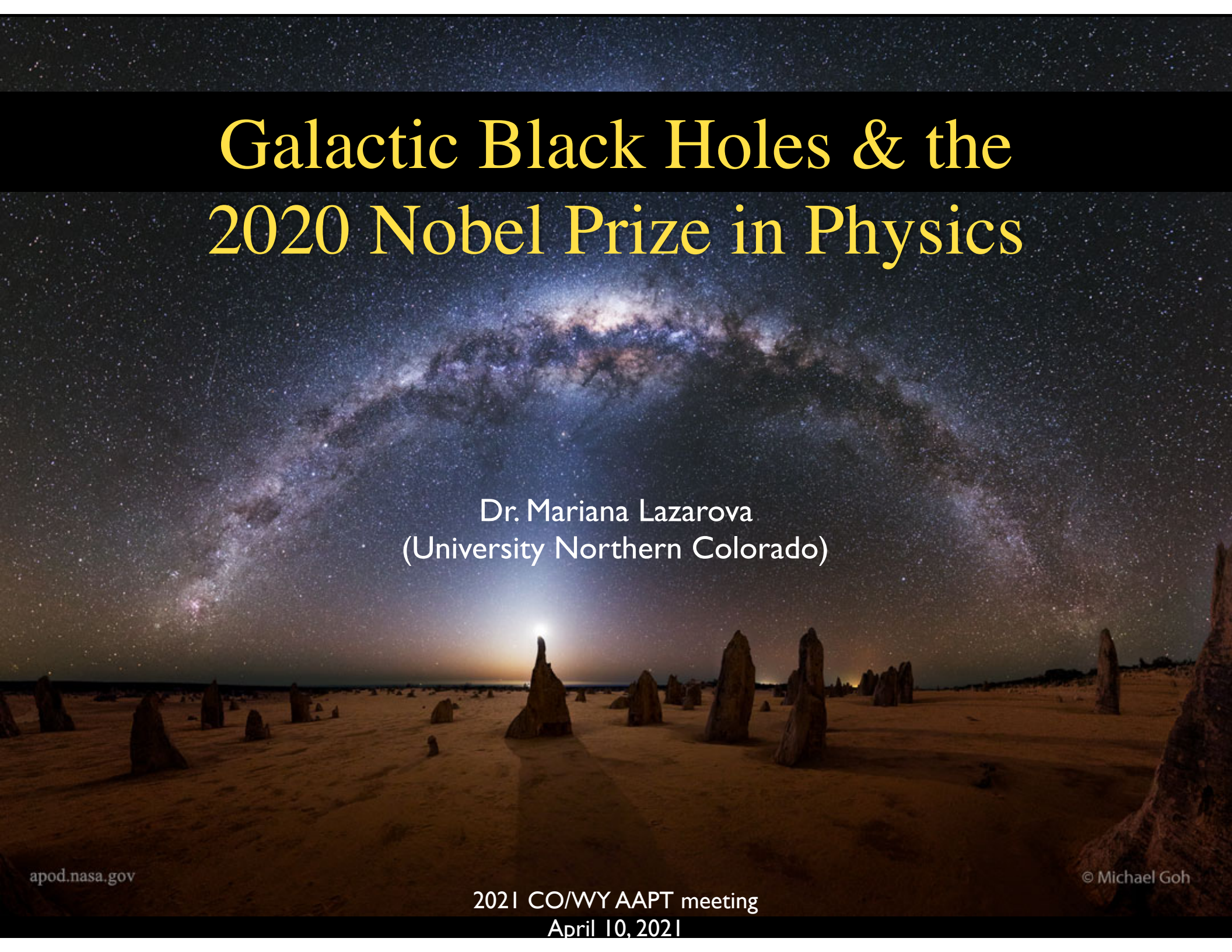


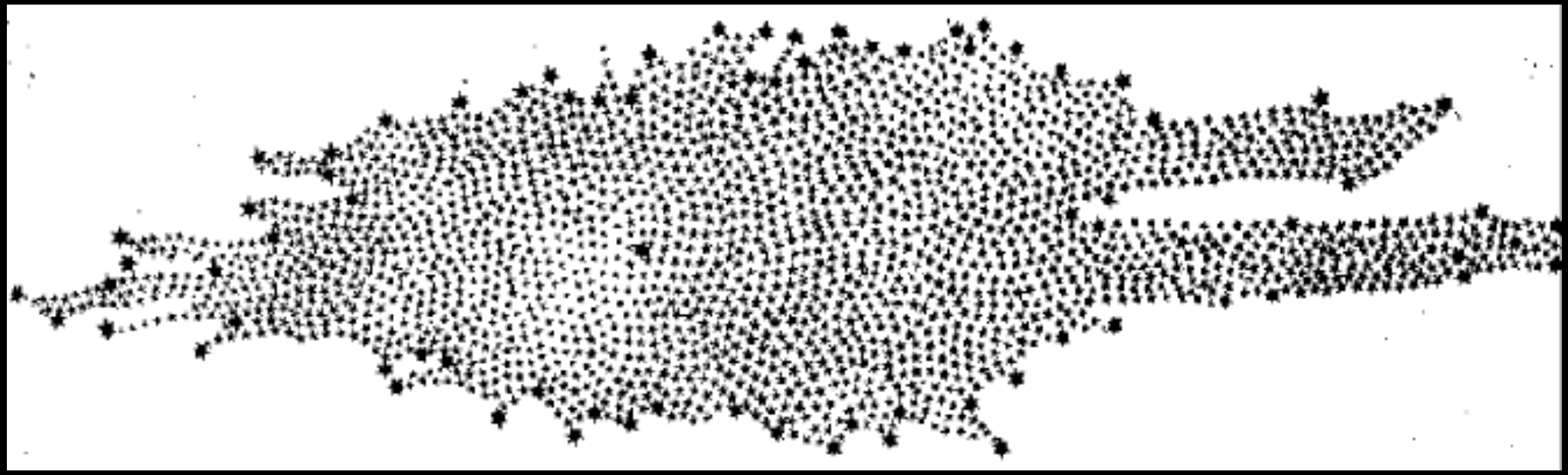
Galactic Black Holes & the 2020 Nobel Prize in Physics

Dr. Mariana Lazarova
(University Northern Colorado)

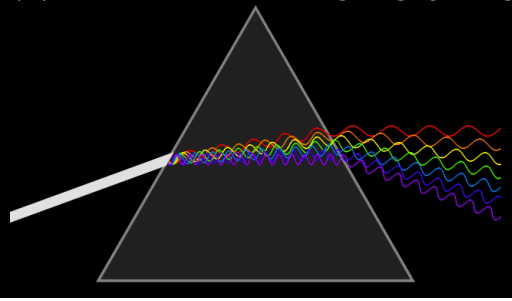
2021 CO/WY AAPT meeting
April 10, 2021

The known universe in 1785

consisted of a small, local part of the Milky Way



mapped by **Caroline** & William Herschel



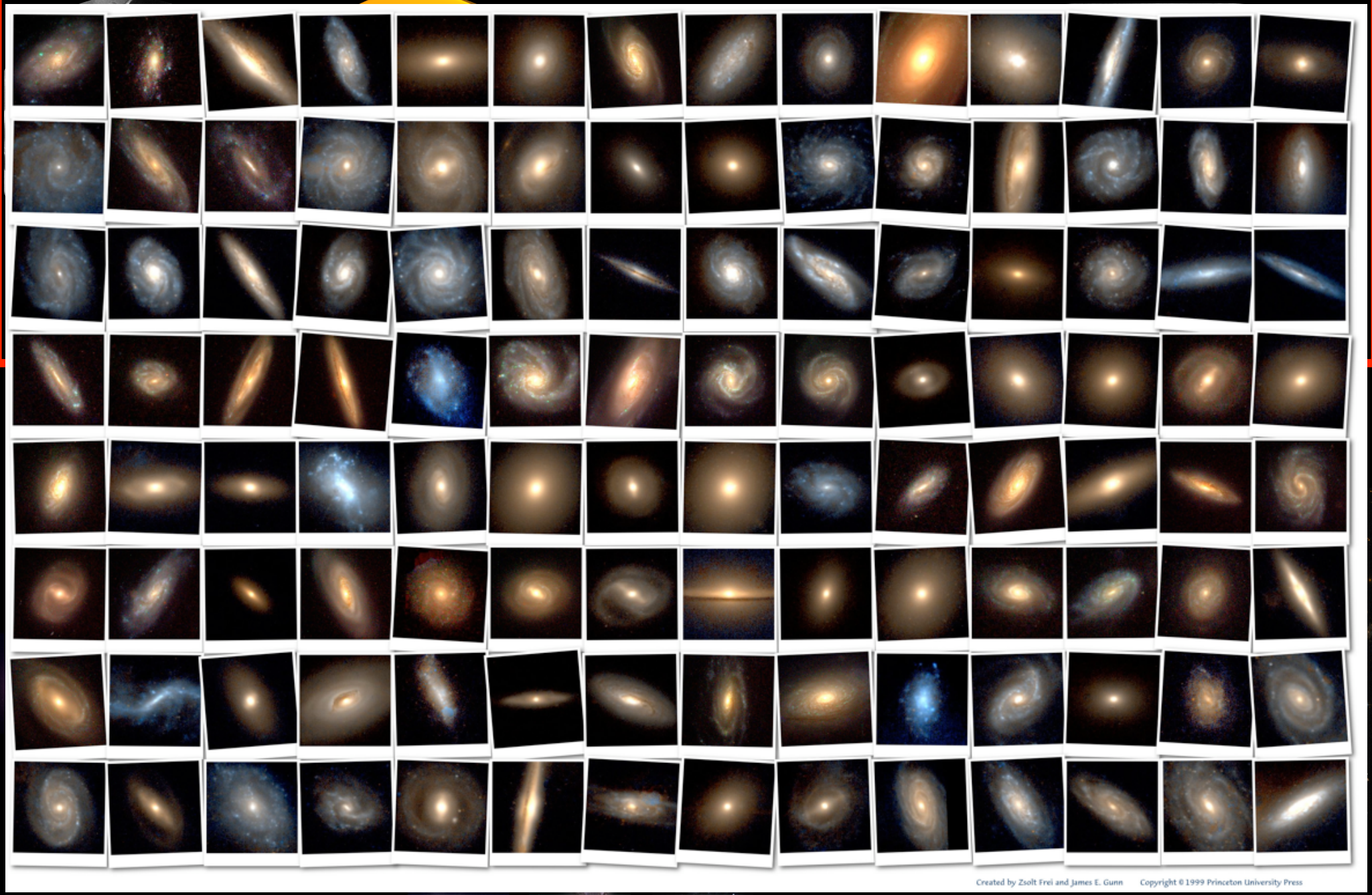

MilkyWay
26g
kcal
116
6%*


MilkyWay
BAR


TRADER JOE'S
QUASAR
BAR
WITH WHIPPED CHOCOLATE
NOUGAT
CARAMEL ENROBED
DARK CHOCOLATE
NET WT. 1.8 OZ (51g)

Edwin Hubble

Henrietta Leavitt



Barred spirals

FAULKES TELESCOPE

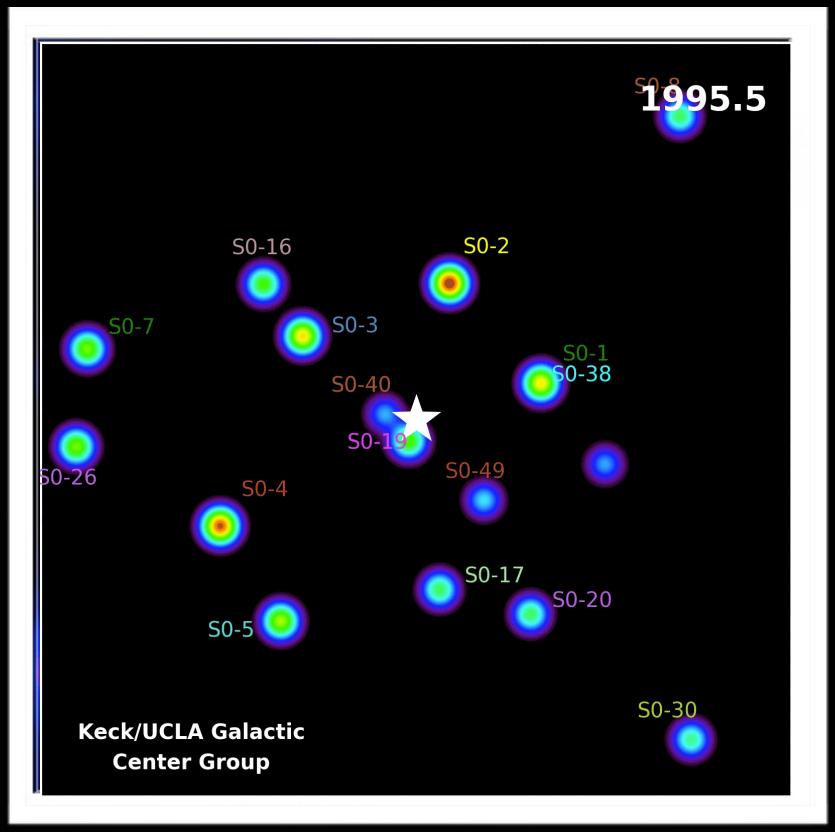
LCOGT.net

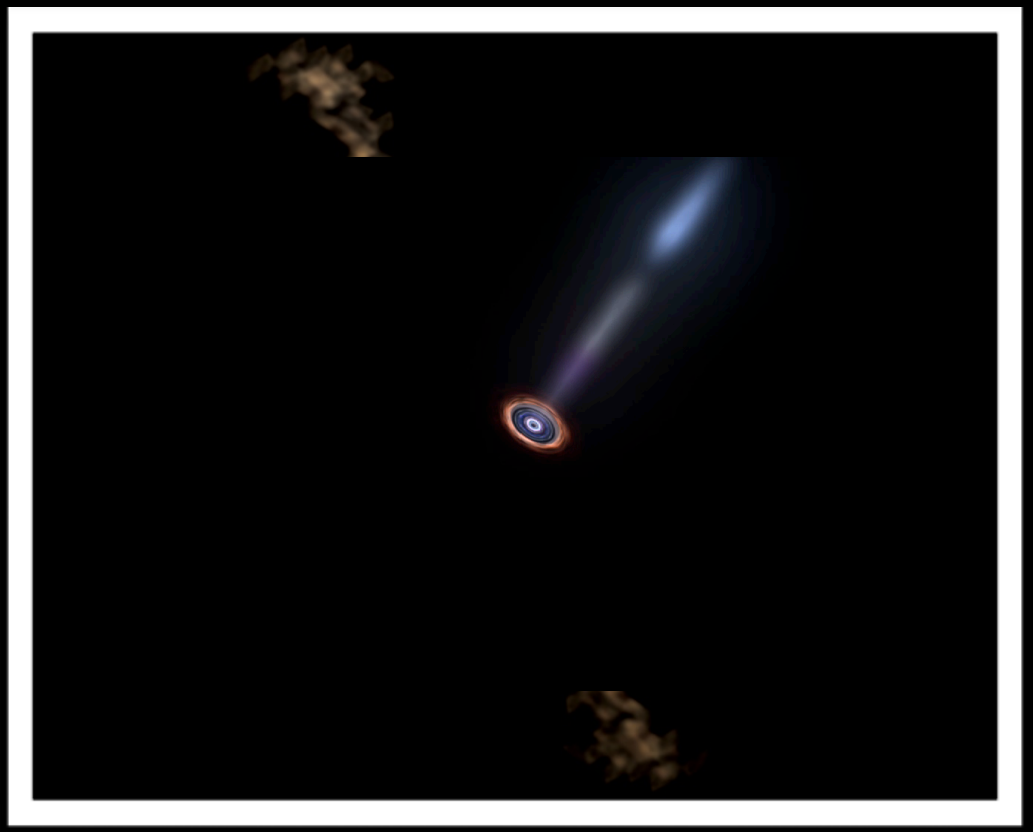
1995

(1) a supermassive* black hole lurks at the center of every galaxy

*supermassive black hole > 1 million x Sun's mass

inactive BH vs. active BH





1995

(2) the mysterious correlation between black hole mass & galaxy bulge mass

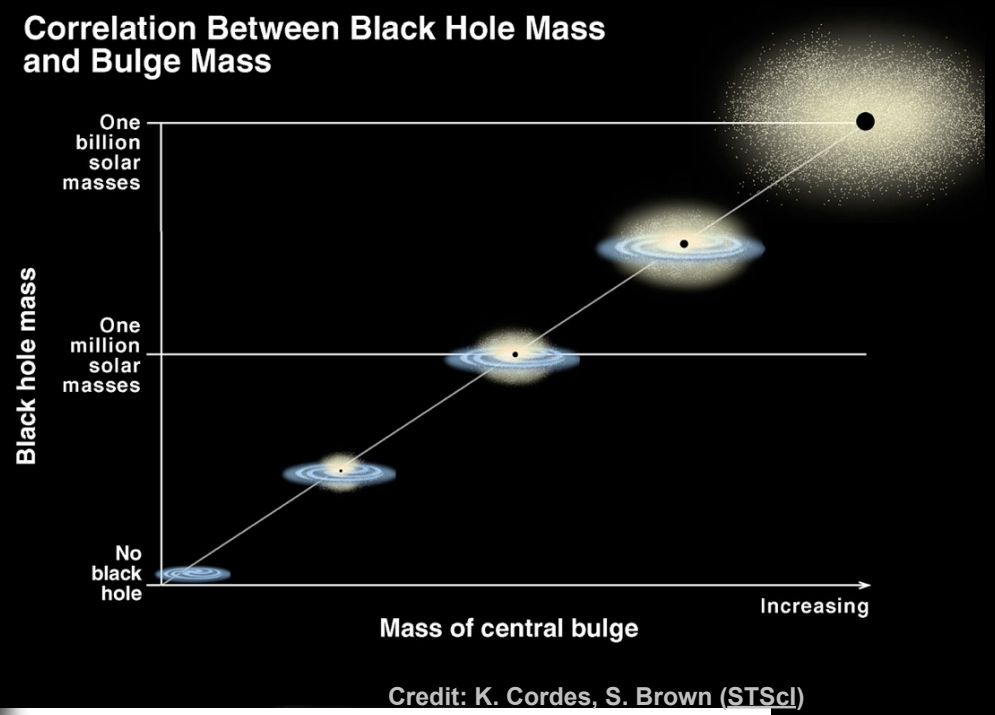
the black hole knows
about the galaxy it lives in

Black holes grow by accretion

LINER M81:
M_{BH} ~ 70 million $M_\odot$
M_{GALAXY} ~ 700 billion $M_\odot$

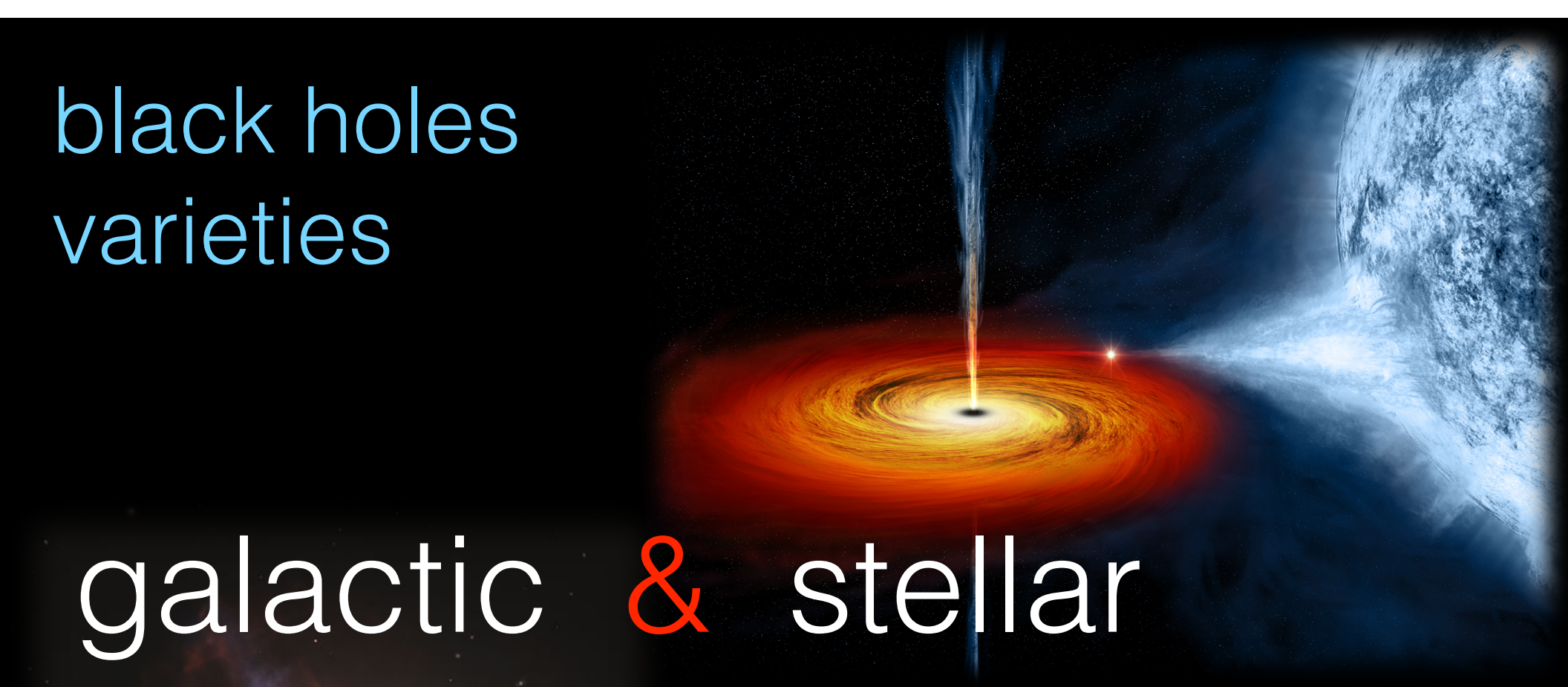
Galaxies grow by forming stars

Black Hole Mass



Galaxy Mass

black holes
varieties

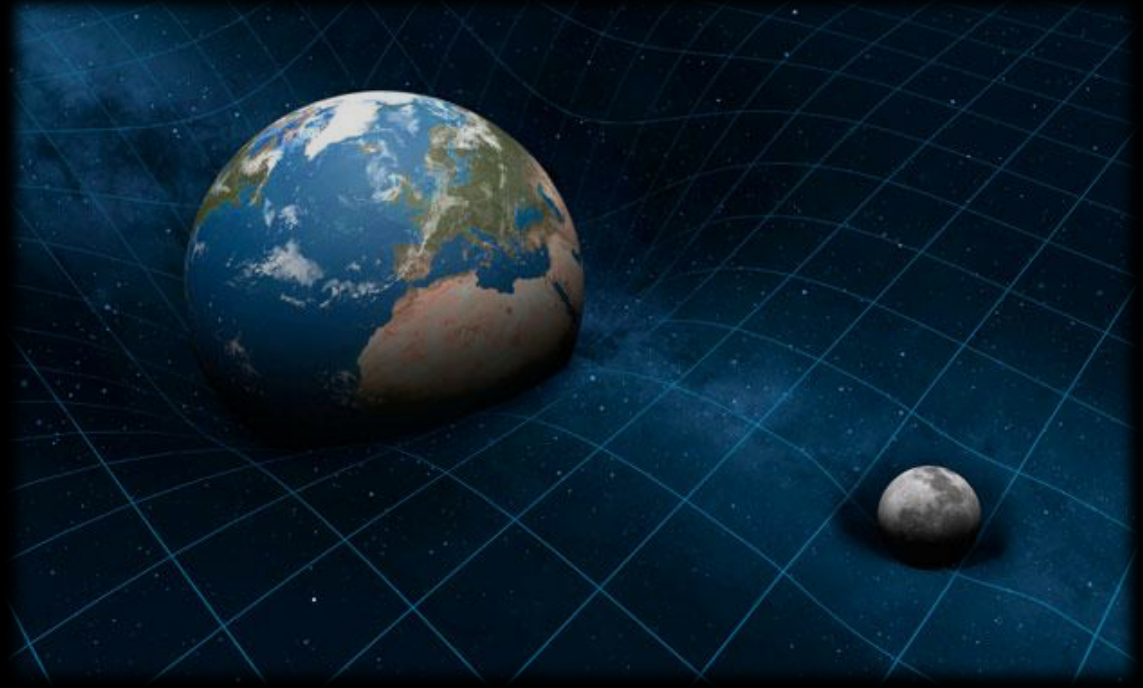


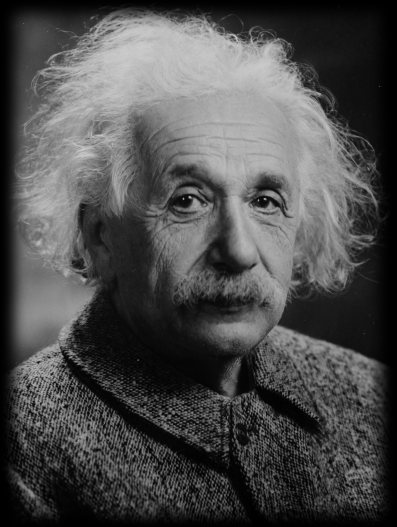
galactic & stellar

What is a black hole?

"Spacetime tells matter how to move;
matter tells spacetime how to curve."

John Wheeler



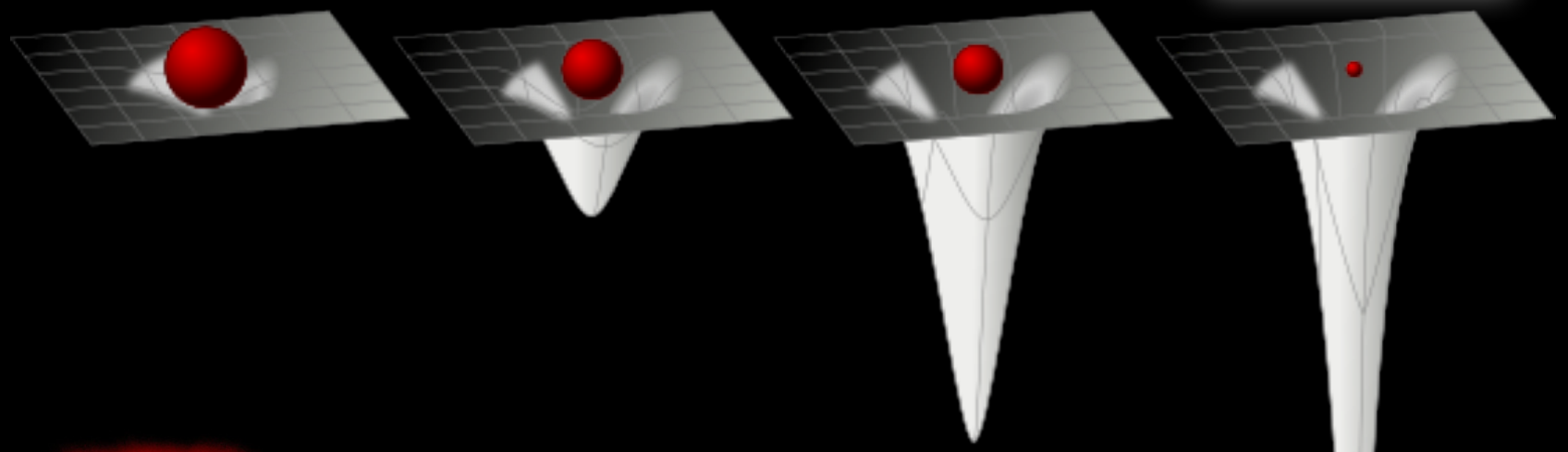


1915: Einstein's General Theory of Relativity

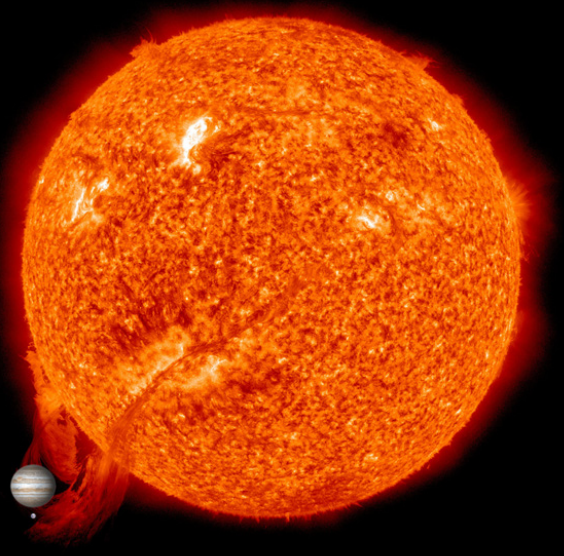
1916: Schwarzschild & Lorentz - GR solutions for non-rotating BH
1968: John Wheeler used the term "black hole"
1971: First black hole observed, x-ray source Cygnus X-1

How to make a black hole:

Star White dwarf Neutron star Black hole



Gravitationnal collapse



shrink 1/200,000

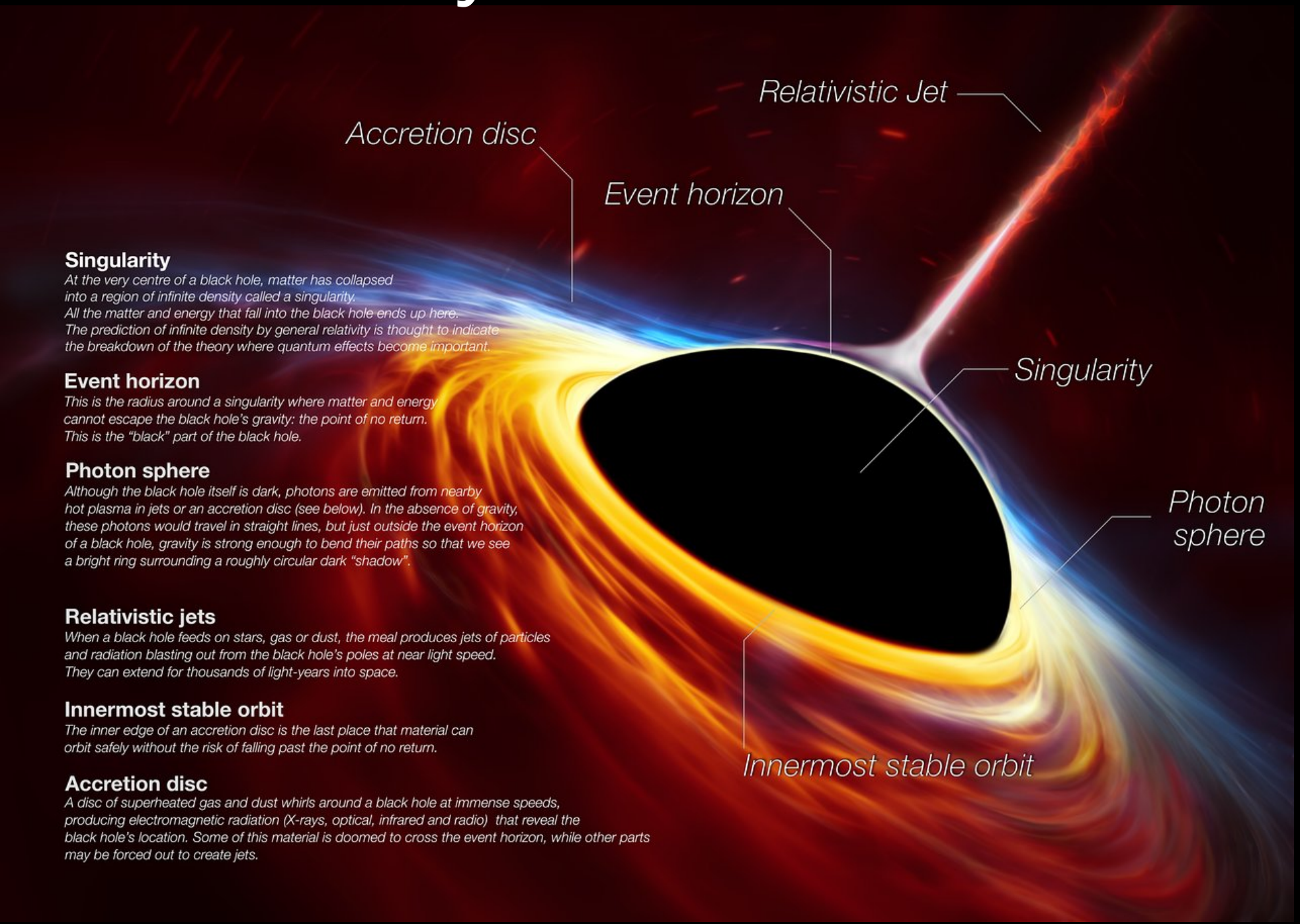
If you could squeeze the Sun to a ball with radius ~3 km

The idea of compact objects that light can't escape is old

1676: Roemer showed light has finite speed

1783: English natural philosopher John Michell pondered stars so massive even light would not escape

Anatomy of a Black hole



Singularity
At the very centre of a black hole, matter has collapsed into a region of infinite density called a singularity. All the matter and energy that fall into the black hole ends up here. The prediction of infinite density by general relativity is thought to indicate the breakdown of the theory where quantum effects become important.

Event horizon
This is the radius around a singularity where matter and energy cannot escape the black hole's gravity: the point of no return. This is the "black" part of the black hole.

Photon sphere
Although the black hole itself is dark, photons are emitted from nearby hot plasma in jets or an accretion disc (see below). In the absence of gravity, these photons would travel in straight lines, but just outside the event horizon of a black hole, gravity is strong enough to bend their paths so that we see a bright ring surrounding a roughly circular dark "shadow".

Relativistic jets
When a black hole feeds on stars, gas or dust, the meal produces jets of particles and radiation blasting out from the black hole's poles at near light speed. They can extend for thousands of light-years into space.

Innermost stable orbit
The inner edge of an accretion disc is the last place that material can orbit safely without the risk of falling past the point of no return.

Accretion disc
A disc of superheated gas and dust whirls around a black hole at immense speeds, producing electromagnetic radiation (X-rays, optical, infrared and radio) that reveal the black hole's location. Some of this material is doomed to cross the event horizon, while other parts may be forced out to create jets.

V616 Monocerotis

3,000 light years away

7 solar masses

companion: K-type star

CLOSEST*

stellar black hole

Cygnus X-1

6,000 light years away

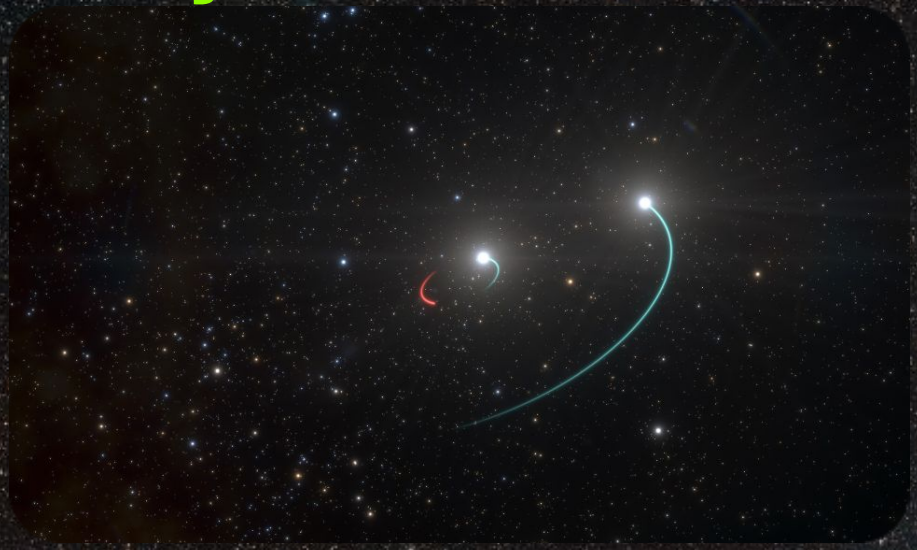
15 solar masses

companion: blue supergiant

FIRST (’64, ’71)

stellar black hole

May 2020



CLOSEST
stellar black hole

HR 6819

1,120 light-years away

~4 solar masses

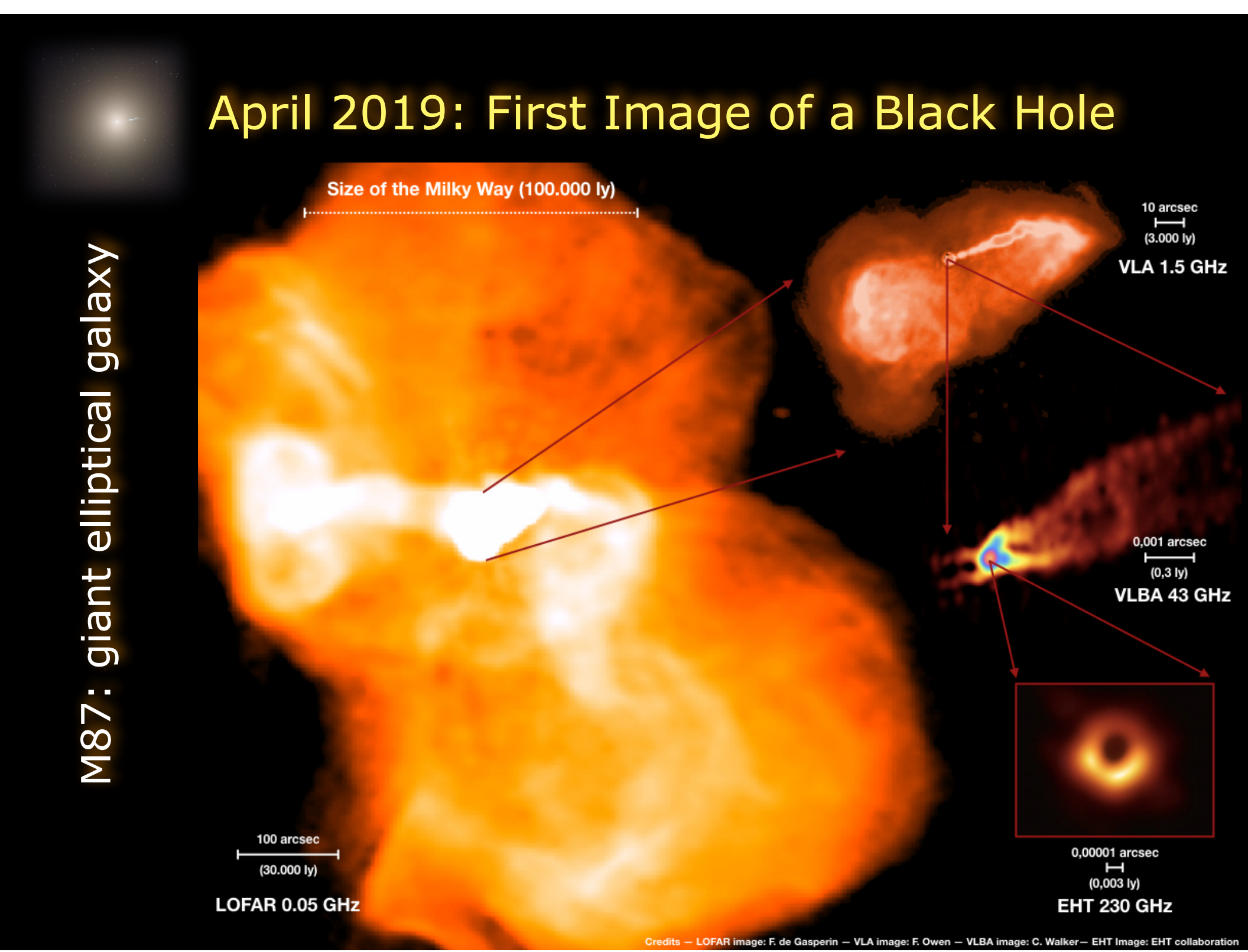
companions: two stars

Telescopium

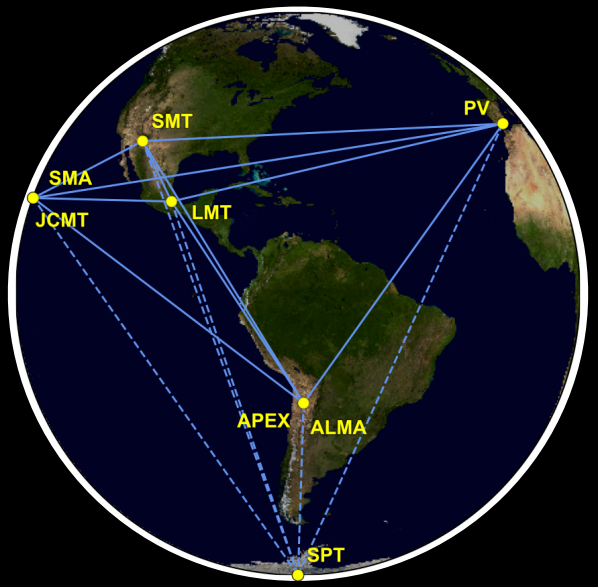
Image credit: ESO

Quasars (discovered in 1963) - galaxies with supermassive actively-feeding black holes at their centers

April 2019: First Image of a Black Hole



2021: Magnetic fields near the M87 black hole



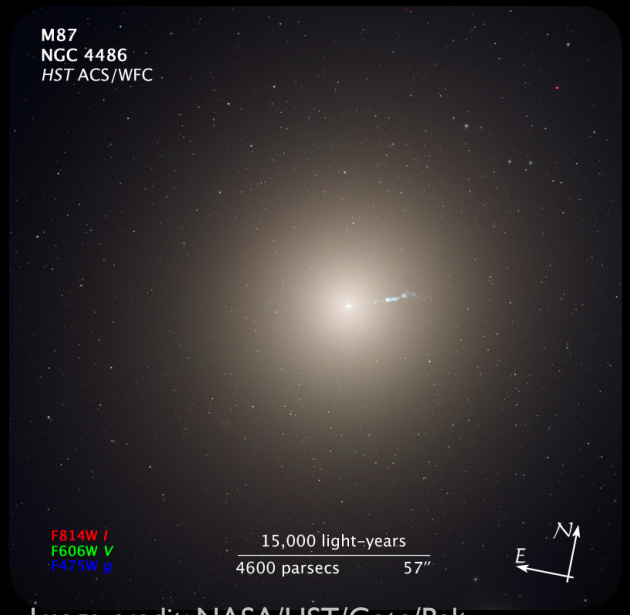


Image credit: NASA/HST/Cote/Baltz

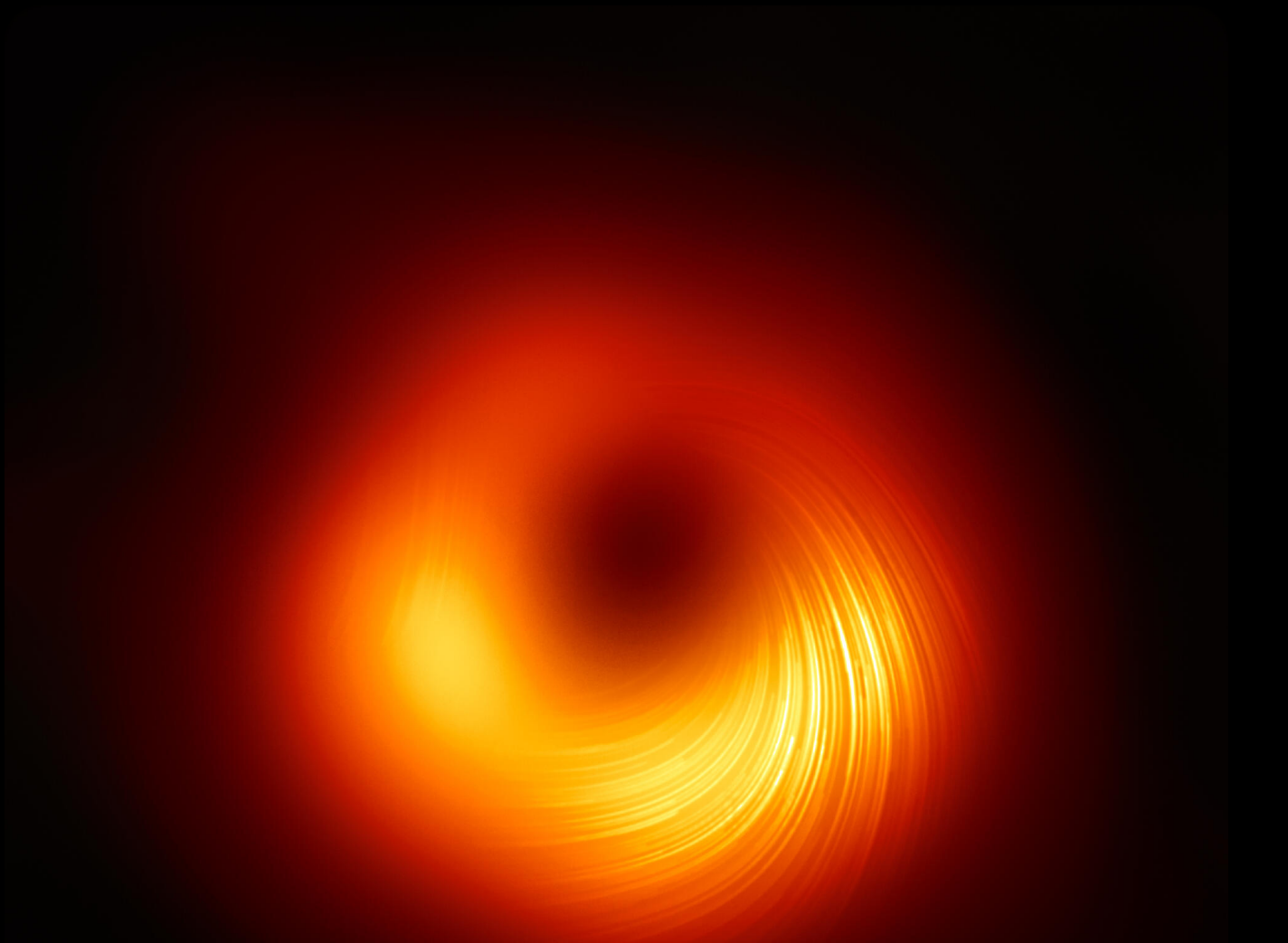


Image credit: Event Horizon Telescope

Achieved magnification analogy:
tennis ball on the Moon

Image credit: Wikipedia

SIZE COMPARISON:
THE M87 BLACK HOLE
AND
OUR SOLAR SYSTEM

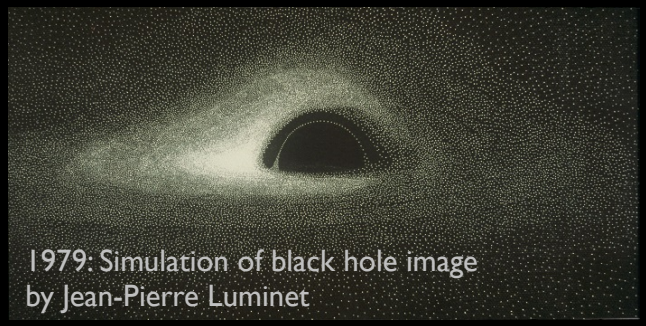
EHT BLACK HOLE IMAGE
SOURCE: NSF

PLUTO
VOYAGER 1
SUN

Shadow ~ 2.6 Schwarzschild radia

6.5 billion solar mass black hole

Image credit: xkcd.com



1979: Simulation of black hole image by Jean-Pierre Luminet

Image of the disk's far side

The black hole's gravitational field alters the path of light from the far side of the disk, producing this part of the image.

Photon ring

A ring of light composed of multiple distorted images of the disk. The light making up these images has orbited the black hole two, three or even more times before escaping to us. They become thinner and fainter closer to the black hole.

Black hole shadow

This is an area roughly twice the size of the event horizon — the black hole's point of no return — that is formed by its gravitational lensing and capture of light rays.

Doppler beaming

Light from glowing gas in the accretion disk is brighter on the side where material is moving toward us, fainter on the side where it's moving away from us.

Accretion disk

The hot, thin, rotating disk formed by matter slowly spiraling toward the black hole.

Image of the disk's underside

Light rays from beneath the far side of the disk are gravitationally "lensed" to produce this part of the image.

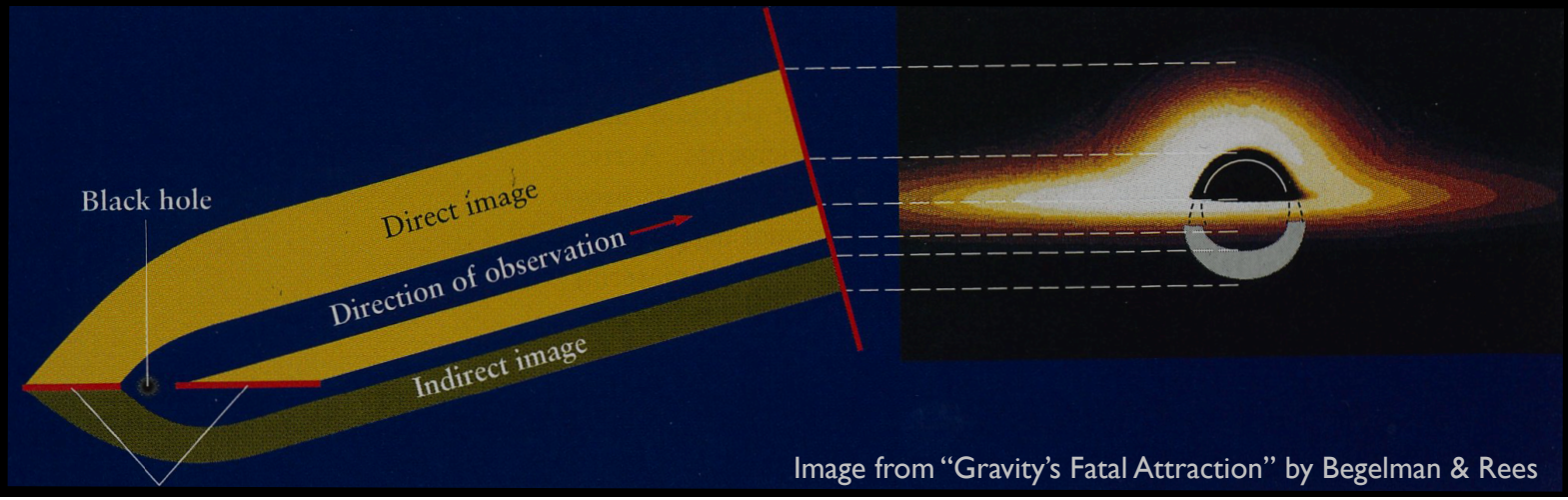
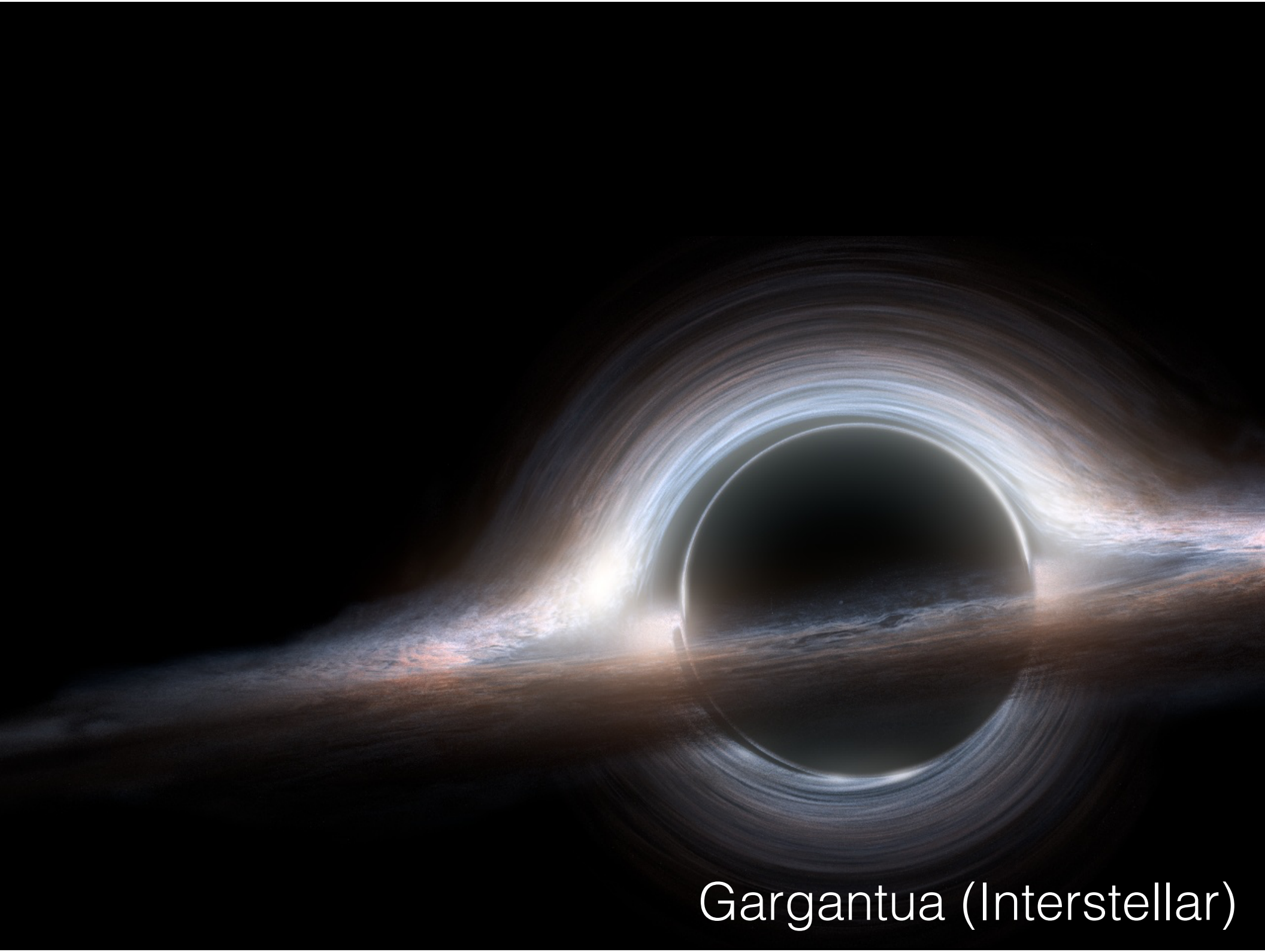


Image from "Gravity's Fatal Attraction" by Begelman & Rees

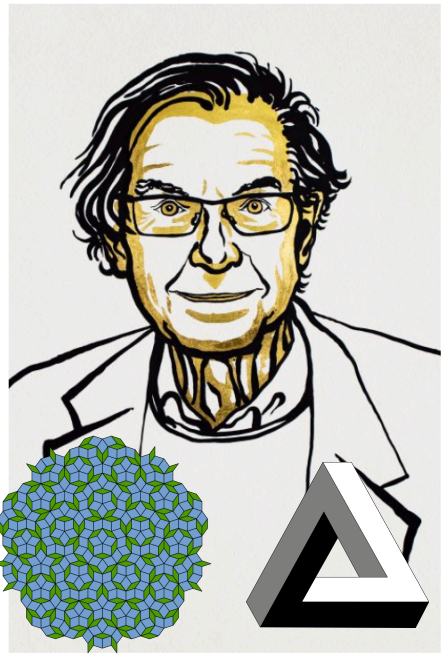

Gargantua (Interstellar)

2020:

Dr. Andrea Ghez is the 4th woman to be awarded the Nobel Prize in Physics

"for the discovery of a supermassive compact object at the center of our galaxy"

The Nobel Prize in Physics 2020



© Nobel Media. Ill. Niklas Elmehed.

Roger Penrose

Prize share: 1/2

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Reinhard Genzel

Prize share: 1/4

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Andrea Ghez

Prize share: 1/4

Radioactivity

1903: Marie Curie

Atomic structure

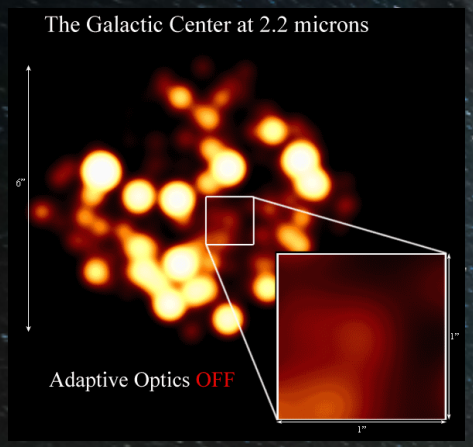
1963: Maria Goeppert Mayer

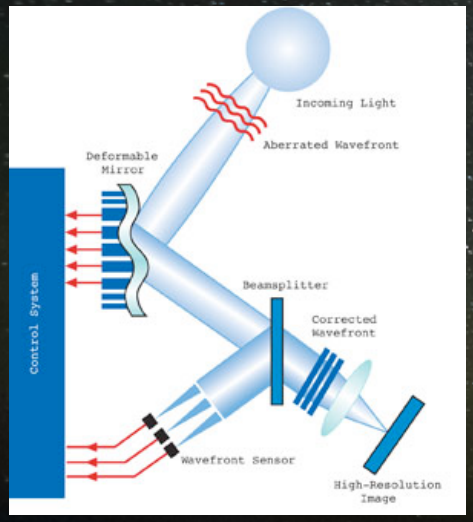
Lasers

2018: Donna Strickland

The Center of the Milky Way

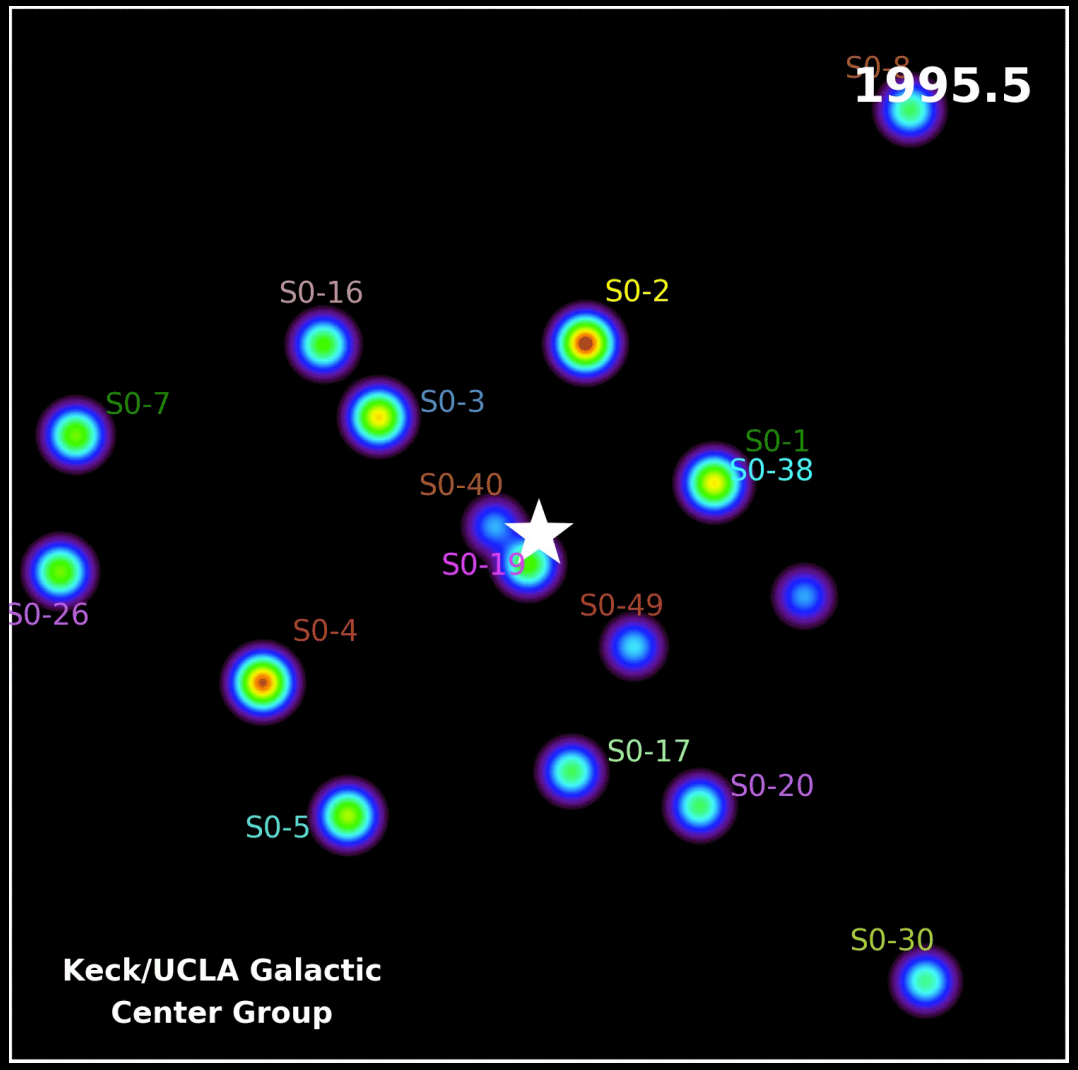
Sgt A* (radio source discovered in the 1970's)





ETHAN TWEEDIE | PHOTOGRAPHY

Dr. Andrea Ghez's research group followed the stars since 1995



Stars appear to be orbiting something massive but invisible

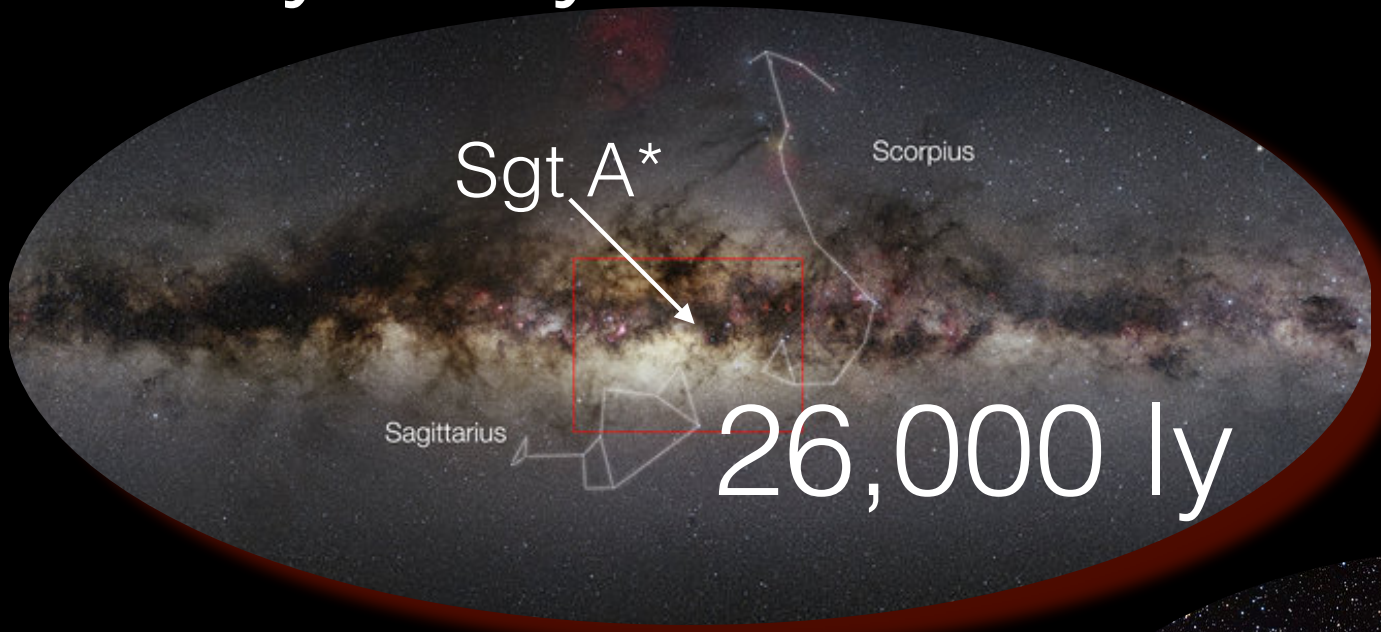
Closest star S0-2 moving at 0.5c with a period of 15 years is a test for GR

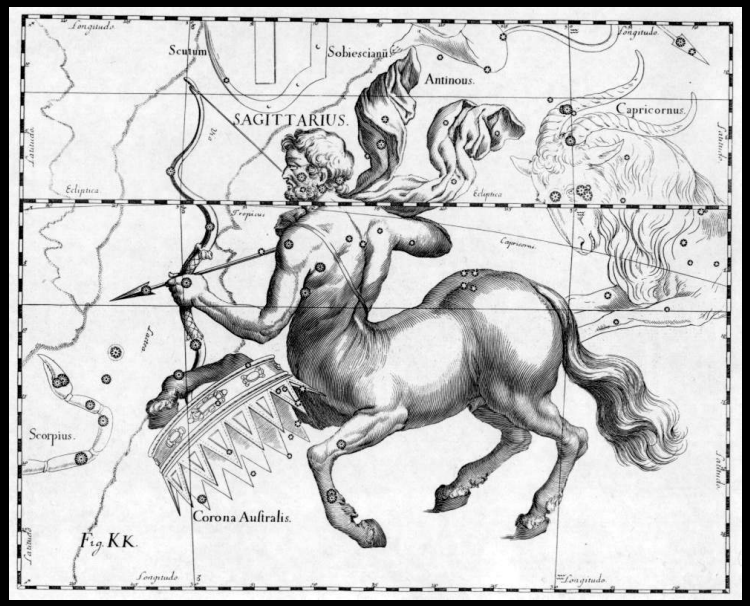
Big surprise: some are massive, young blue stars

Milky Way's black hole is ~4.2 million solar masses

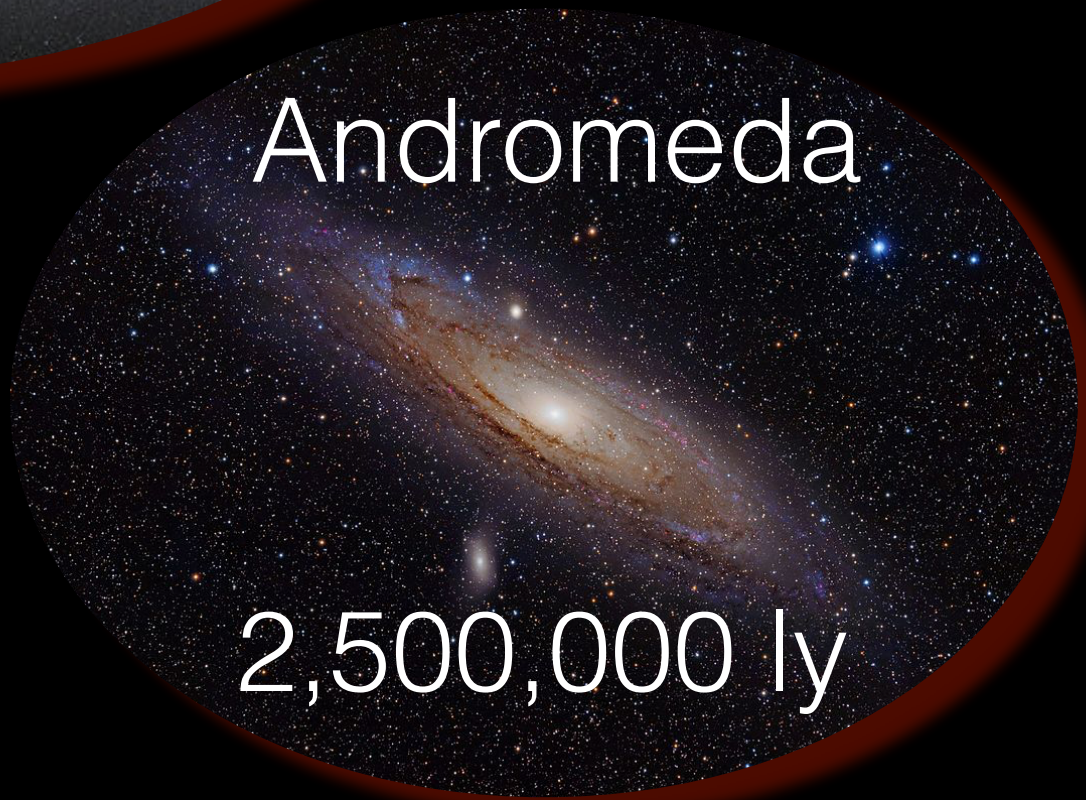

Why should you care about
supermassive black holes?

Milky Way's black hole

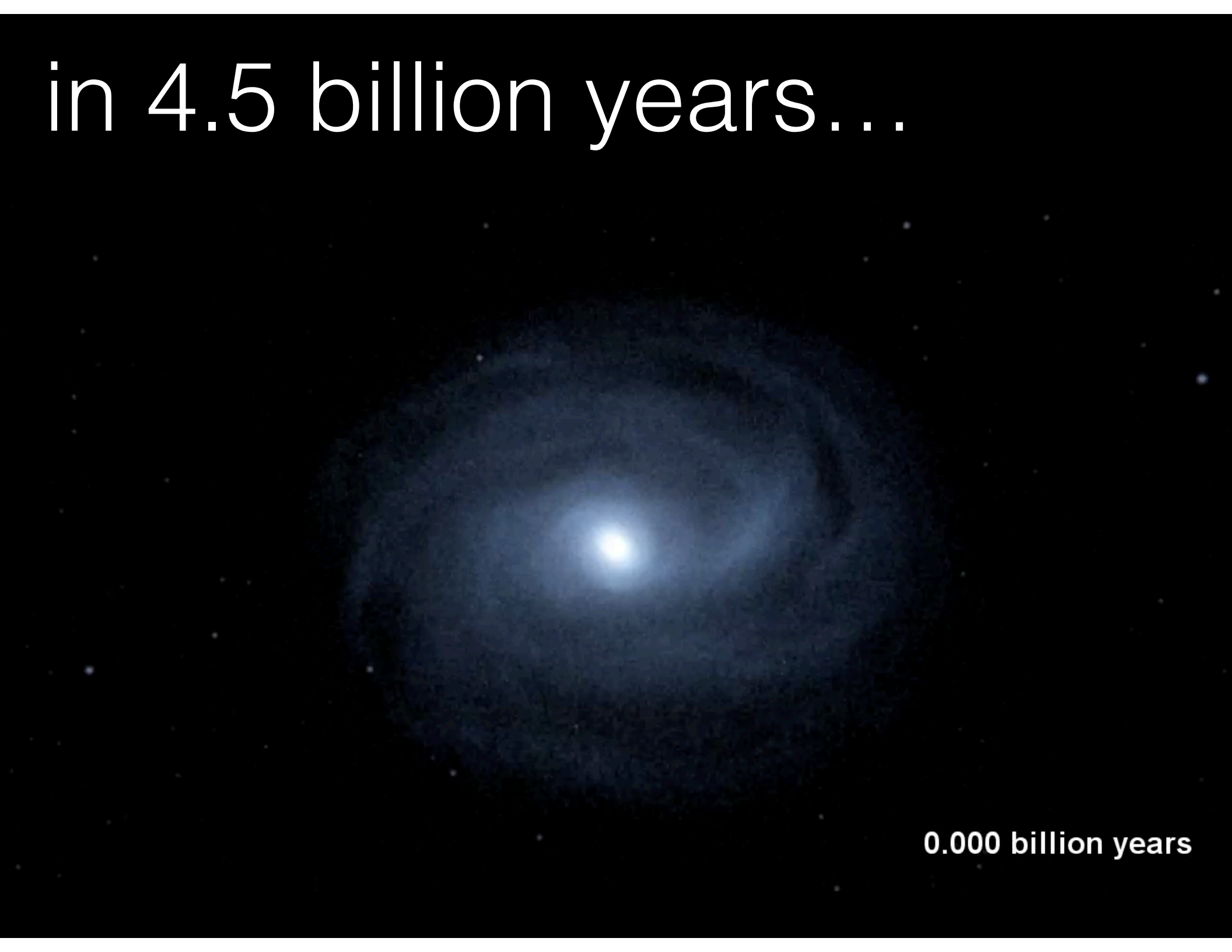




@ 4:30am above the SE horizon



in 4.5 billion years…



Credit: NASA