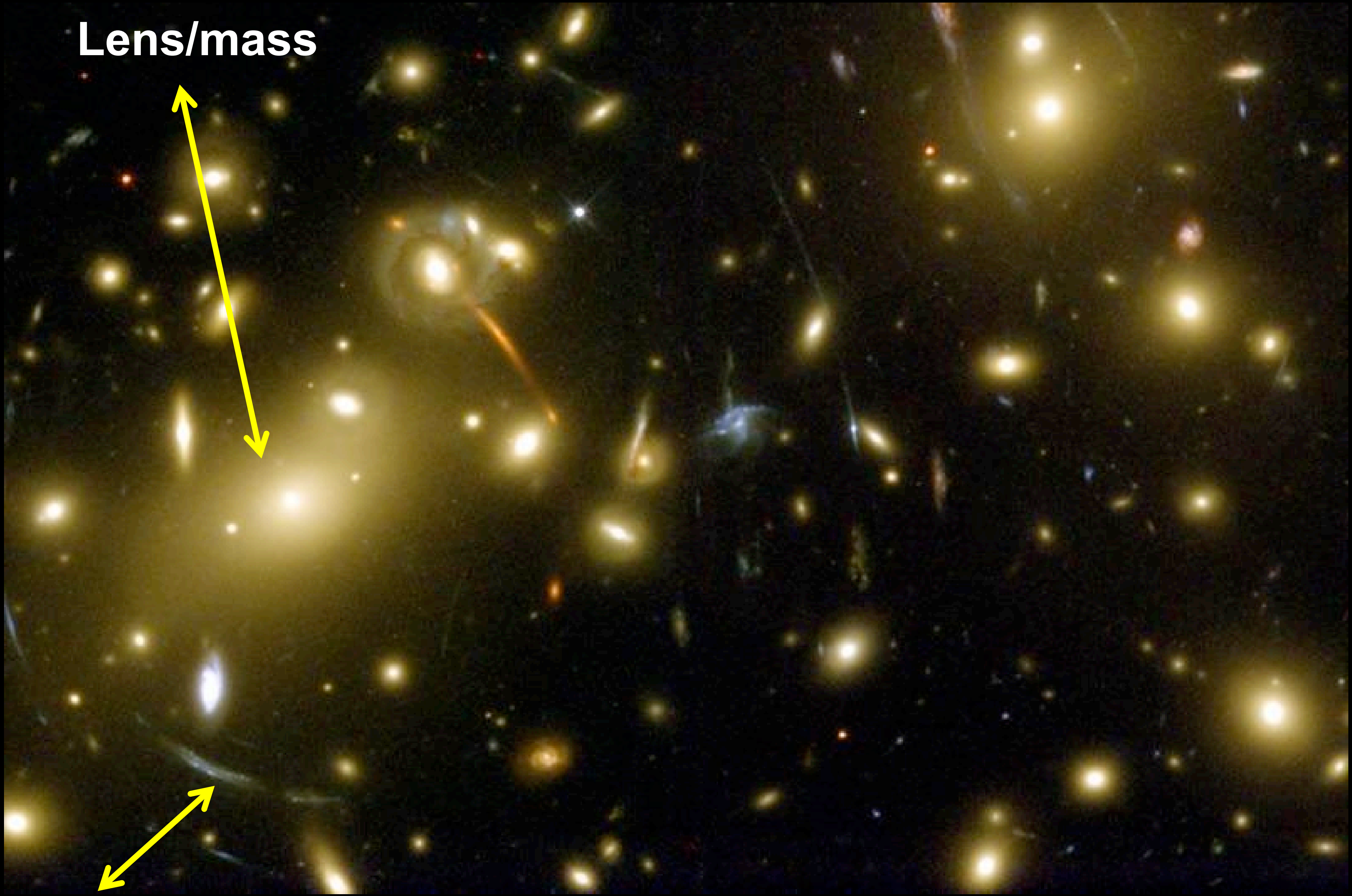




This three-dimensional grid gives a better idea of what curved space-time might look like than the two-dimensional analogies do.

Famous prediction of Einstein's general theory of relativity: Gravitational bending of light

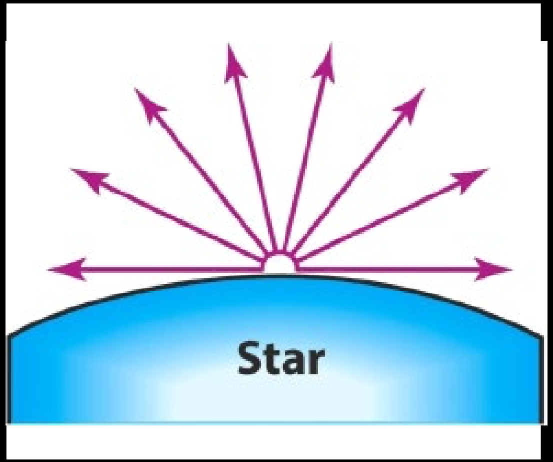


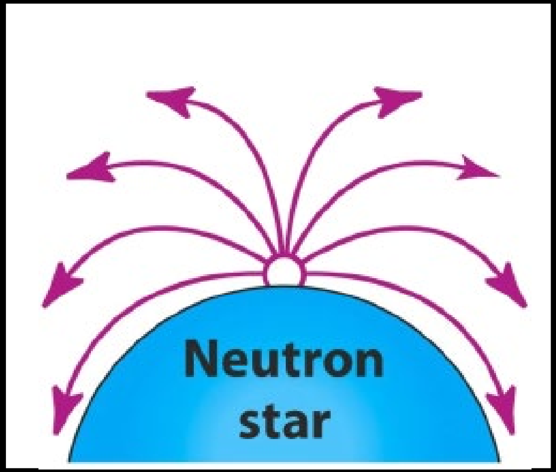


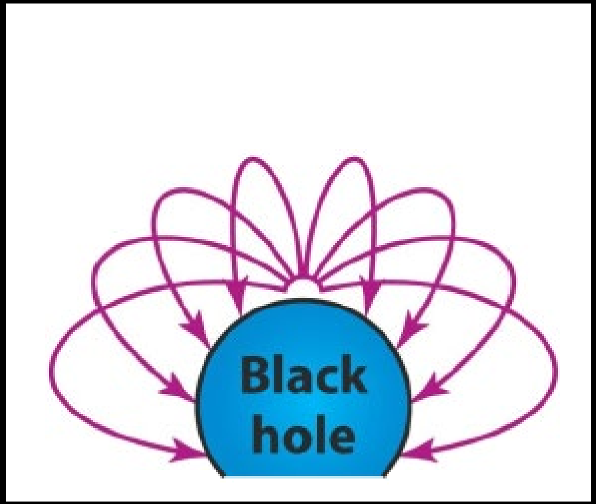
Distorted galaxy

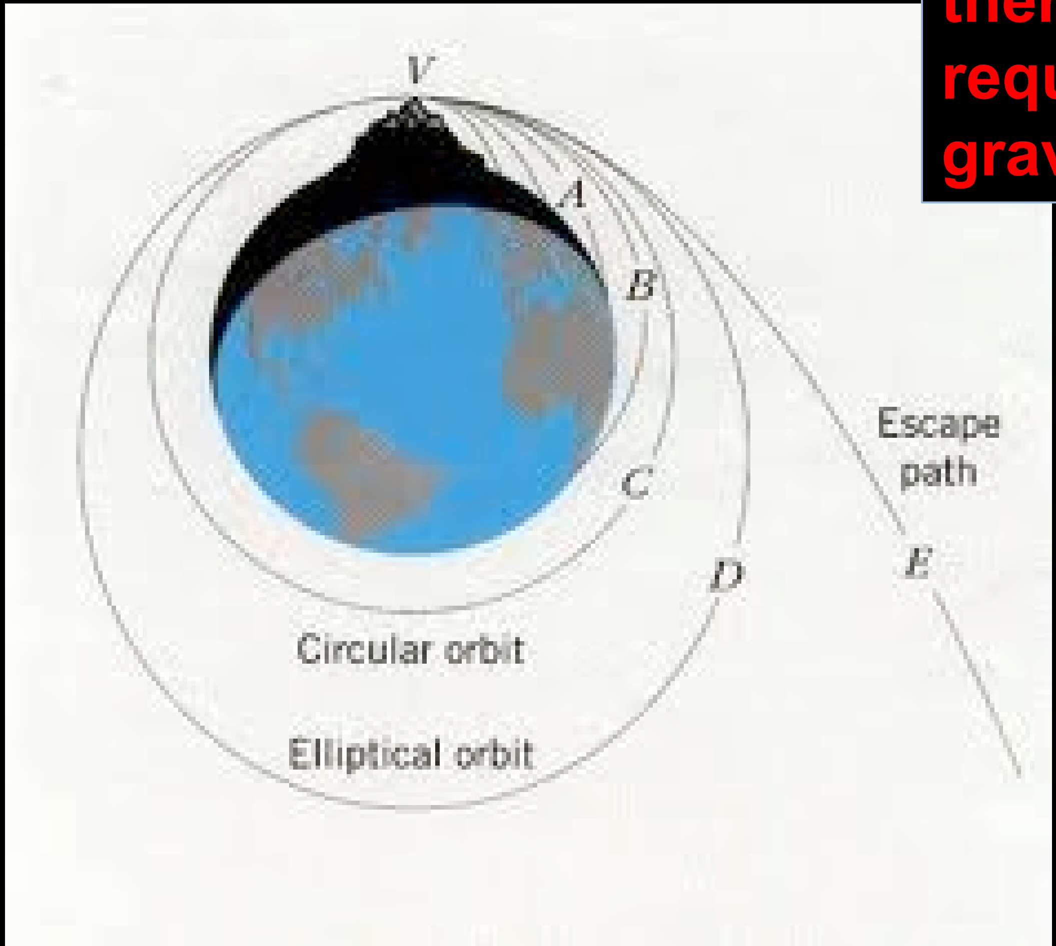
(real) Gravitational lens image

Representations of how compressing a mass into a smaller and smaller volume bends the paths of light.









For every massive object, there is a minimum speed required to escape its gravitational field.

$$\frac{1}{2}mv^2 = \frac{GMm}{R}$$

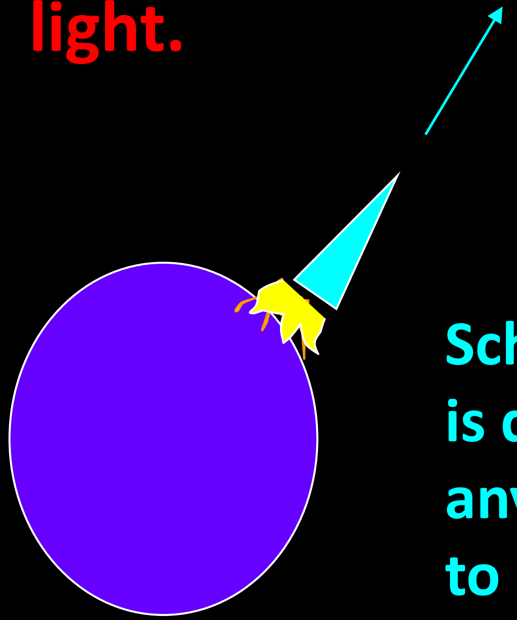
$$v_{esc} = \sqrt{\frac{2GM}{R}}$$

for Earth v_{esc} = 11.4 km/sec

For a black hole of ANY mass, its escape velocity is defined as the speed of light.

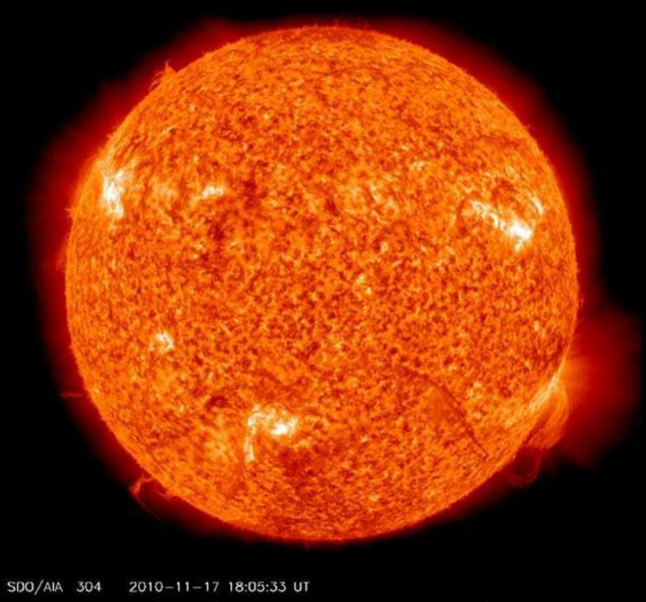
$$\frac{1}{2}mv^2 = \frac{GMm}{R}$$

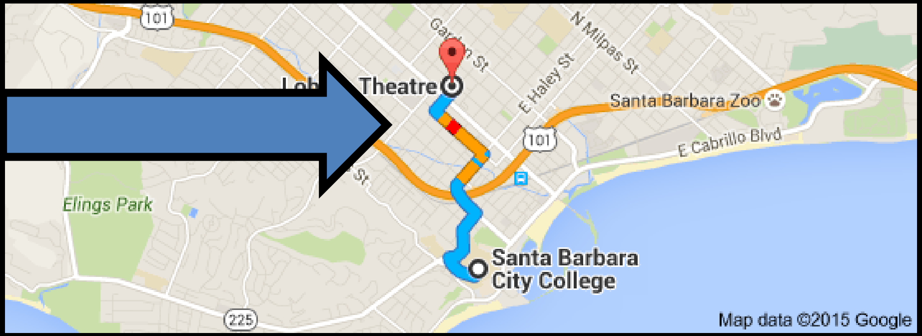
$$v = \sqrt{\frac{2GM}{R}} = c$$

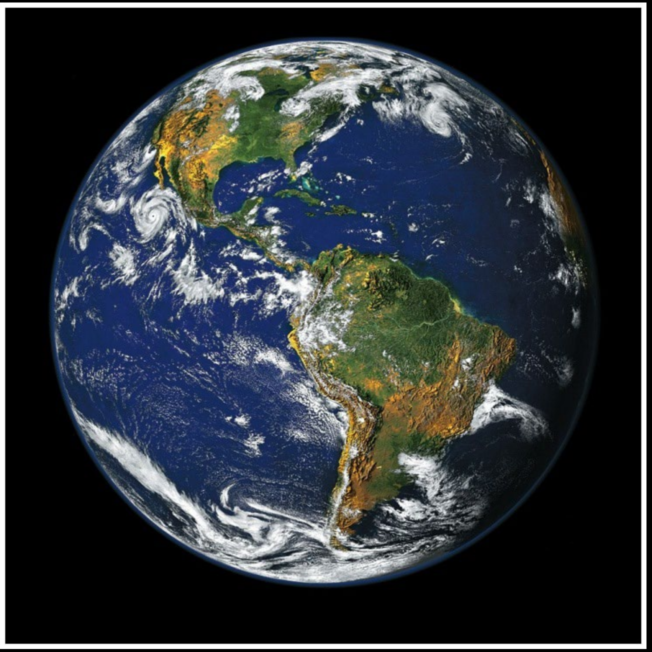


Schwartzhchild Radius
is defined as the radius
any mass must be shrunken
to so that the escape velocity is
equal to the speed of light.

If the Sun were squished down to a radius of around 3 km, it would be a black hole!



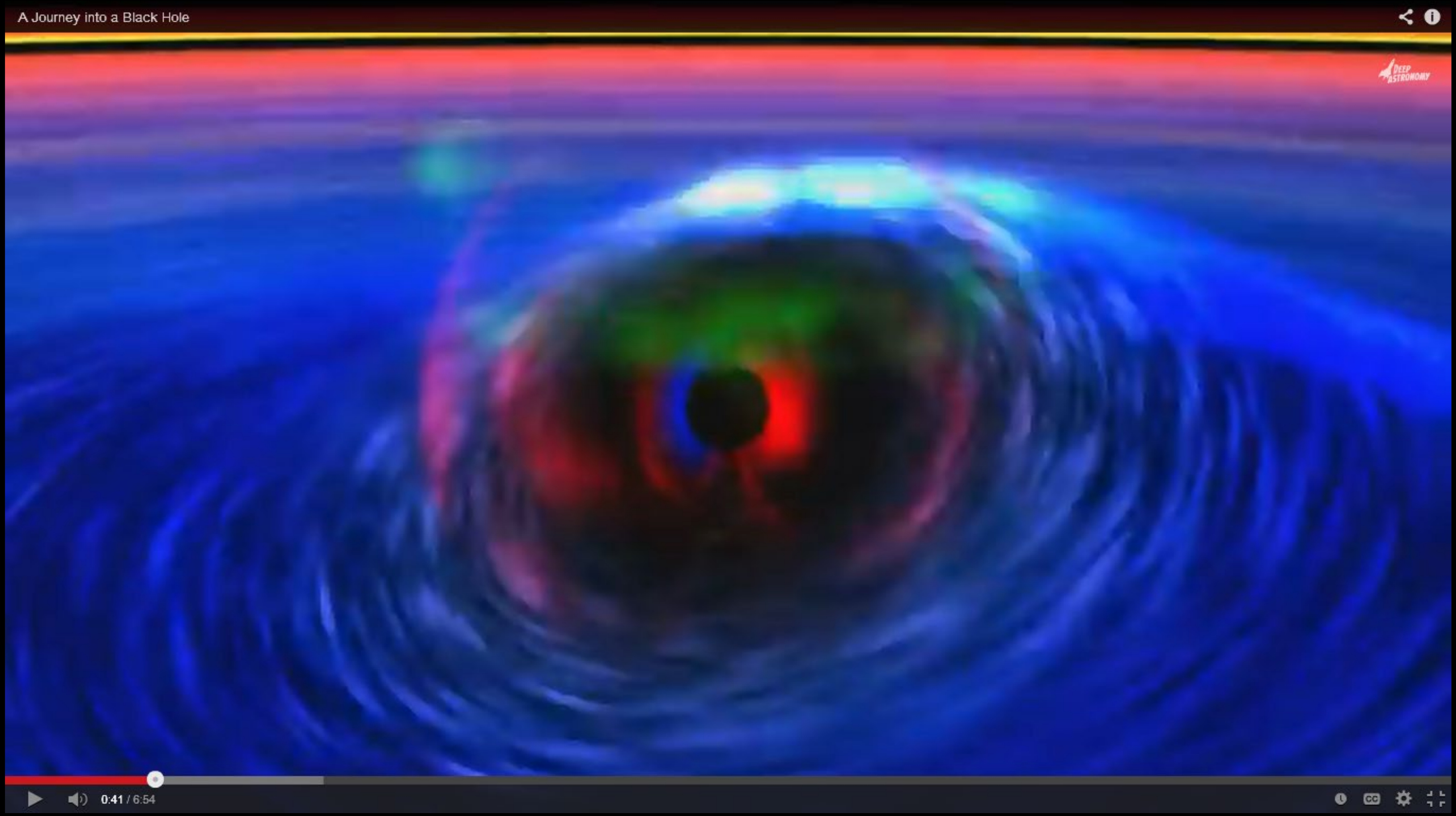




If the Earth were squished down to the size of a single chickpea, it would be a black hole!

What to expect if you journey inside a black hole:

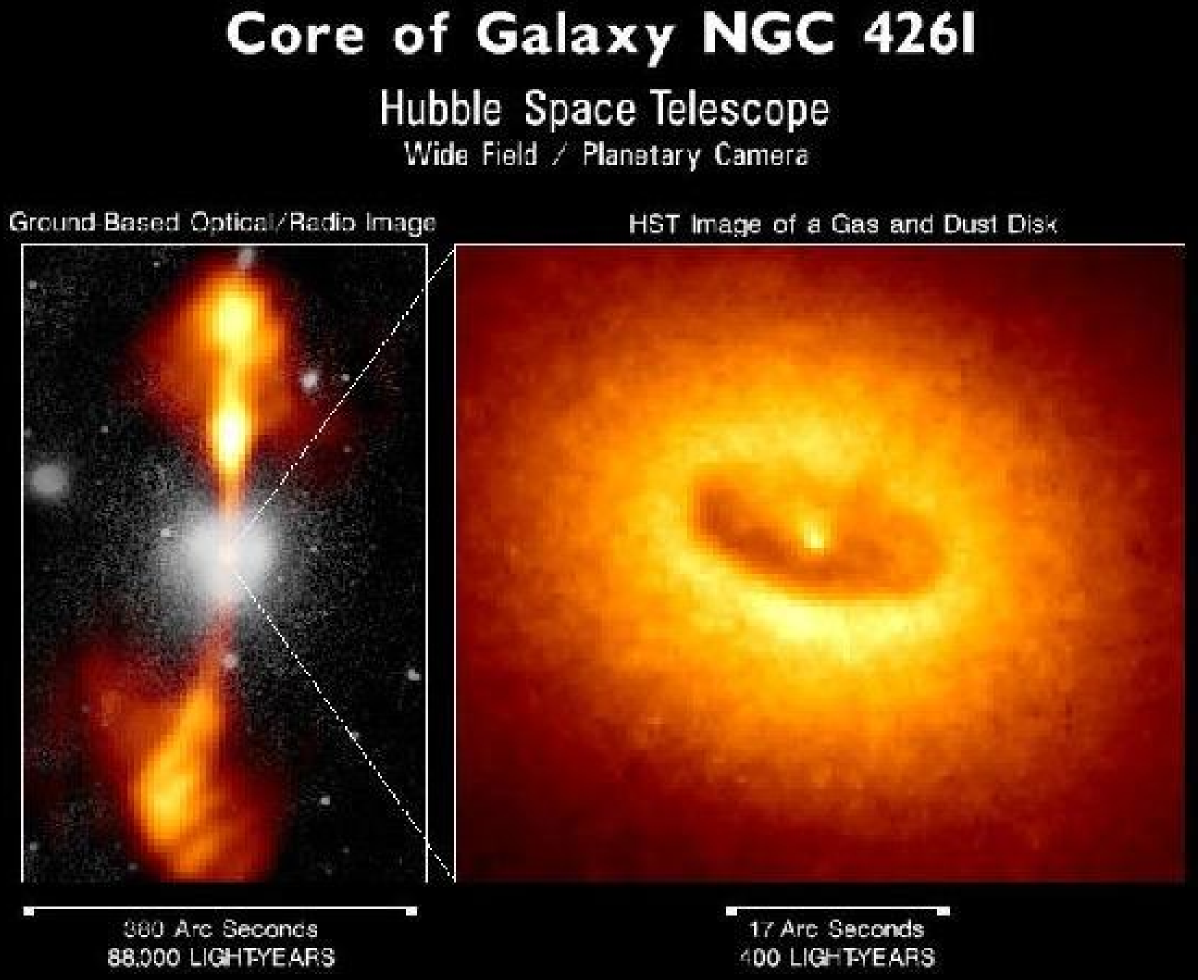
http://www.youtube.com/watch?v=eI9CvipHl_c



JETS:

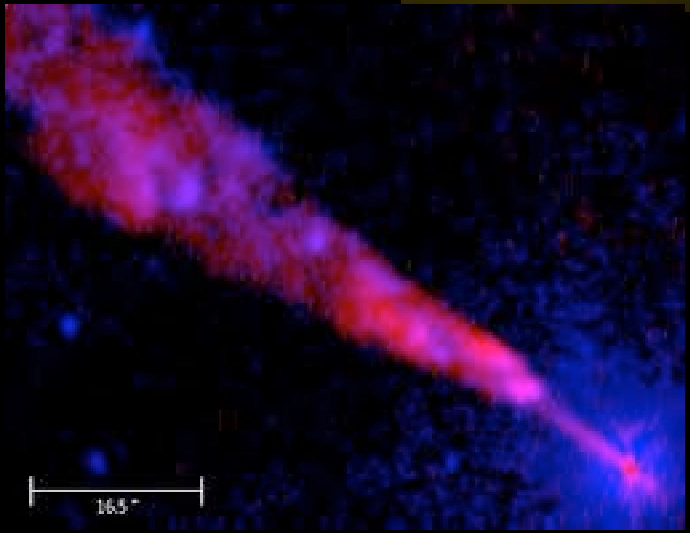
Twisted
magnetic fields
generated by the
twisting of spacetime
between the inner
and outer horizons of
a rapidly rotating
black hole
spit out energy

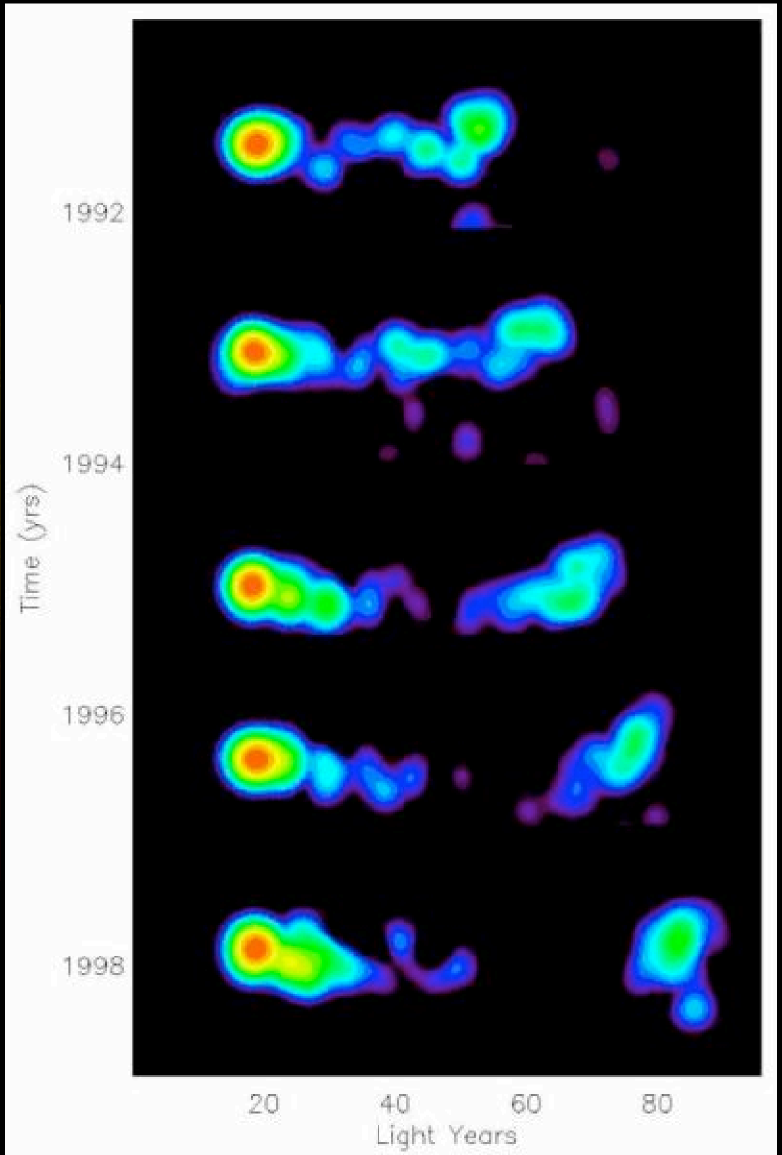
By the mid 1990’s the Hubble Space Telescope discovered supermassive black holes at the centers of many galaxies by detecting the bipolar jets coming from the core of the galaxy. These are evidence of a supermassive black hole at the galactic center.

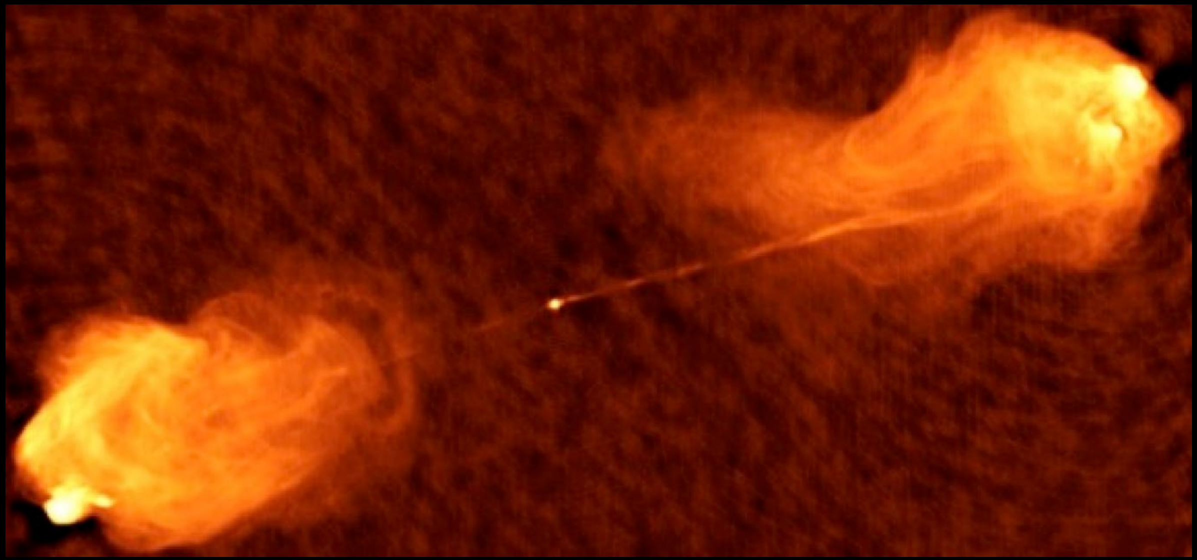


Discovered in 1995

JETS – real images from the cores of galaxies, now known as a sign that supermassive black holes are at the cores of all galaxies





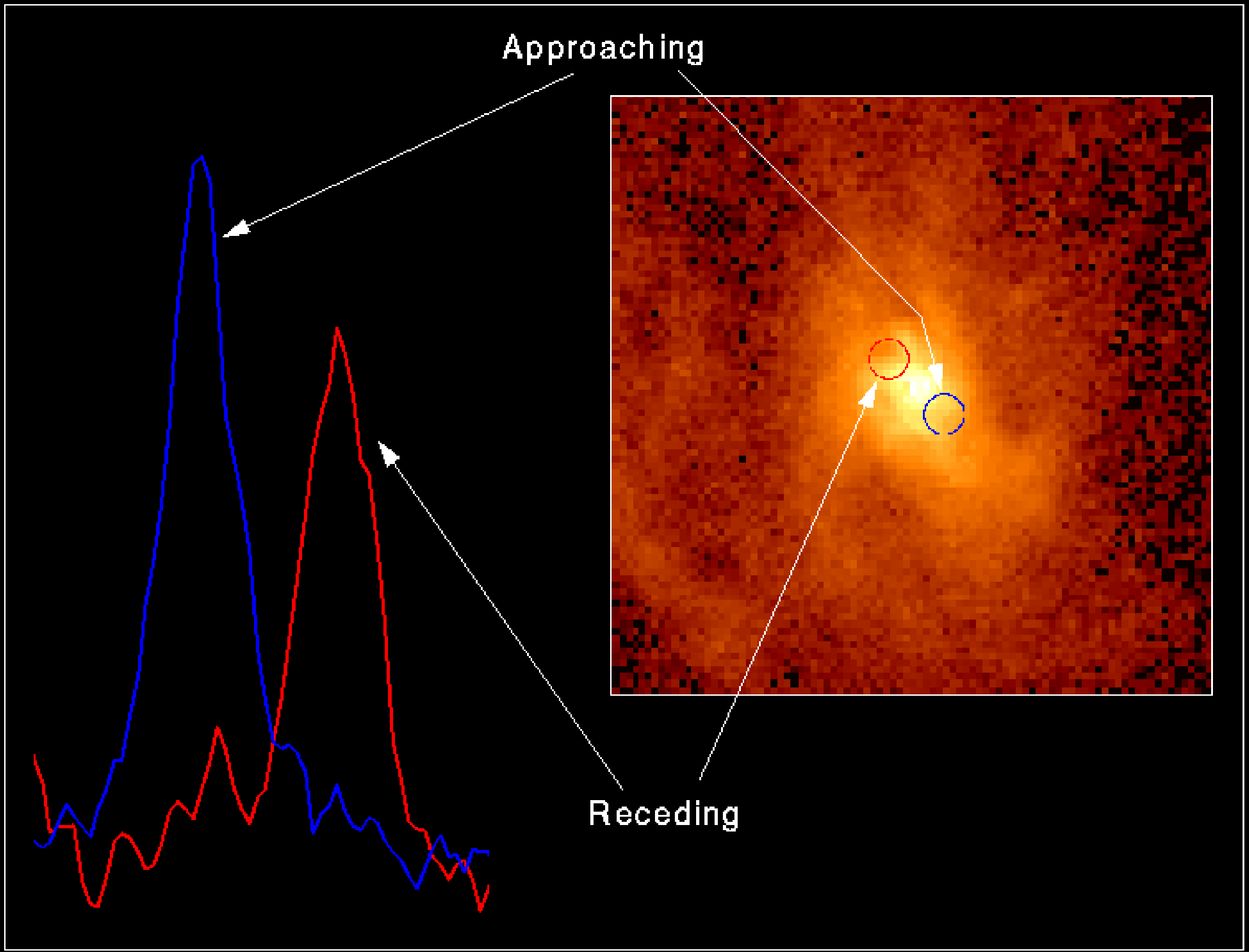


Radio jets, blasting far out of the galaxy!

(real image in radio waves!)

https://www.nasa.gov/topics/universe/features/radio-particle-jets.html

Spectrum of Gas Disk in Active Galaxy M87



Hubble Space Telescope • Faint Object Spectrograph

SPACE TELESCOPE SCIENCE INSTITUTE

Rotation rate of the central region of M87 was revealed by Doppler shifts in its light, first observed by the Hubble Space Telescope in the mid-1990s

Using Kepler #3: $a^3 = P^2$ central mass of over 10^9 M_{sun} within 10 ly of the center

The conclusion was that it must be a black hole.

M87's central massive black hole is one of the most studied objects.

New view of M87:
FIRST ACTUAL IMAGE OF A BLACK HOLE TAKEN WITH THE EVENT HORIZON TELESCOPE
in April, 2019 with the Event Horizon Telescope.

Watch this!
https://youtu.be/S_GVbuddri8

The Event Horizon Telescope is the largest aperture radio telescope in the world. It consists of 19 large radio telescopes linked electronically across the globe. Read more about the Global Network that comprises the Event Horizon Telescope here:
https://eventhorizontelescope.org/blog/global-web-tour-eht-observatories

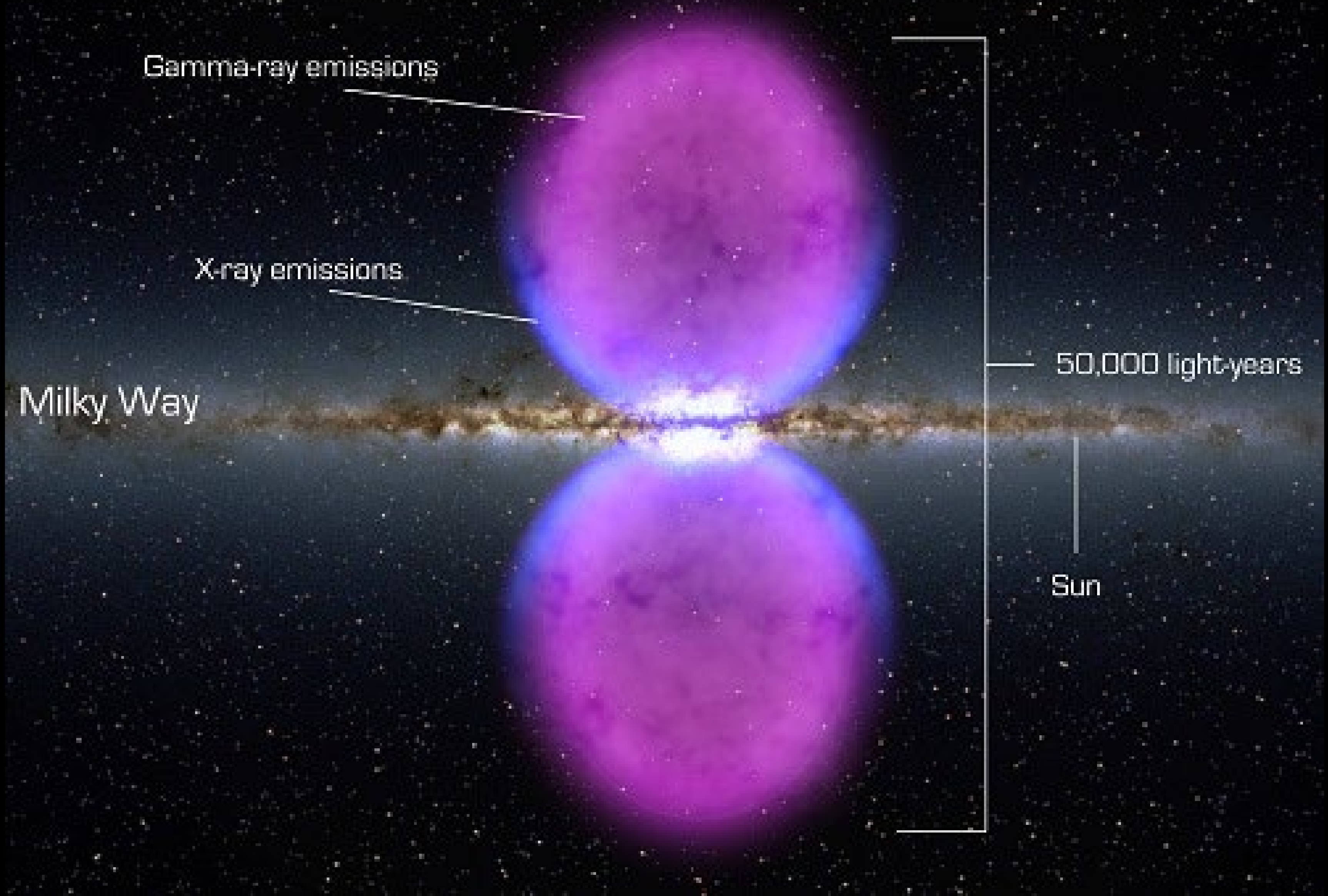
News from the EHT: Astronomers Image Magnetic Fields at the Edge of M87’s Black Hole March 24, 2021. *This image shows the polarised view of the black hole in M87. The lines mark the orientation of polarisation, which is related to the magnetic field around the shadow of the black hole. Credit: EHT Collaboration*

The ‘stripes’ indicate the direction of polarization of the light around the black hole and its shadow (dark region).

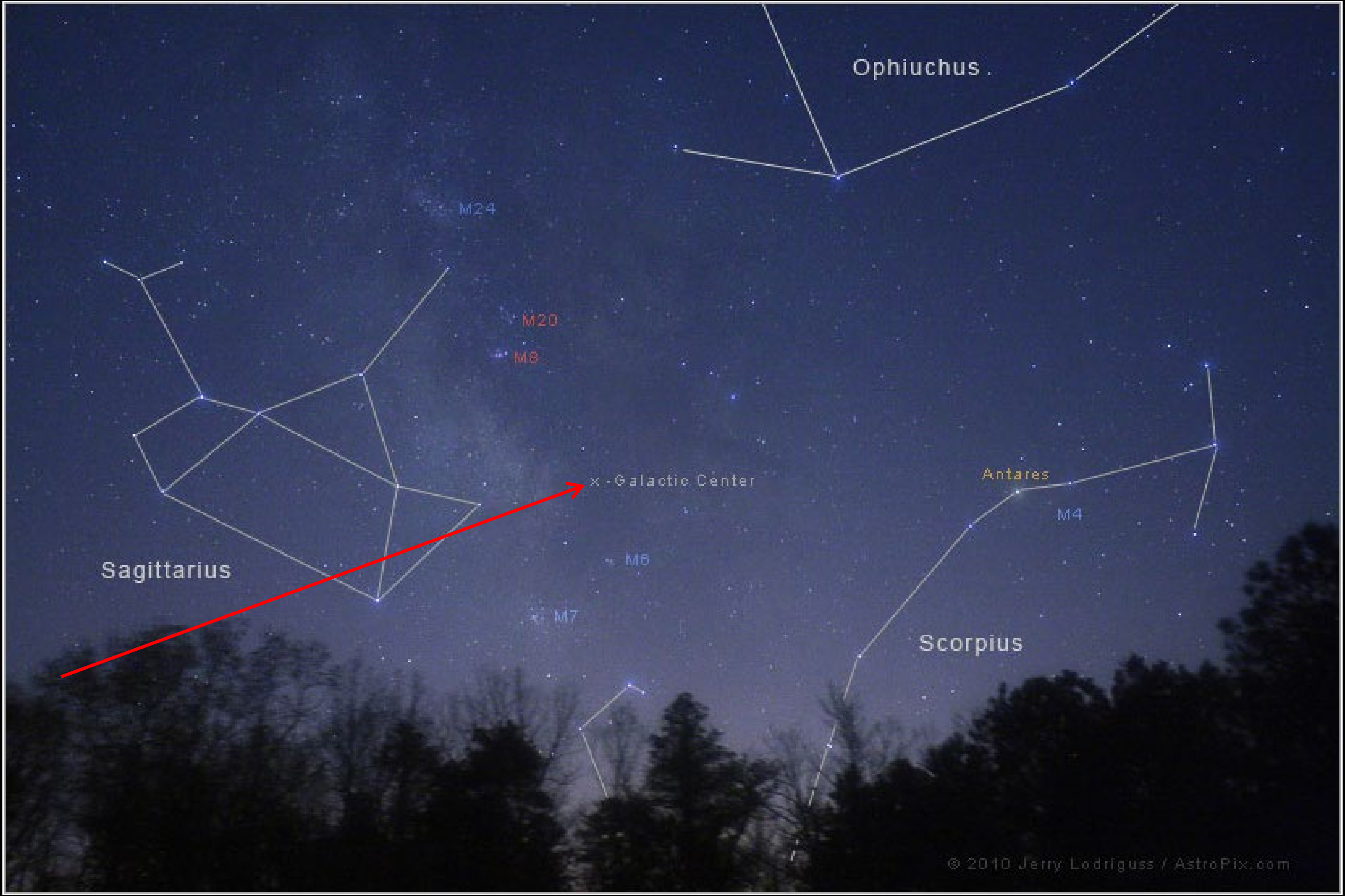
It is understood that the strong magnetic fields can push the strongly magnetized gas out into the jets that are observed.

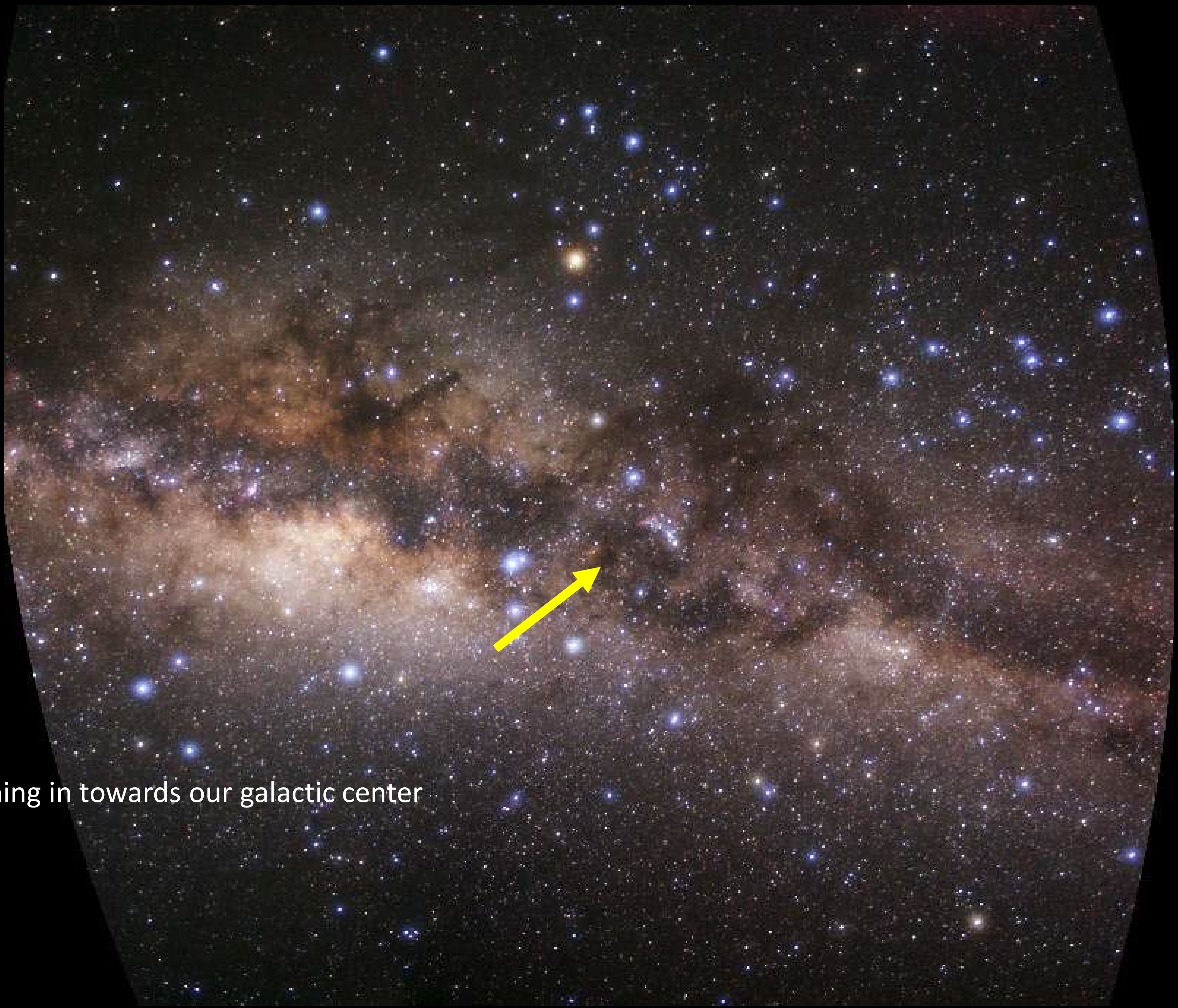
See https://eventhorizontelescope.org/blog/astronomers-image-magnetic-fields-edge-m87s-black-hole

NASA's Fermi Telescope found remnants of our galactic black hole "belching" out twin bubbles of hot gas, visible only in gamma ray and X-ray wavelengths. According to research, these bubbles were ejected from our central black hole around 6 million years ago as a result of the black hole consuming large quantities of gas.



Want to locate our galactic supermassive black hole?
Look toward the center of our galaxy
between the constellations Scorpius and Sagittarius

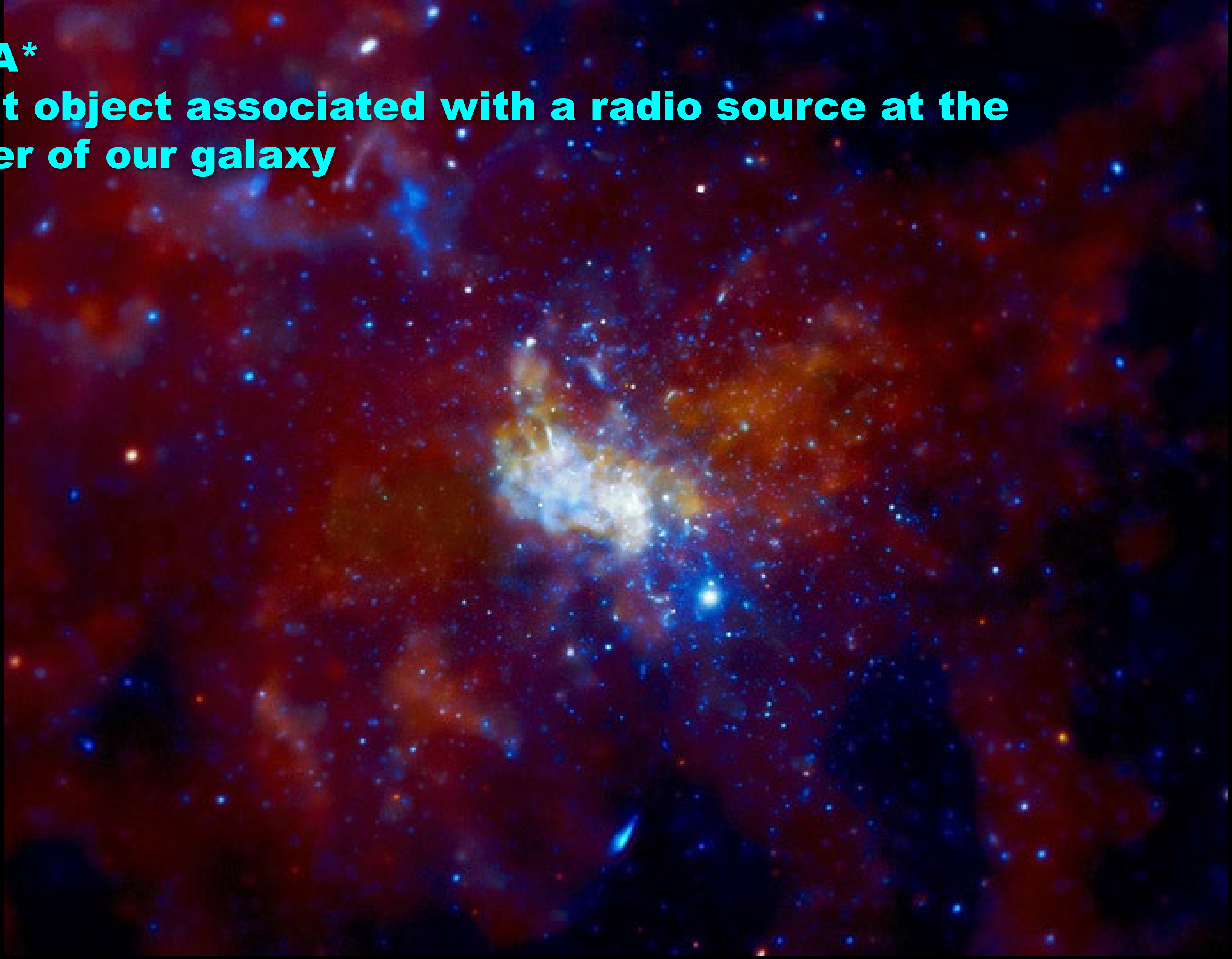




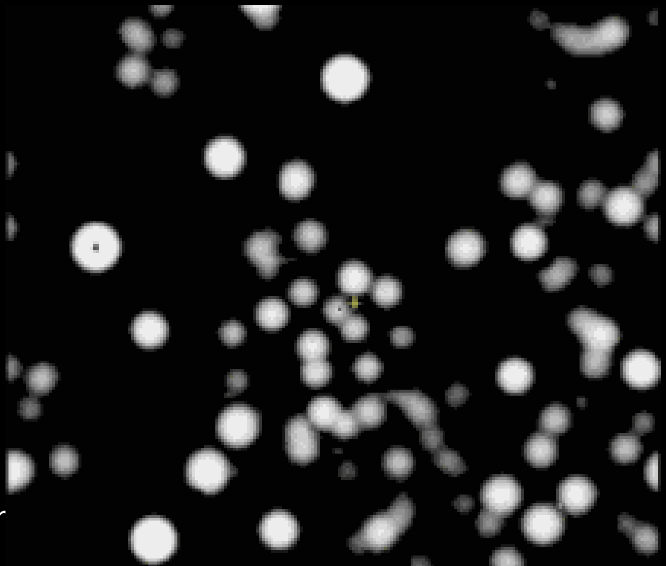
zooming in towards our galactic center

Sag A*

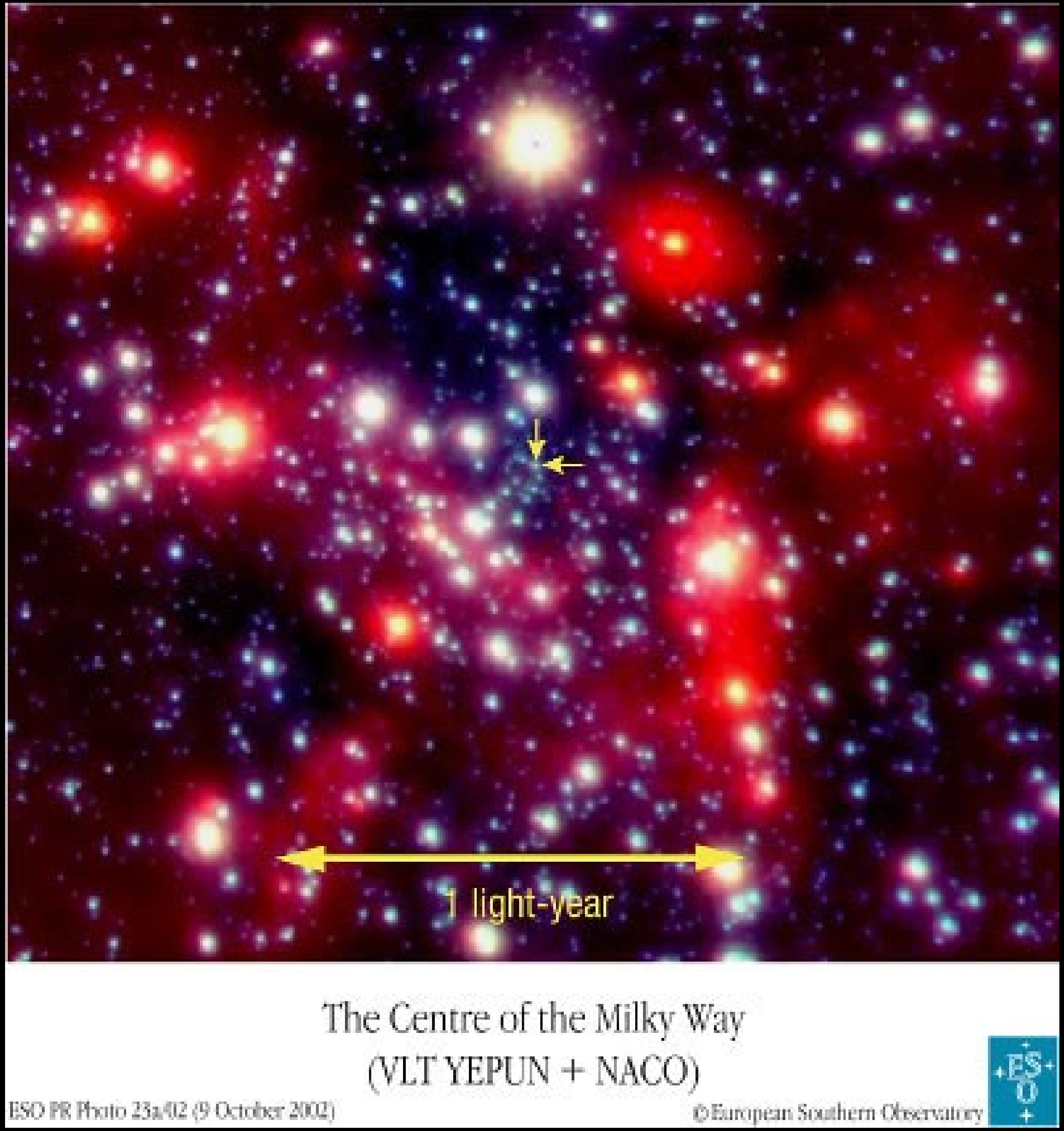
bright object associated with a radio source at the center of our galaxy

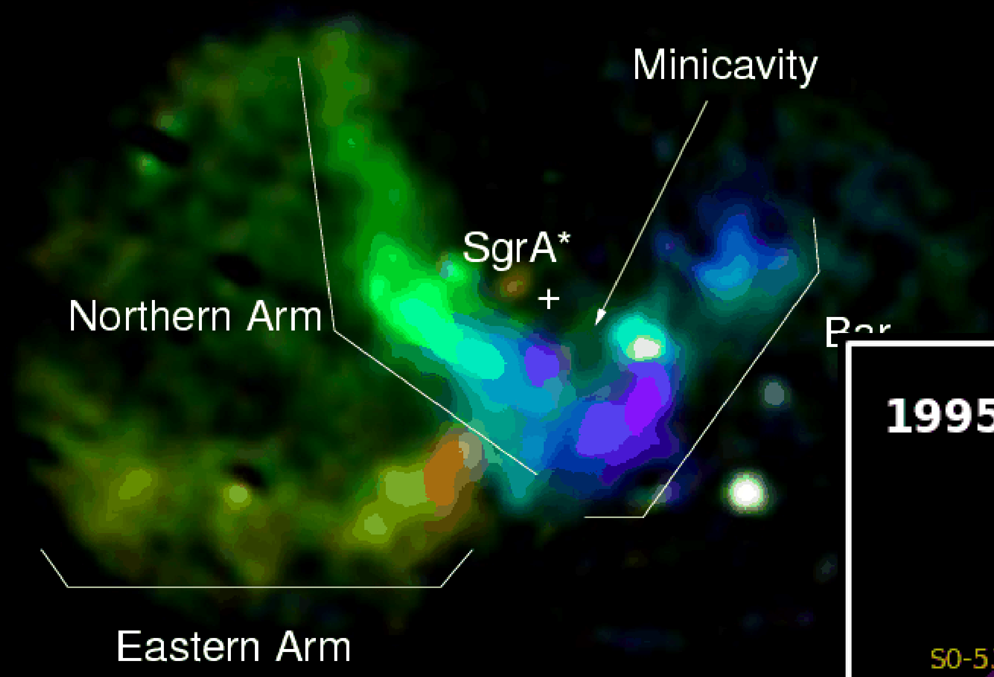


chaotic velocities of stars near our central super-massive BH mark its presence

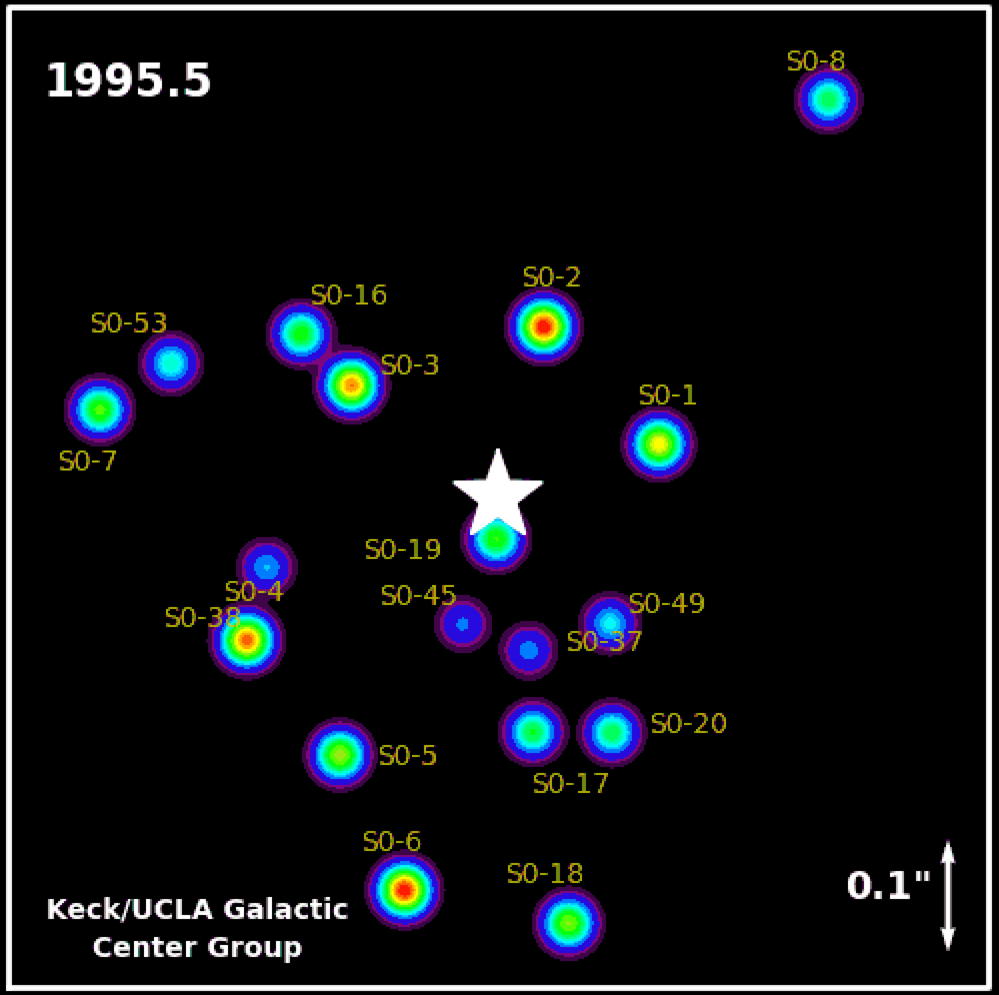


J. van der Veer





chaotic velocities of stars near our central super-massive BH – more detailed view

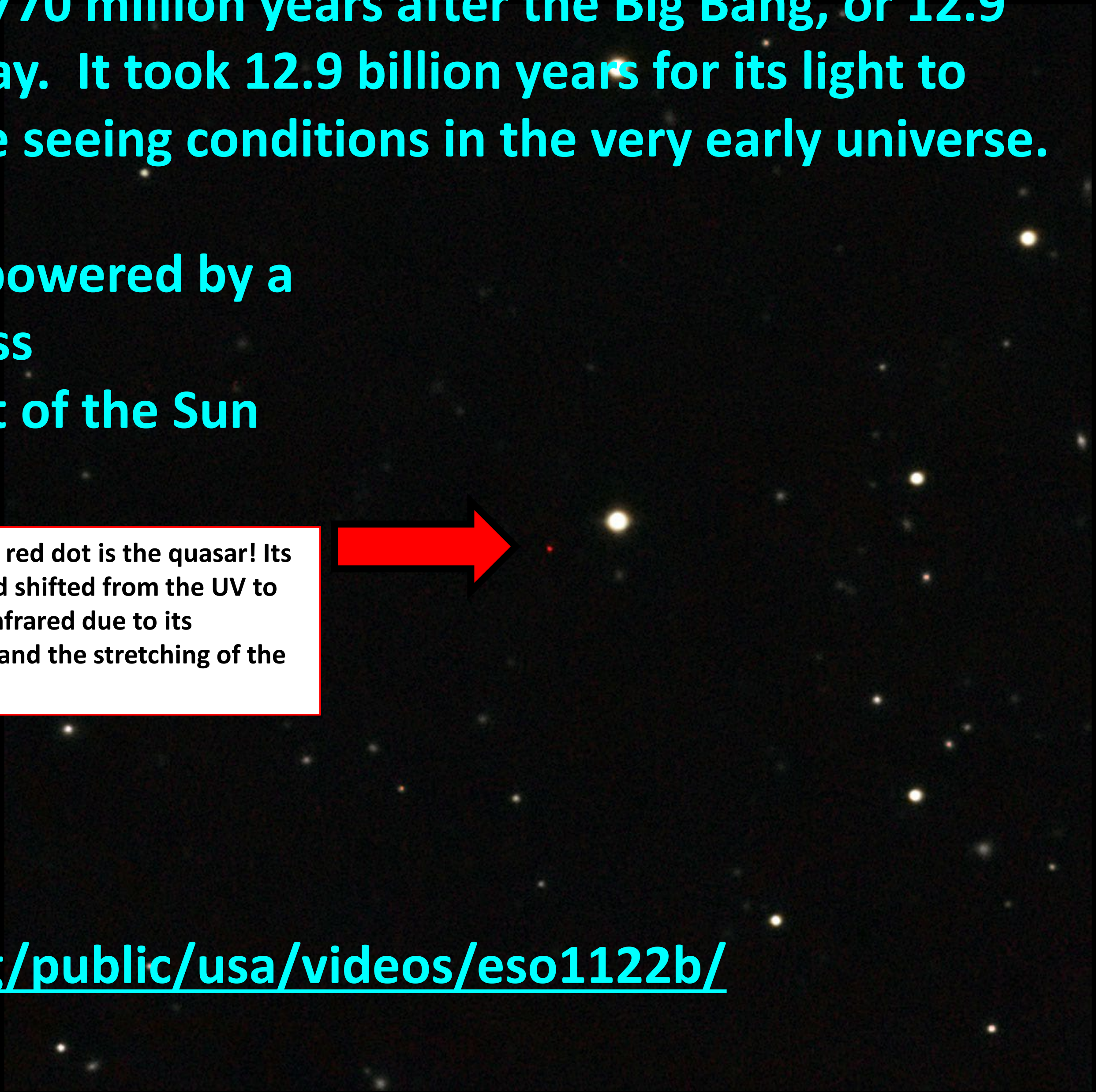


We now understand that every galaxy has a massive to super massive black hole in its center, and globular clusters likely have intermediate-sized black holes in their centers!

QUASARS - Quasi-stellar objects - the most distant and brightest objects in the universe.
For a long time there was a debate as to what they were: such bright radiation, coming from a small region a few light hours across, and with extremely high red shifts.
Now we understand that quasars are the outpouring of supermassive black holes at the centers of the young galaxies in the early universe.

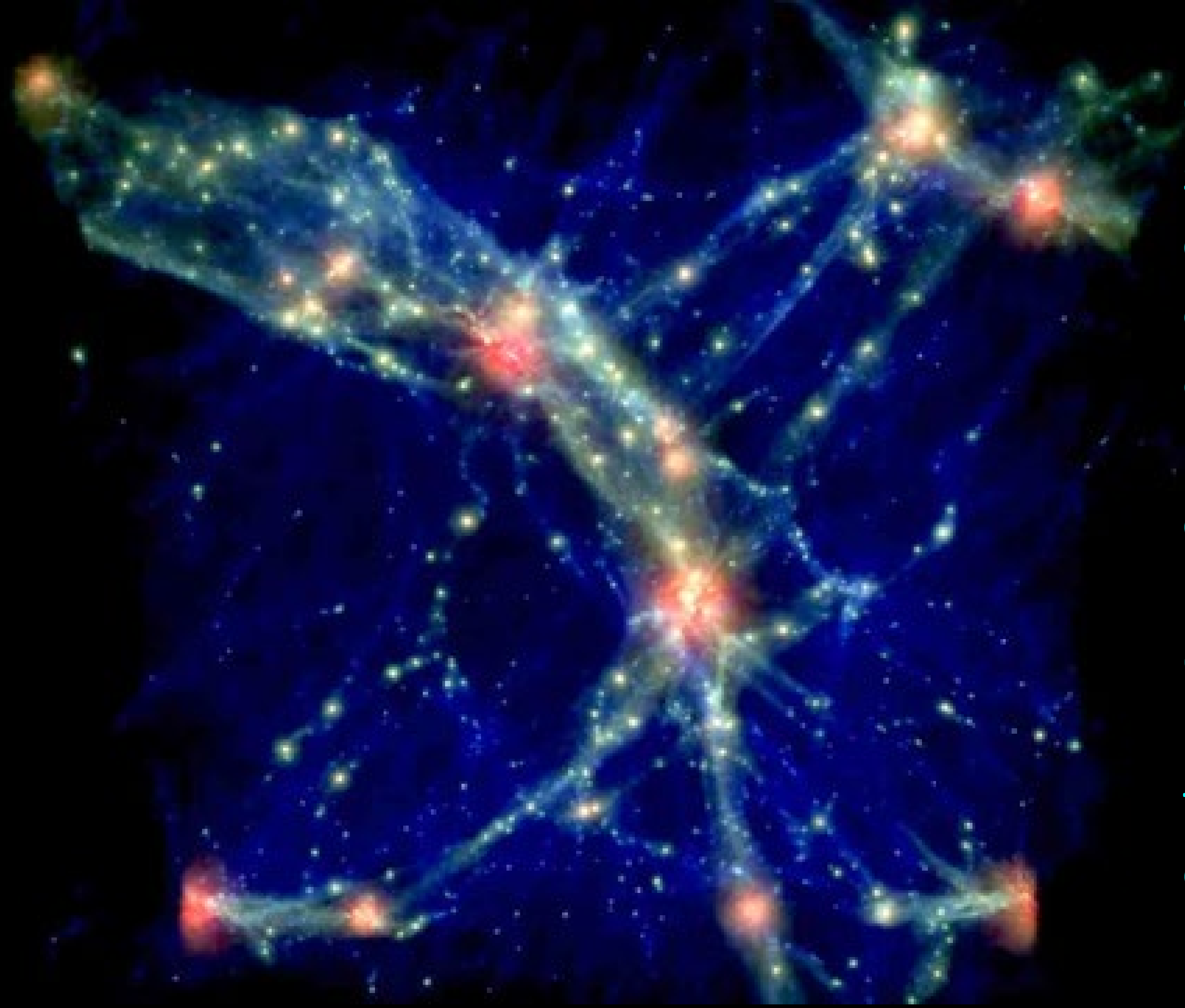
The most distant quasar discovered: ULAS J1120+0641, at a red shift of 7.1, only 770 million years after the Big Bang, or 12.9 billion light years away. It took 12.9 billion years for its light to reach us. Thus we are seeing conditions in the very early universe.

ULAS J1120+0641 is powered by a black hole with a mass two billion times that of the Sun



That little red dot is the quasar! Its light is red shifted from the UV to red and infrared due to its distance, and the stretching of the universe.

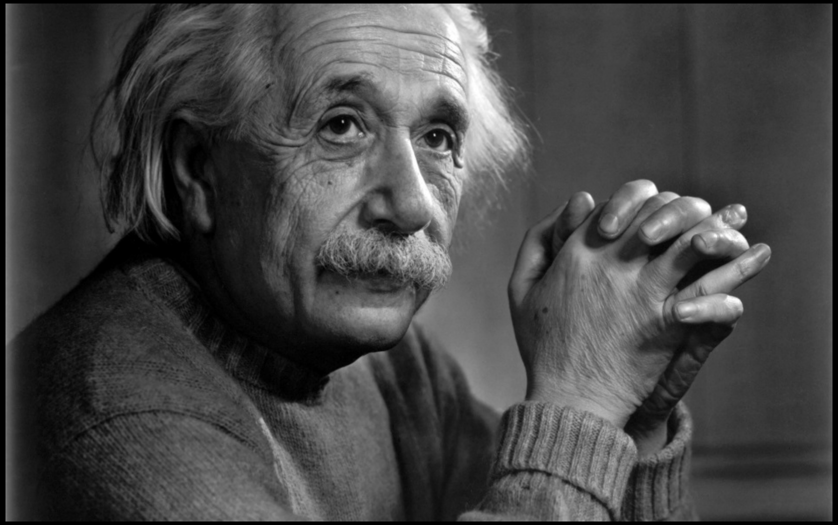
https://www.eso.org/public/usa/videos/eso1122b/



Computer simulation: A collection of extremely luminous quasars powered by supermassive central black holes

Quasars are the nuclei of galaxies from the early days of the universe that undergo brief periods of extreme brightness

To understand something about the nature of black holes, which deform *both* space *and* time, we need to take a look at a few of the major theoretical frameworks in contemporary physics:



Quantum Mechanics
and
Einstein's Special and General Relativity

We learned a bit of Newtonian (classical) physics to understand the motions of planets and gravity – Kepler's Laws and Newton's Laws. To understand the behavior of black holes we need to understand some Modern Physics, which will be discussed in the next lecture.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