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Black Holes: Myths, Legends and Truths

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BLACK HOLES: MYTHS, LEGENDS & TRUTHS

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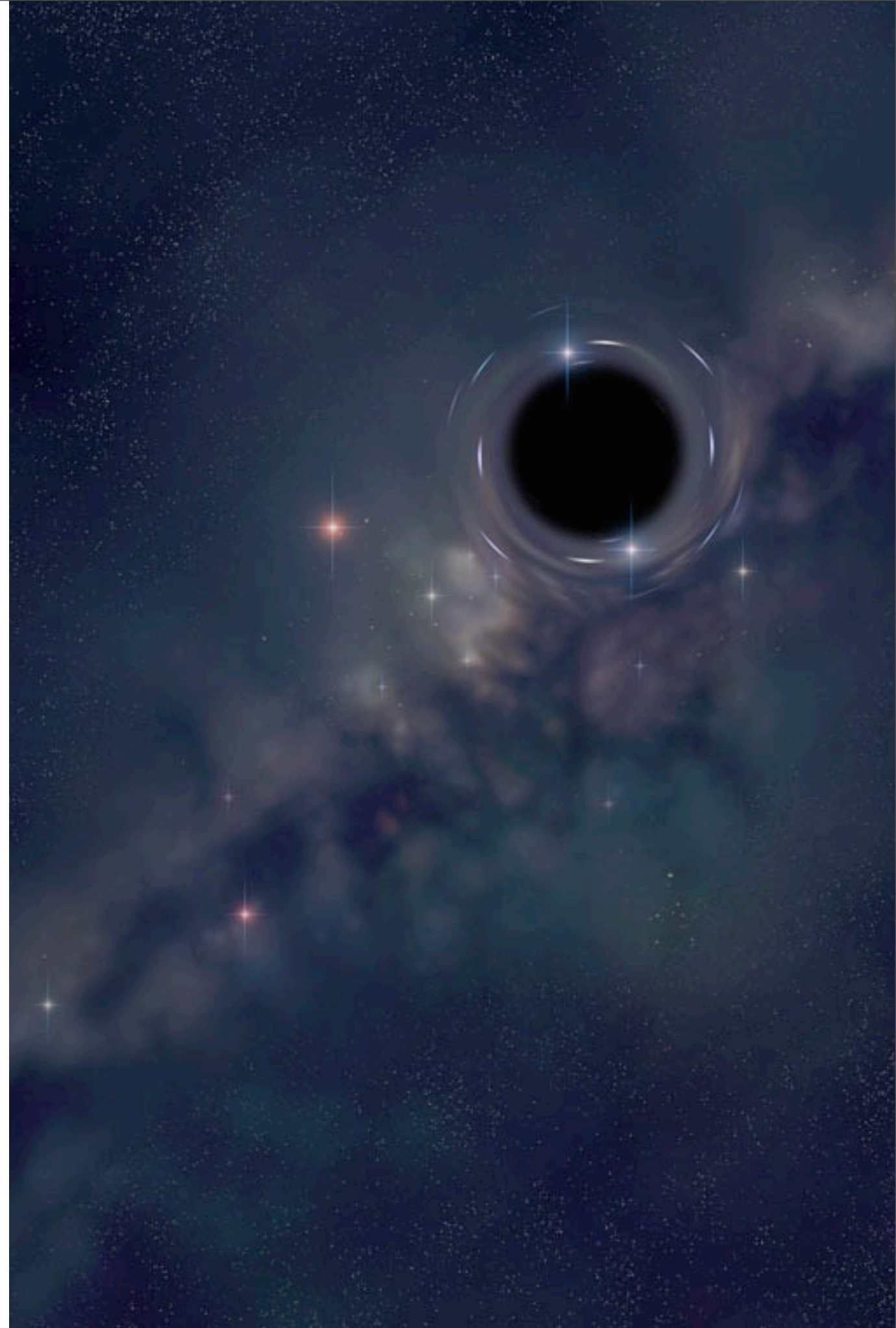
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RMSGC Workshop
USU – Uintah Basin
24 June 2010

Storyline

- Modern gravity
- Black holes we have known
- Seeing black holes
- Listening to the songs of gravity



Albert Einstein

- 1905: Working as a patent clerk in Bern, Switzerland
- In this “Miracle Year”, he published 3 papers that transformed physics
 - Brownian motion
 - Photoelectric effect & the revival of photon theory
 - Special relativity: the ultimate speed limit



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Gravity: Isaac Newton

- Isaac Newton (1642-1726)
- Lucasian Professor at Cambridge
 - 1687 — Principia
 - 1704 — Optiks
- 🍏 Newtonian gravity was the first great physical law
- **Attractive force** between masses, falls off with distance
- Einstein knew this was **incompatible with Special Relativity**, and in 1915 introduced General Relativity

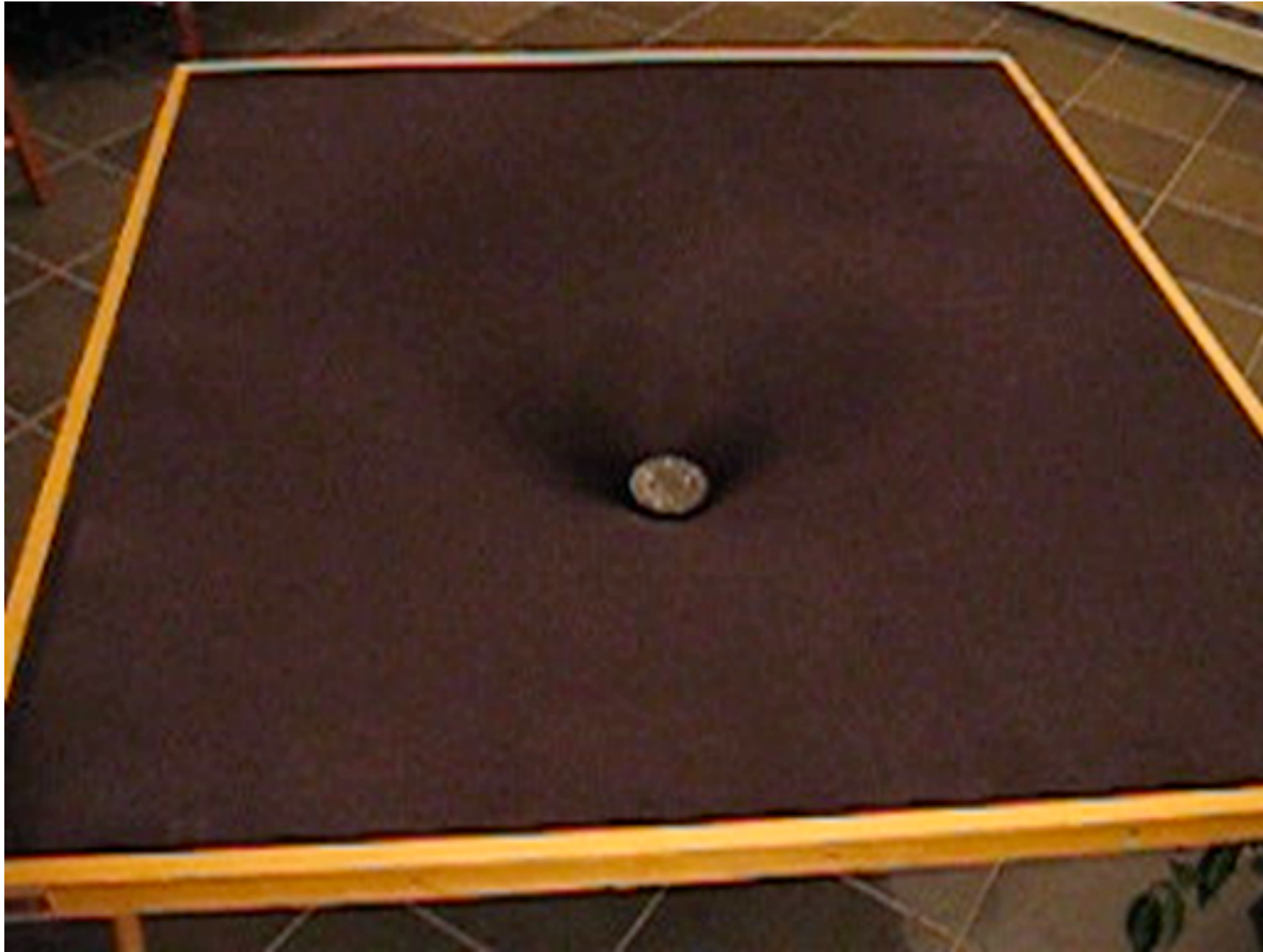


General Relativity: Flat Spacetime



- When there is no gravity, particles travel in straight lines

General Relativity: Curved Spacetime



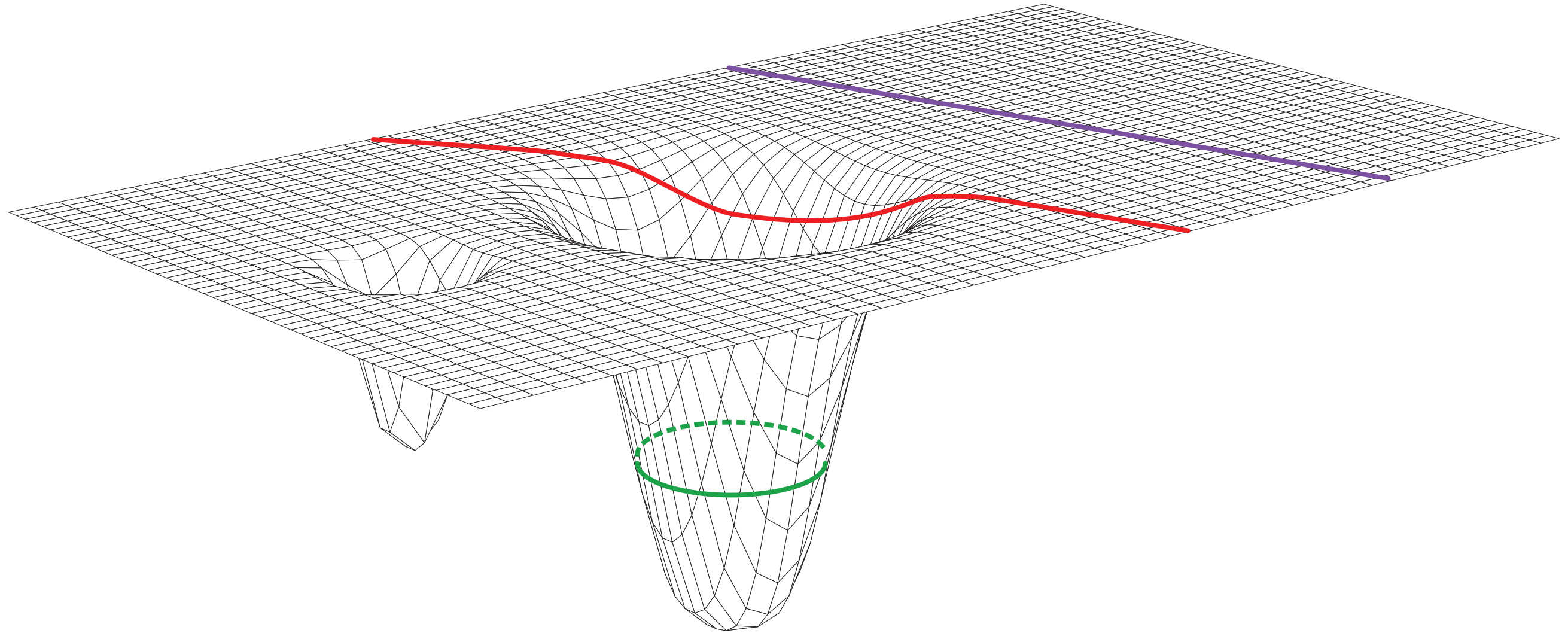
- When there is gravity, particles travel on curved lines

General Relativity: Orbits



- General relativity correctly gives everything Newtonian gravity does, like orbits!

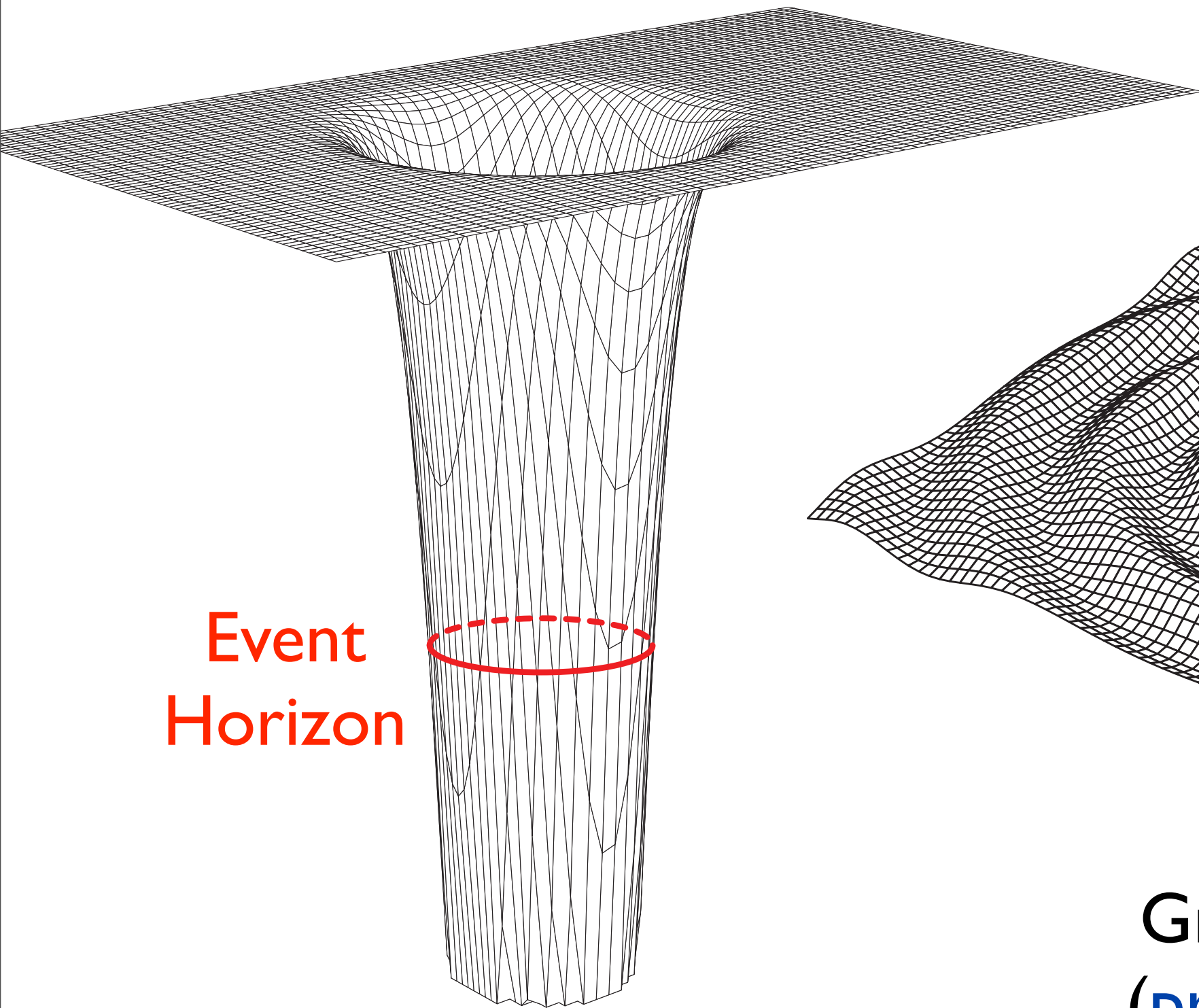
General Relativity: One page mantra...



- ***Matter tells space how to curve***
- ***Space tells matter how to move***

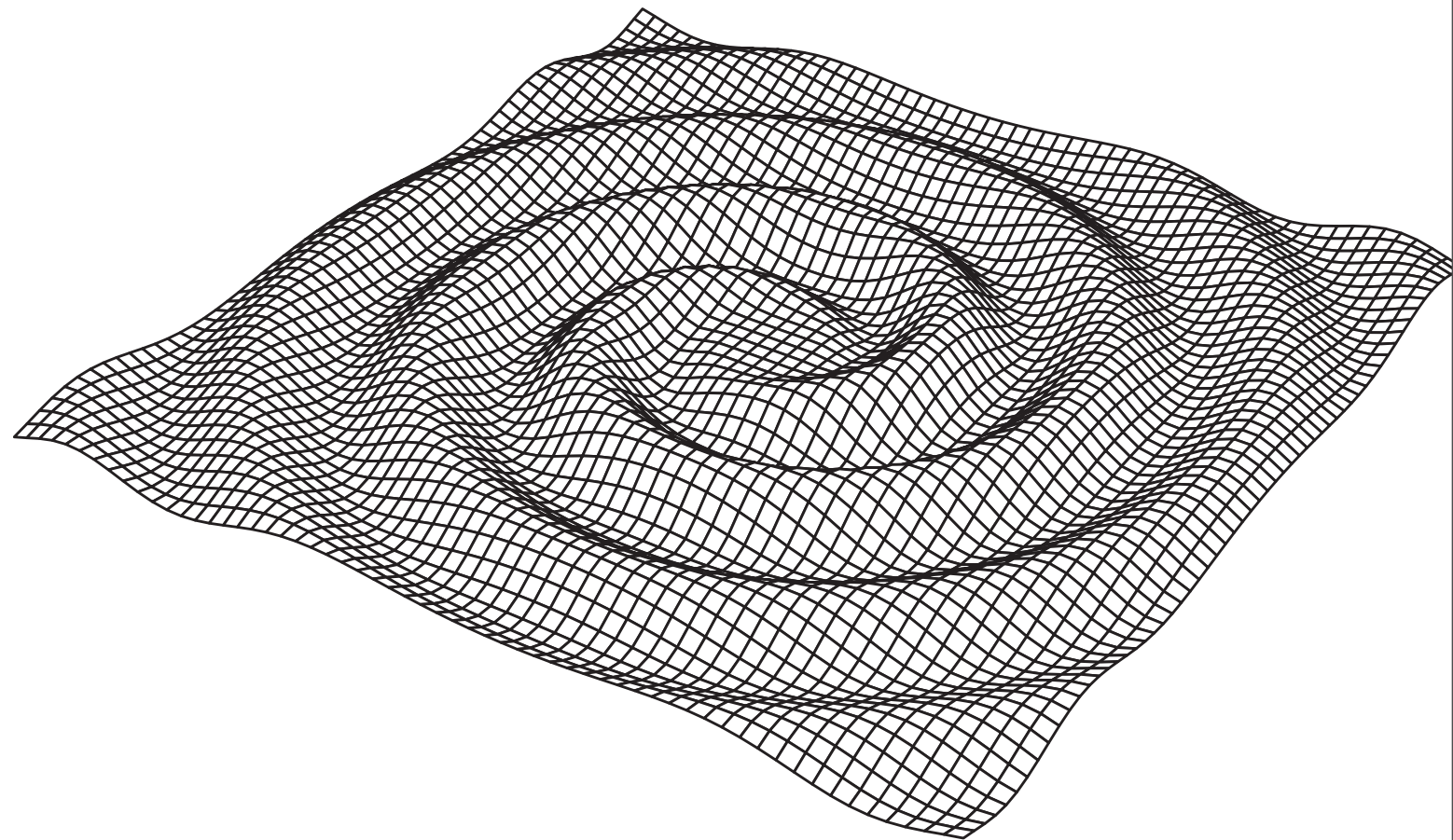


Consequences of General Relativity



Event
Horizon

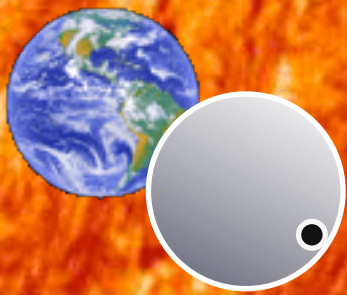
Black holes
(infinite wells)



Gravitational waves
(propagating gravity)
(ripples in spacetime)

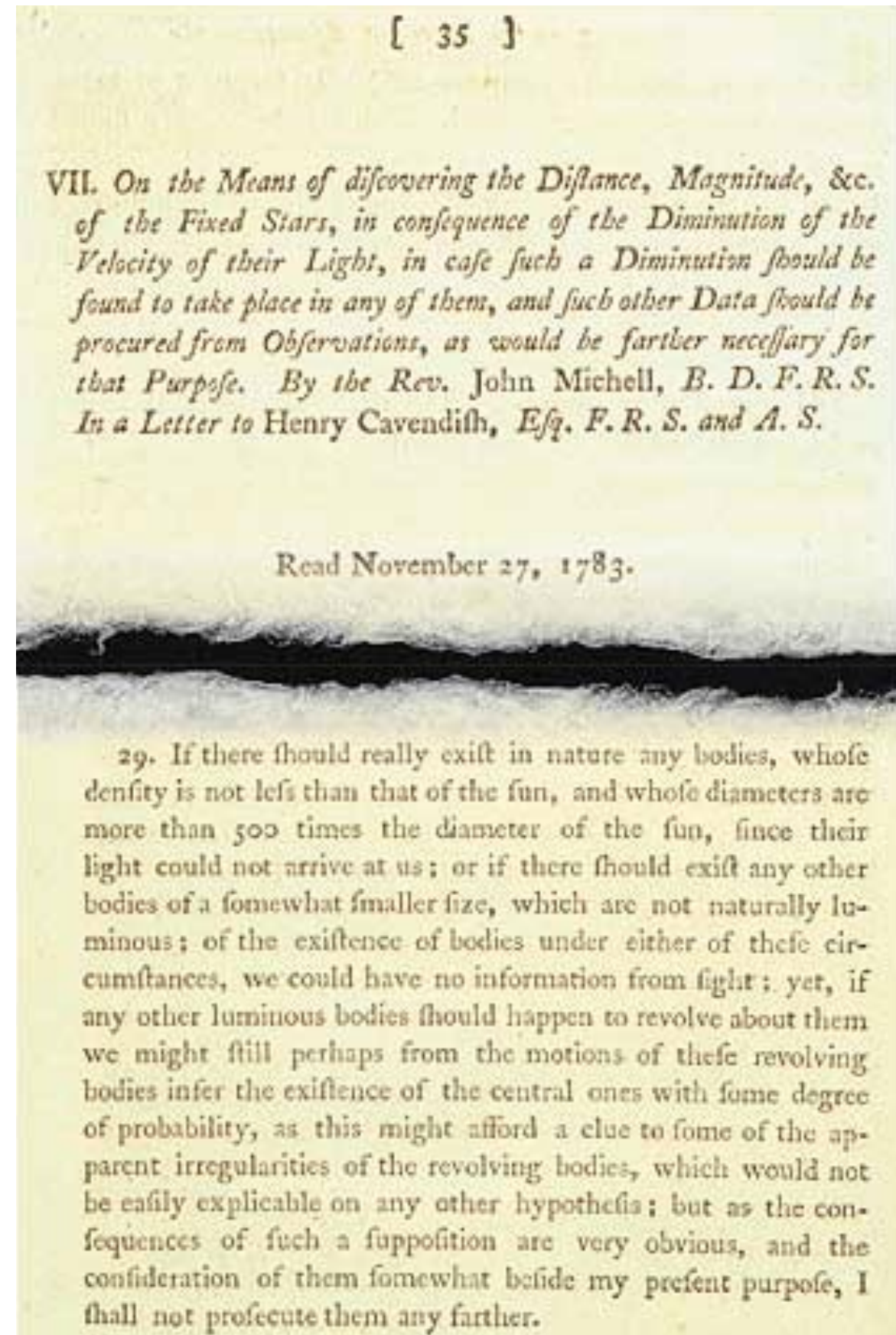
What is a Black Hole?

- Compact object, with **HIGH ESCAPE VELOCITY**
- Sun: radius = 1.4 million km
 - $v = 618 \text{ km/s}$
- Earth: radius = 6400 km
 - $v = 11 \text{ km/s}$
- white dwarf: radius = 6400 km
 - $v = 6450 \text{ km/s}$
- black hole: radius = 3 km
 - $v = c = 300,000 \text{ km/s}$



Not a new idea!

- **Einstein did not invent black holes!**
- Black holes are a **natural consequence** of gravity!
- Black holes were discovered in **Newtonian gravity** by Rev. John Michell in **1783** (!)
- What did Einstein add to the idea of black holes?
 - **You cannot escape from a black hole**
 - **The speed of light is a maximum speed limit (special relativity)**



Black hole observer's report...

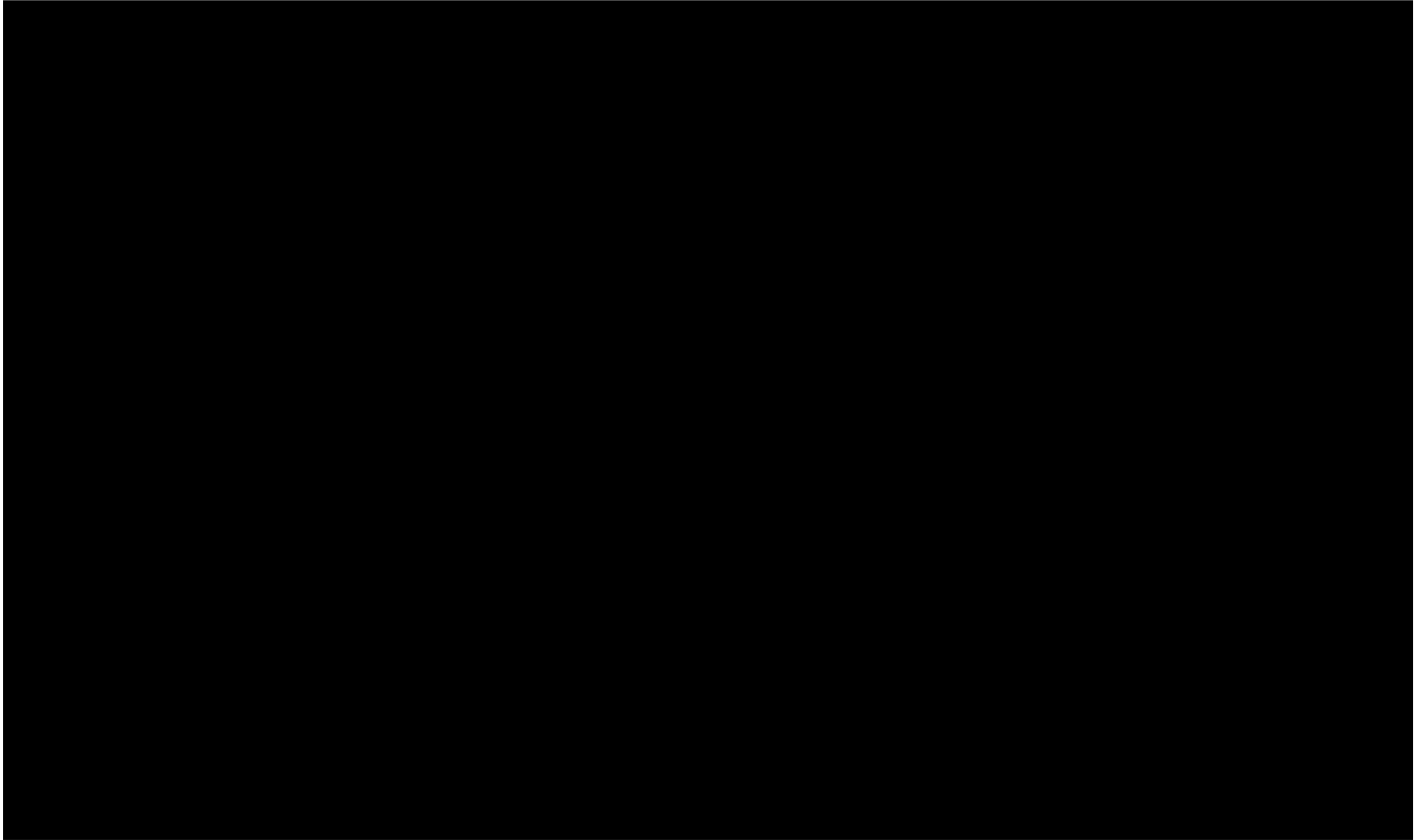
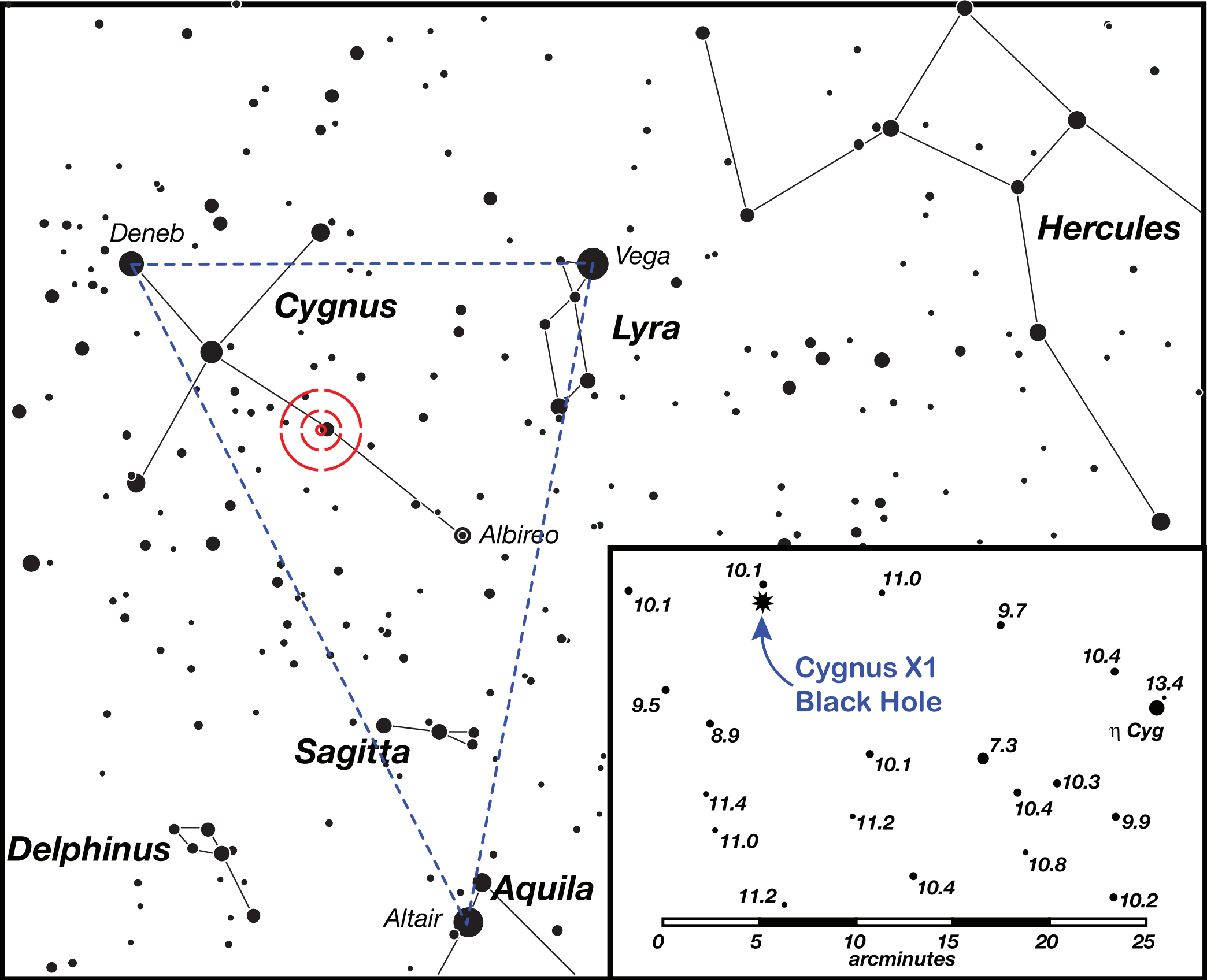
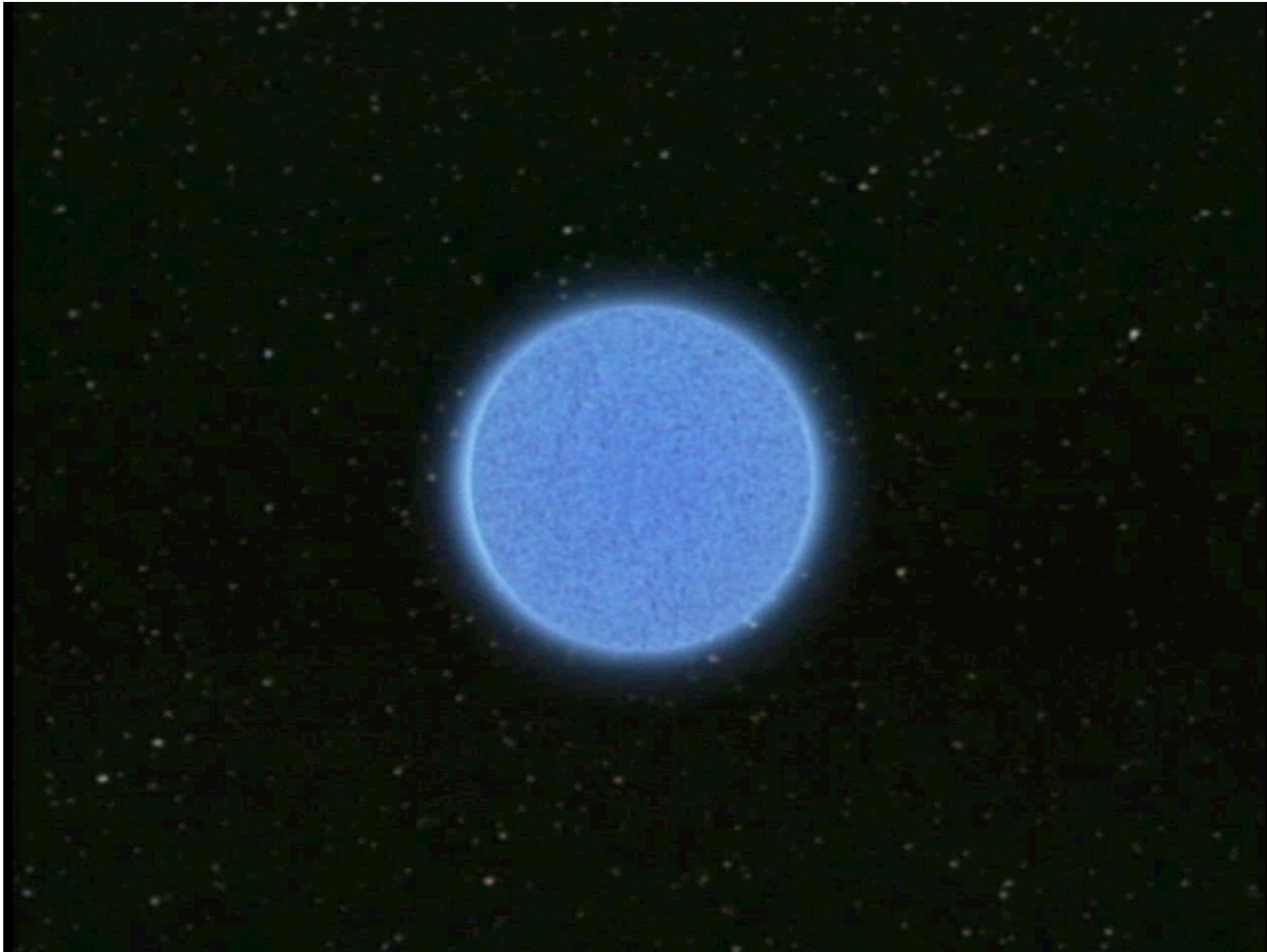


Image credit: M. Larson

Candidate: Cygnus X-1

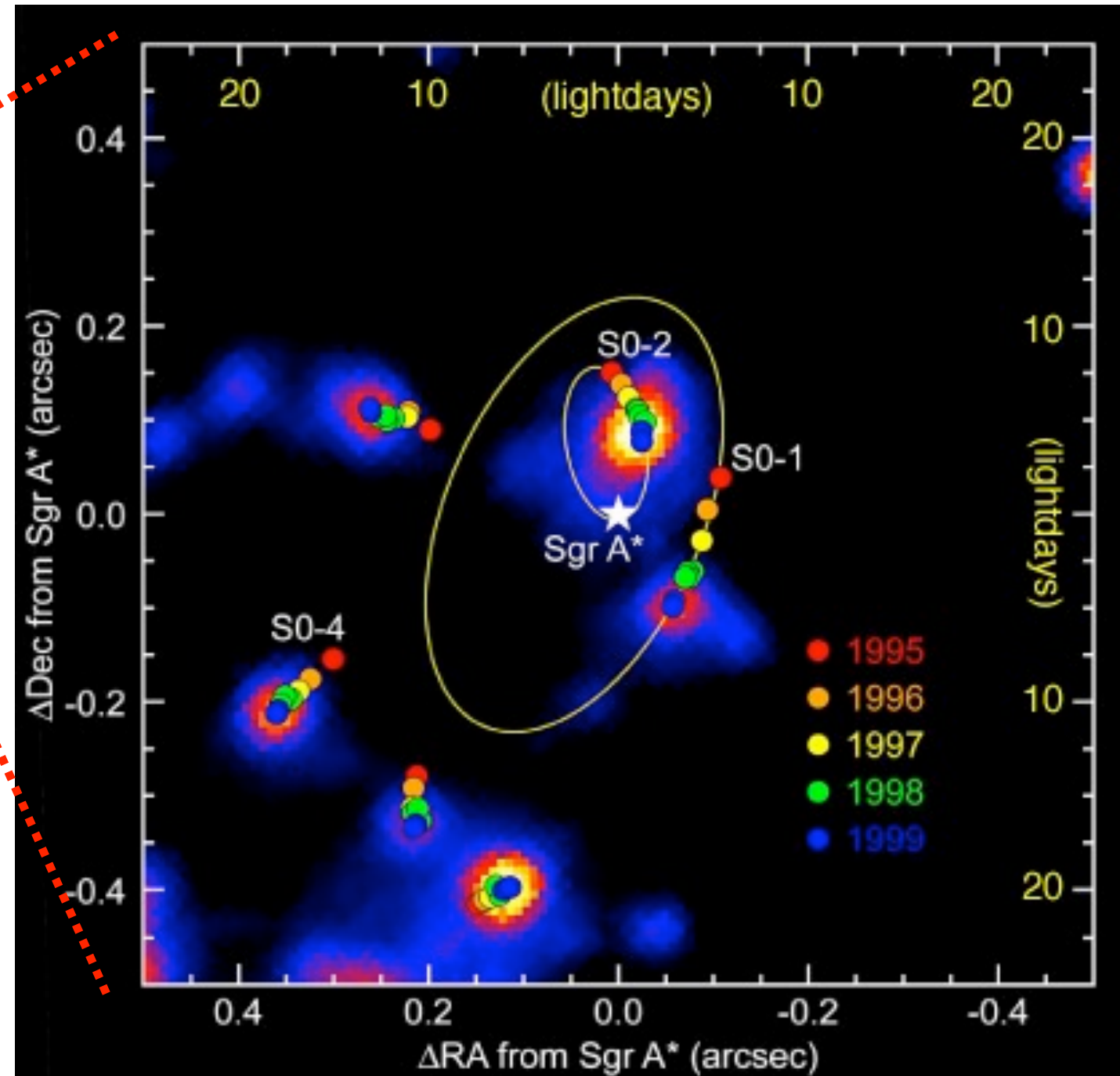
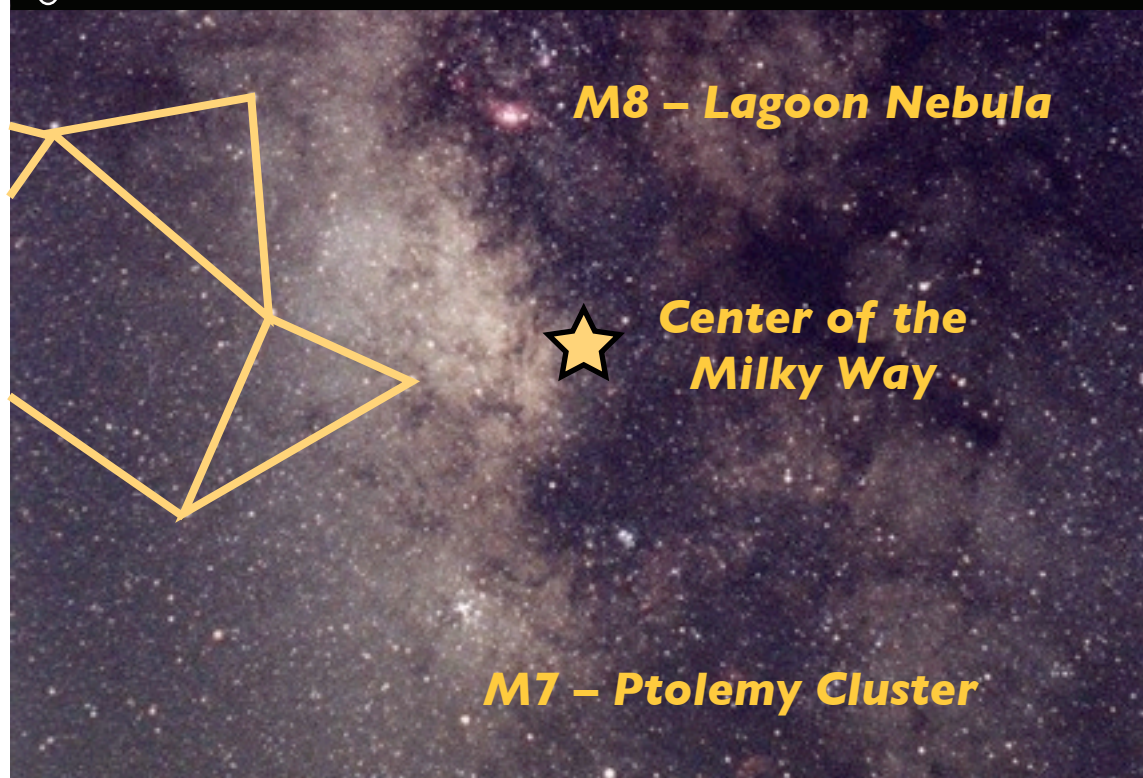
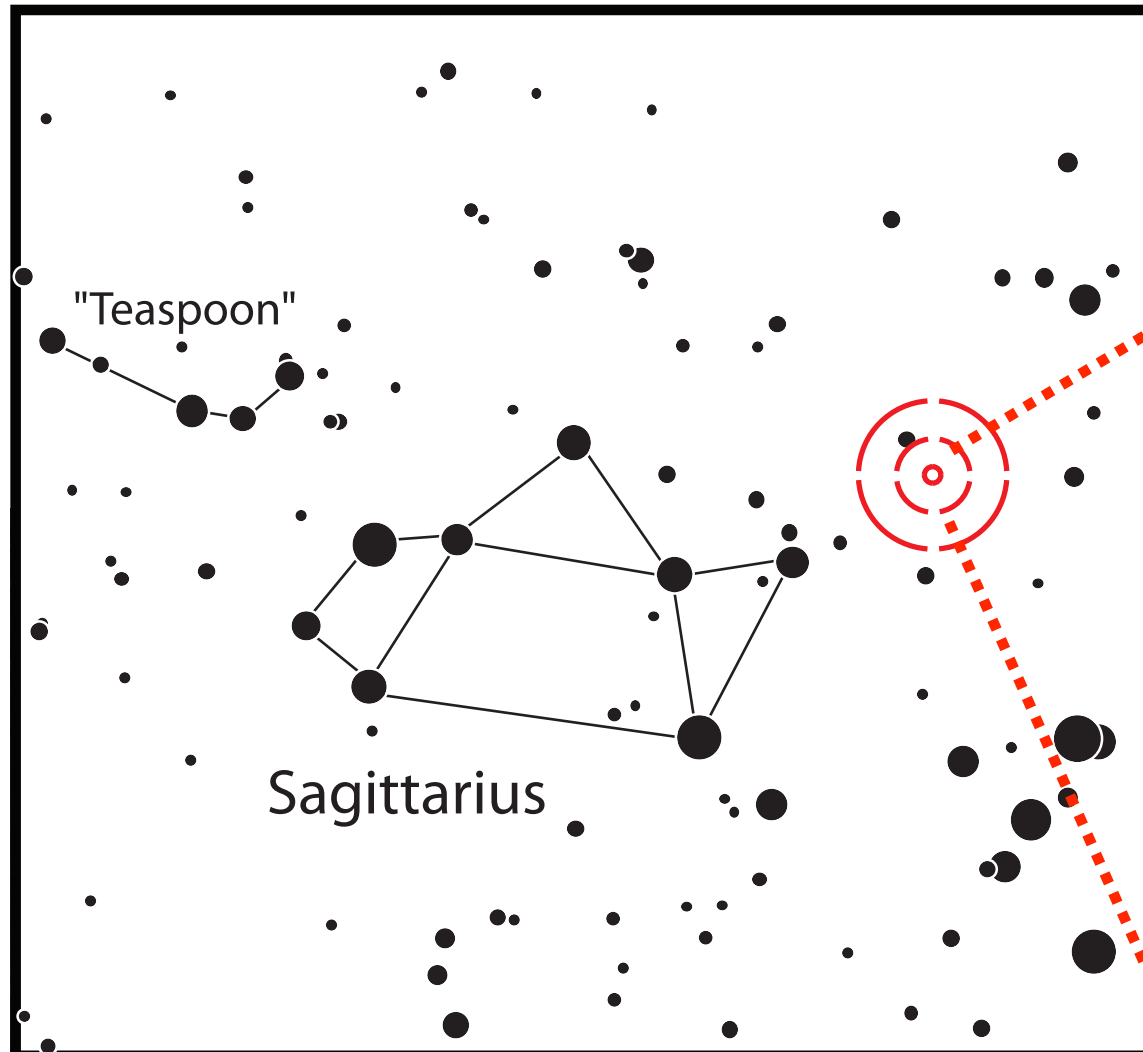


Candidate: Cygnus X-1

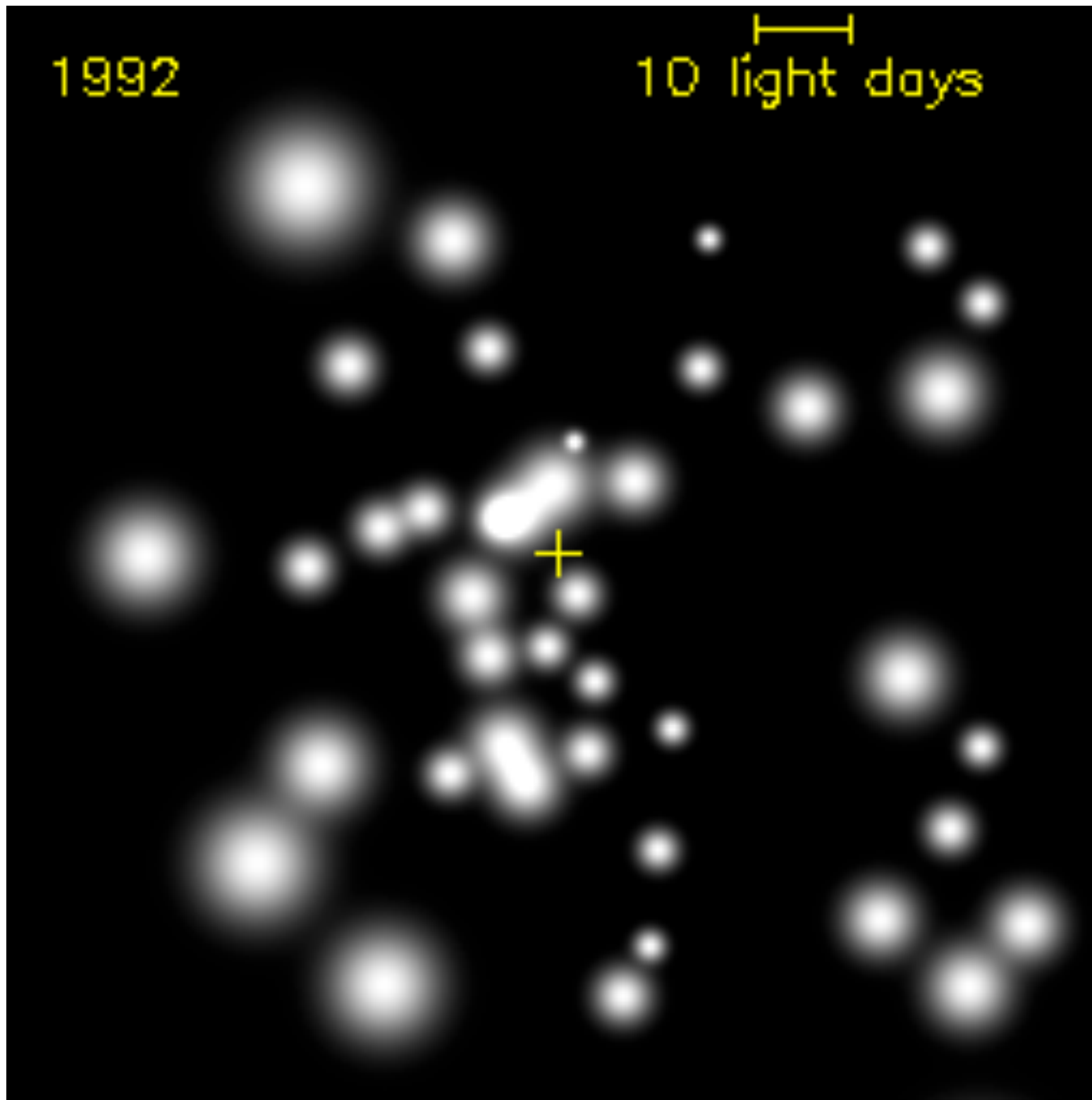


- Invisible companion of a blue supergiant star is a suspected 10 solar mass black hole – the closest black hole to Earth (~5900 lyr)!

Center of the Milky Way

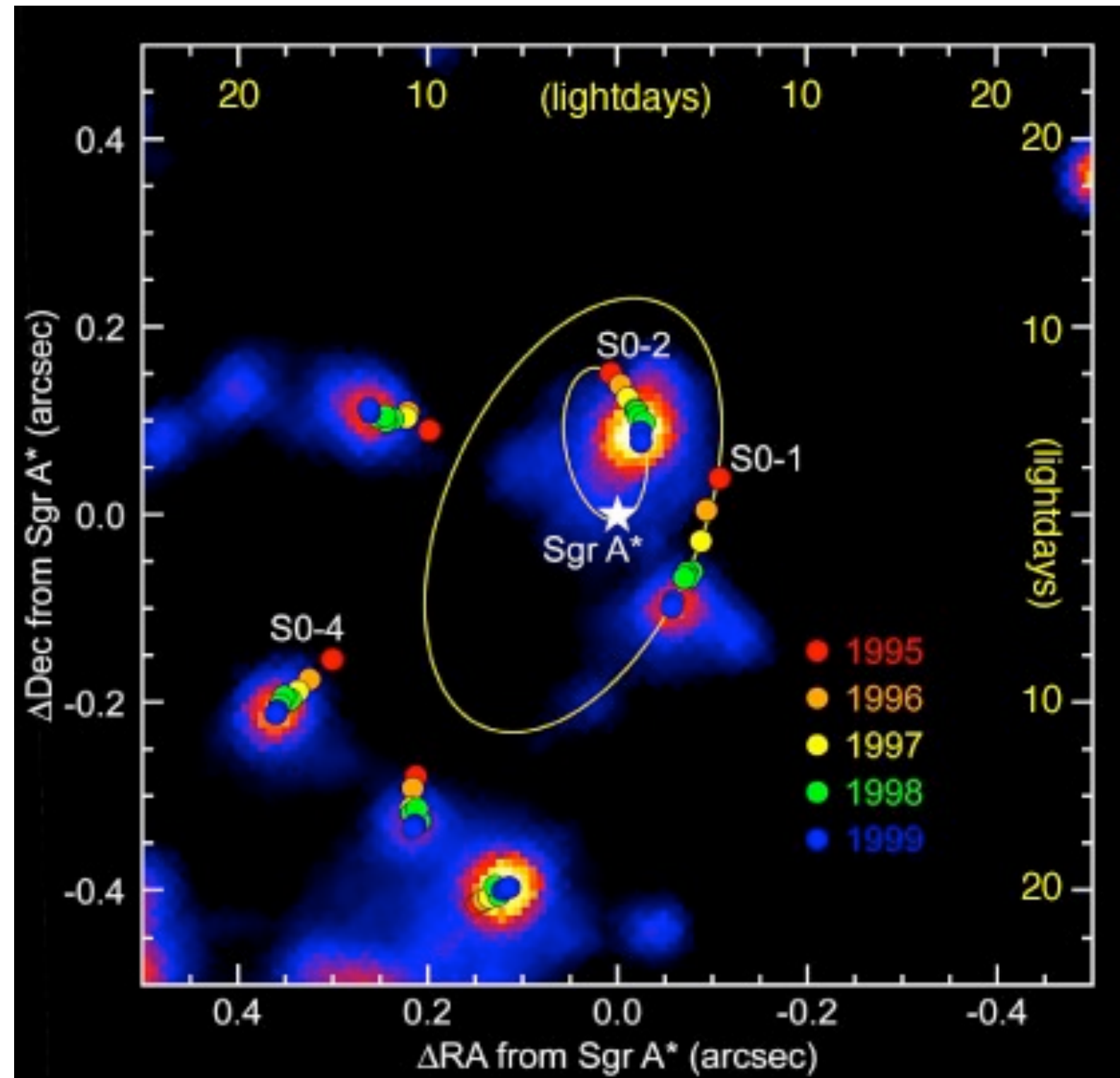


Stars in Motion...



Explanation: 4 million solar mass black hole

- **Why do we think this is a black hole?**
- To explain the motion we see in the stars, you need 35 billion stars per cubic lightyear
- If this were caused by stars and not a black hole, there should be **90 million stars** in this picture!



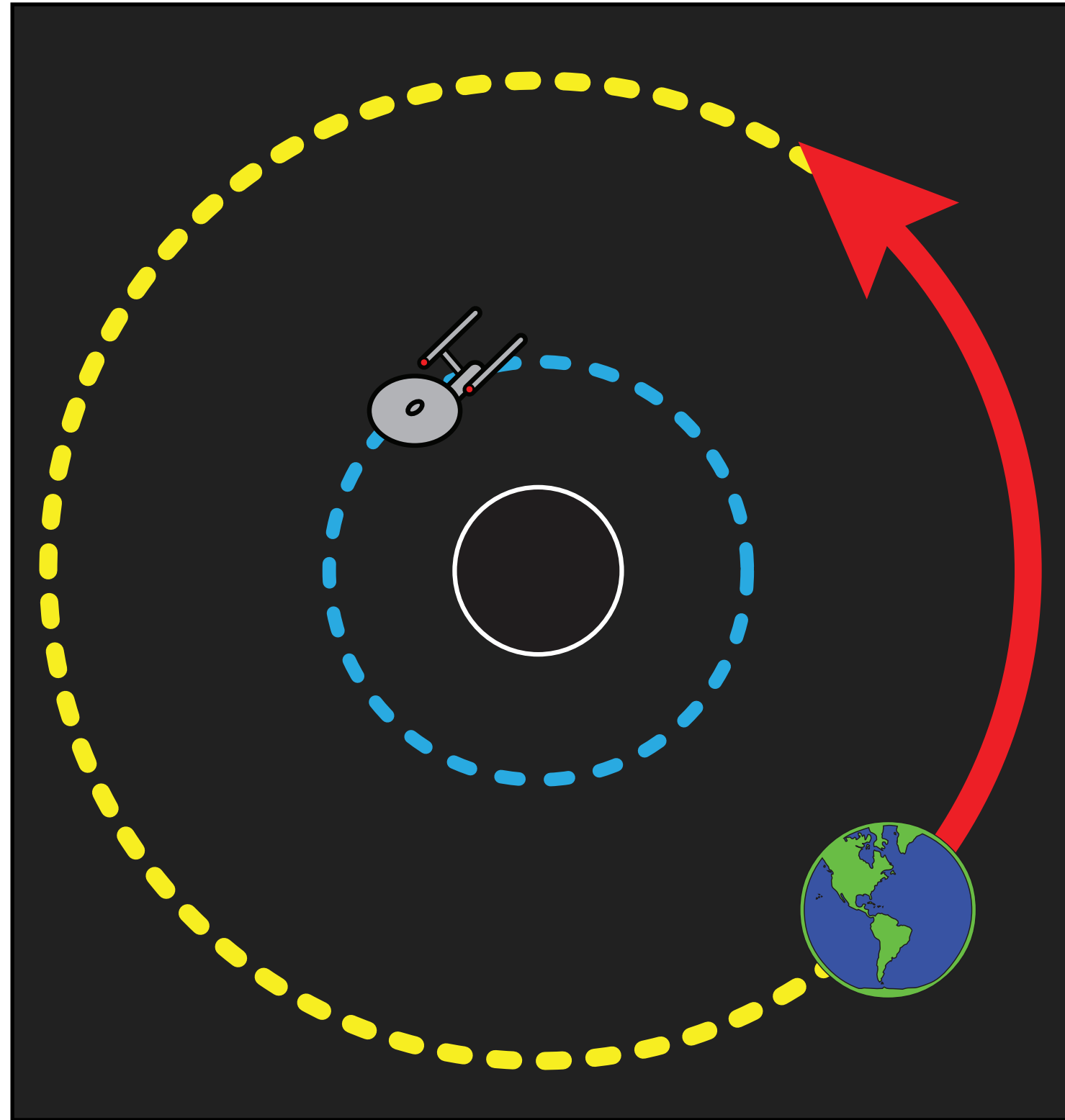
Exploring black holes

- Intrepid explorers (or infalling matter -- stars, hydrogen gas, etc.) are needed to explore close to a black hole.



Near the black hole

- Far away, **you can't tell its a black hole**
- As you get closer, the black hole **stretches space and time**
- Starship clocks **run slow** near the black hole
- Your friends you left behind **measure different distances** than the crew



Tidal forces...

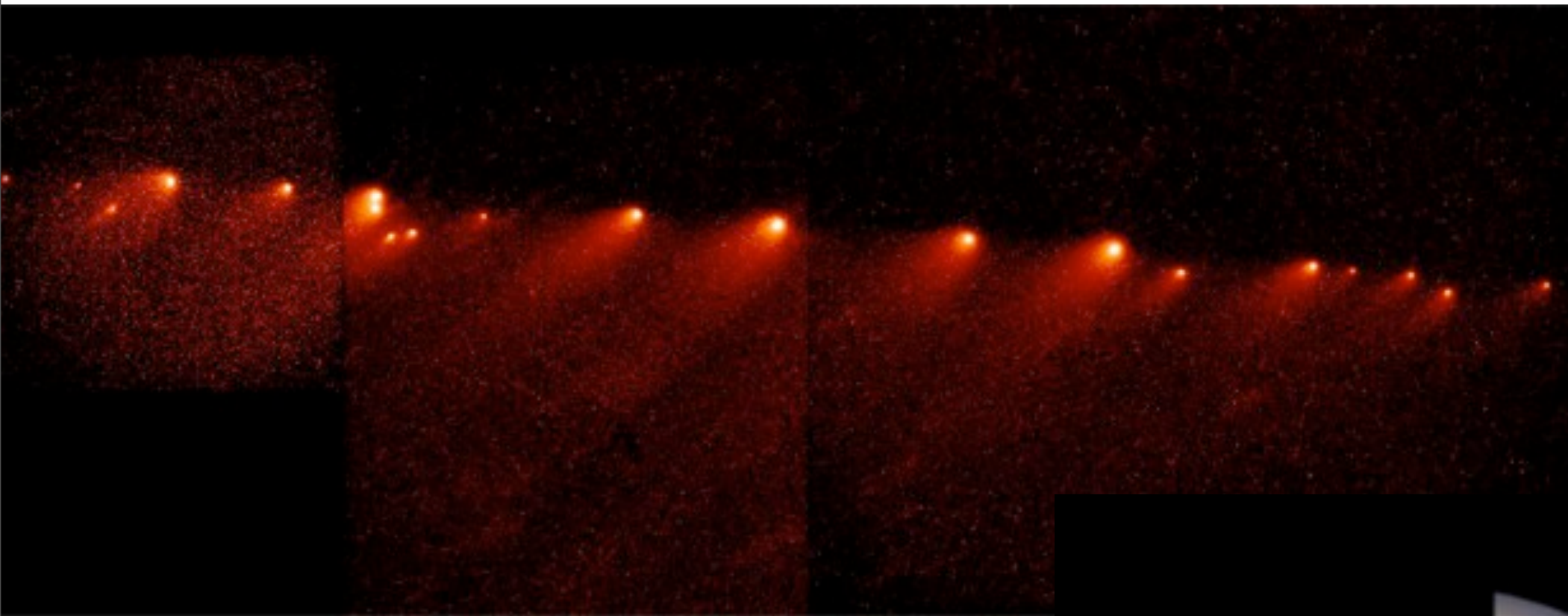
- As you approach a black hole, it pulls harder on the parts close to it -- **tidal forces**
- Eventually, tidal forces pull you apart
- ***Spaghettification***
- Black holes can destroy stars this way



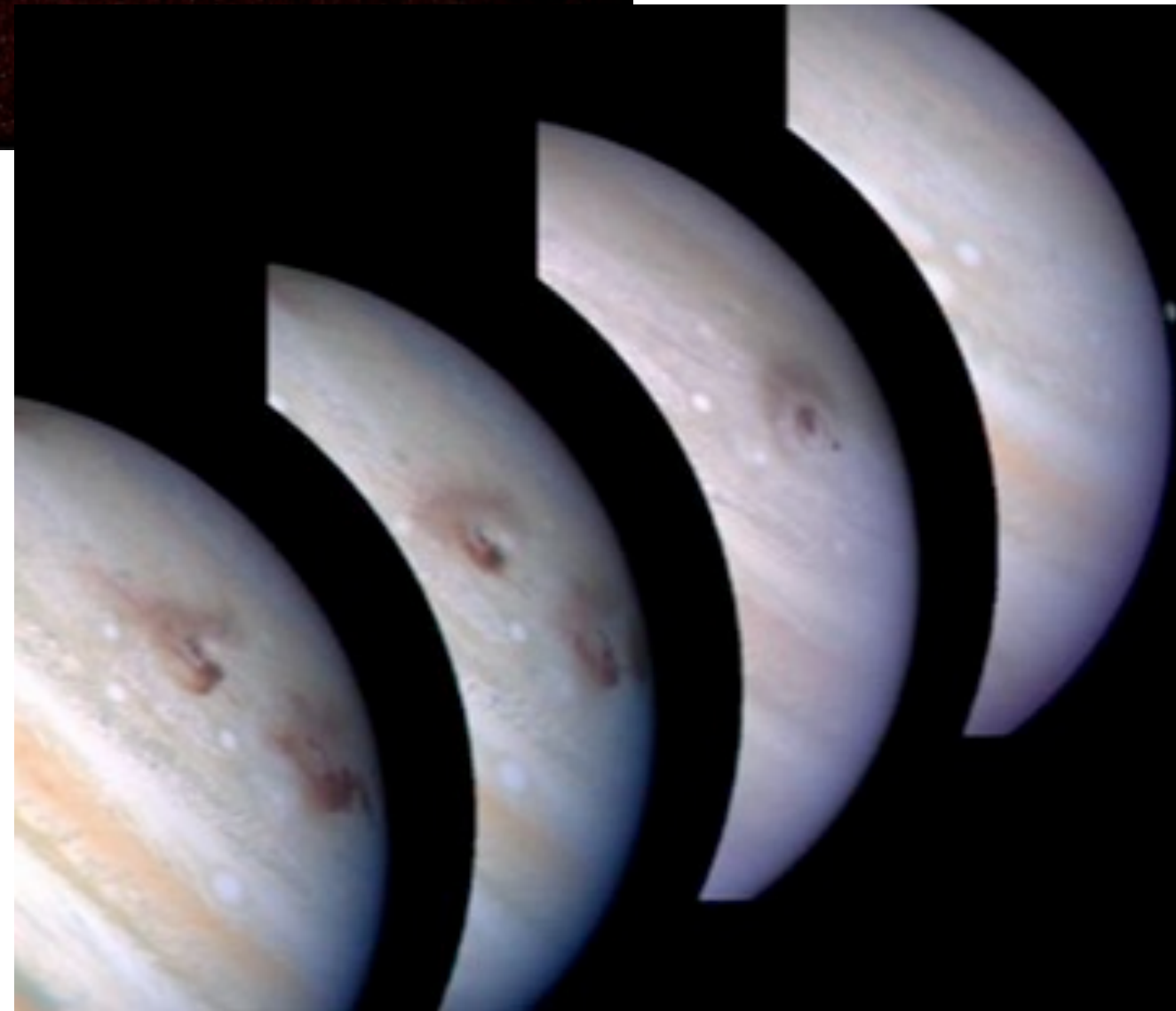
Black holes eating stars...



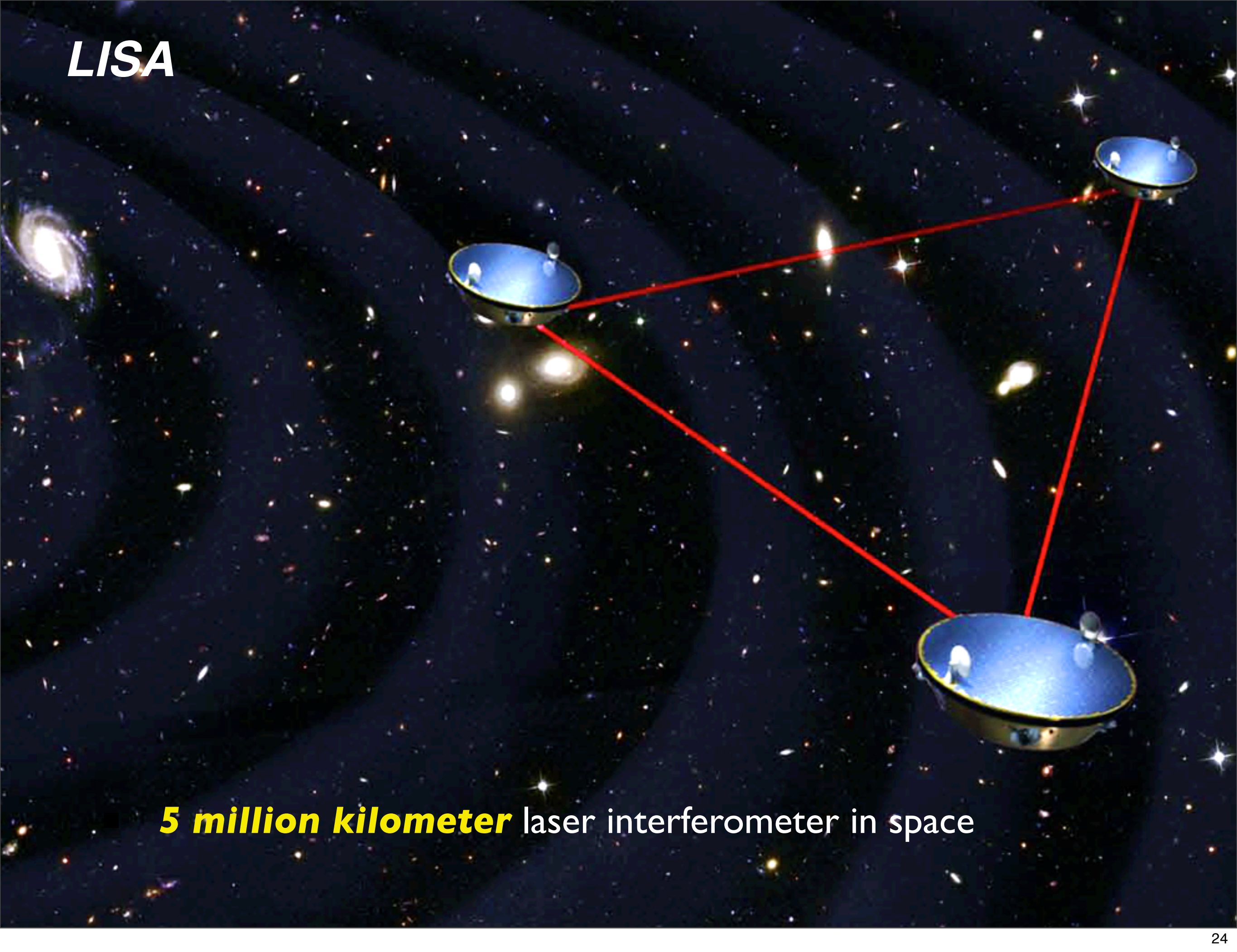
Tidal forces in Nature...



- Tidal forces are ***not unique to black holes***
- **1992**: Tidal forces rip apart Shoemaker-Levy 9
- **1994**: Remnants of SL9 impact Jupiter

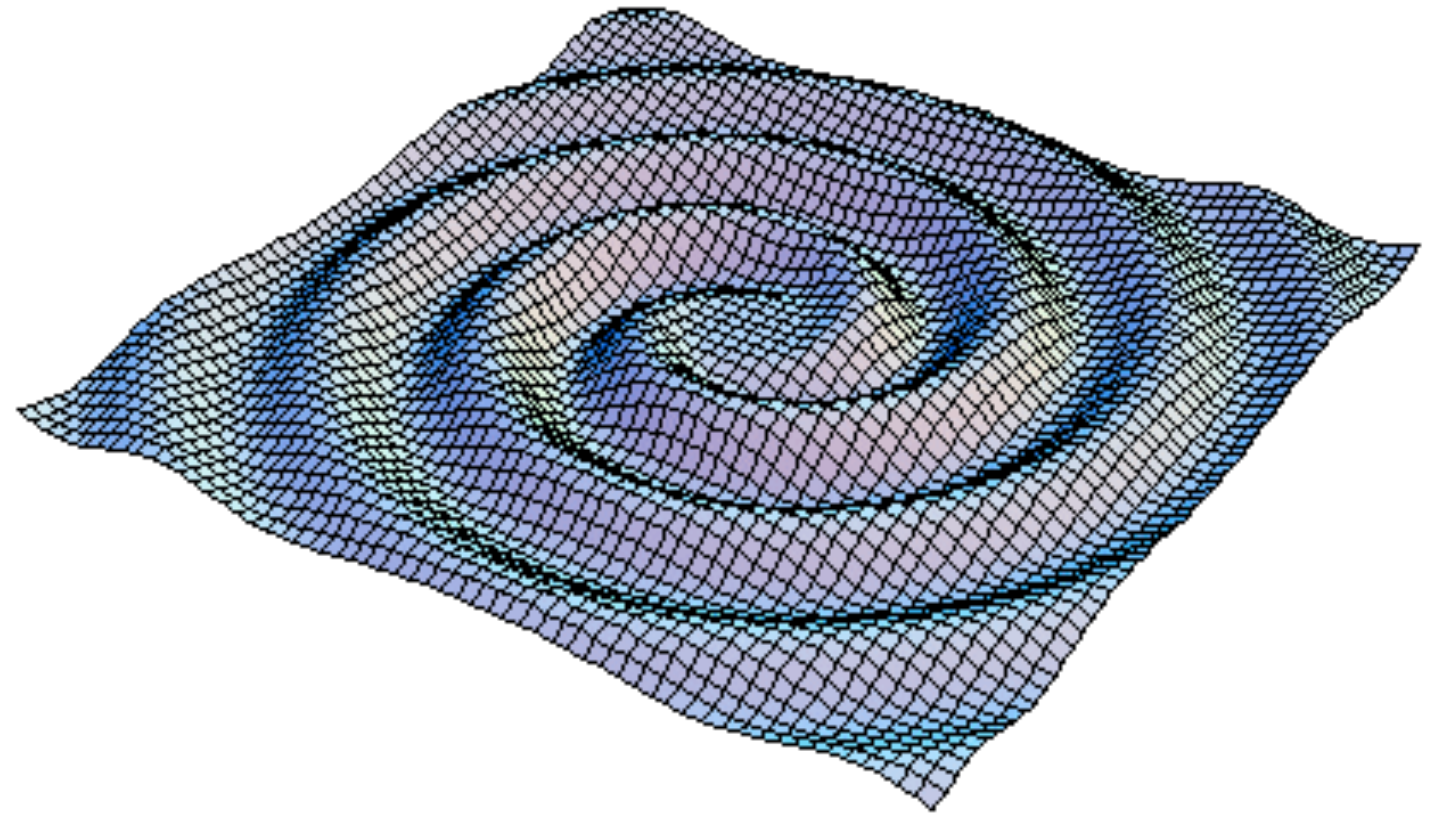
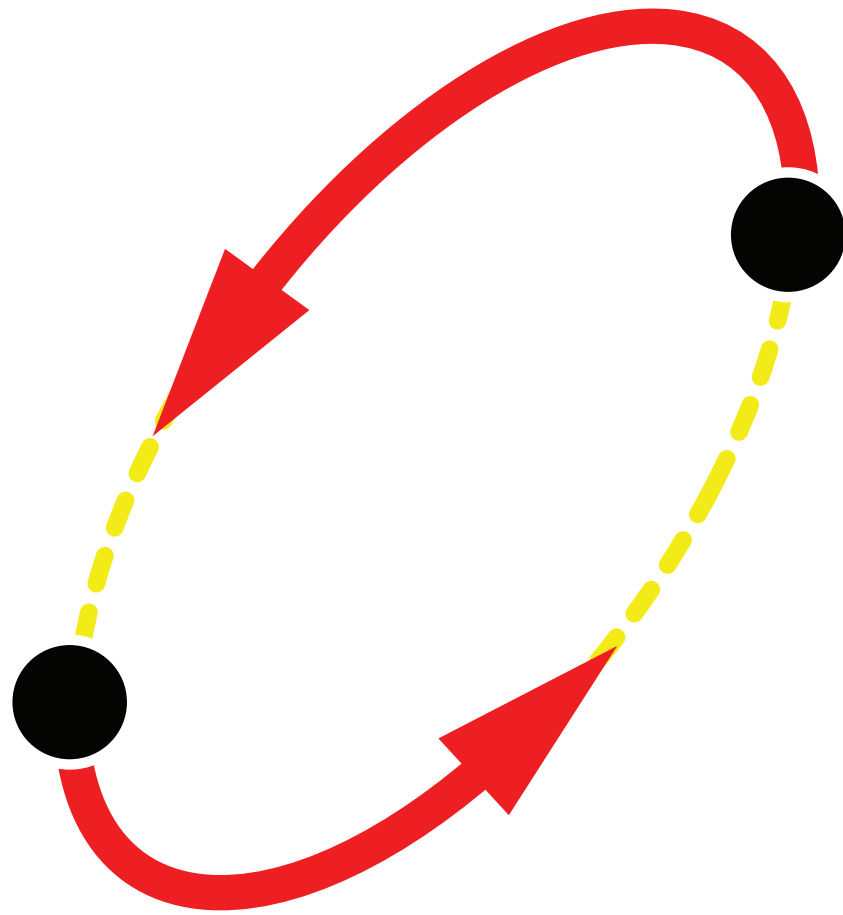


LISA



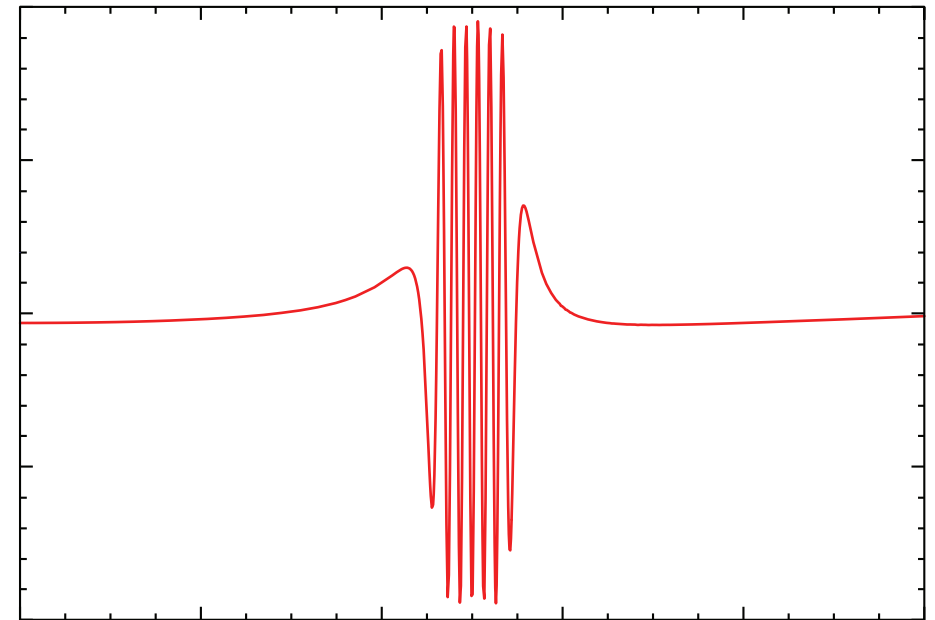
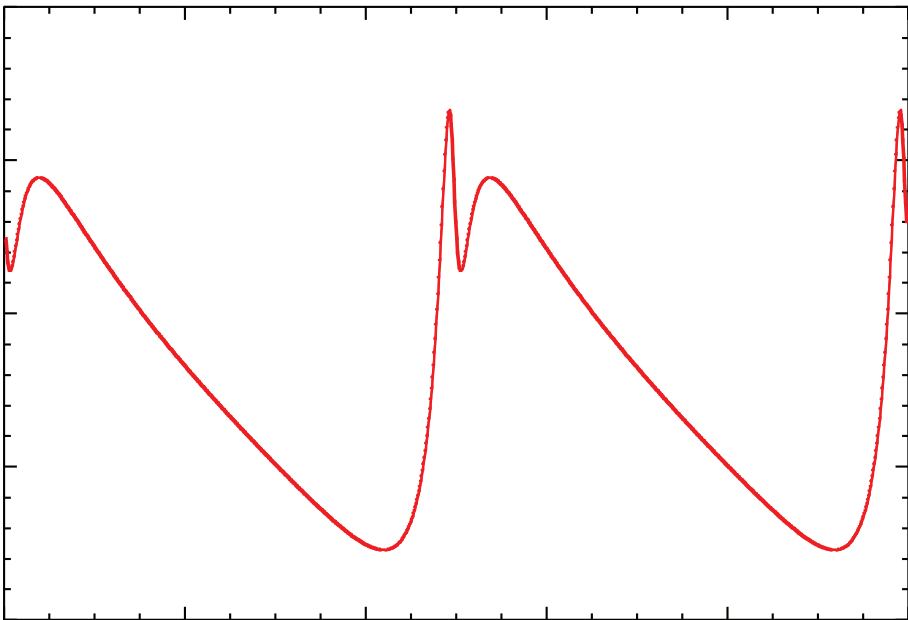
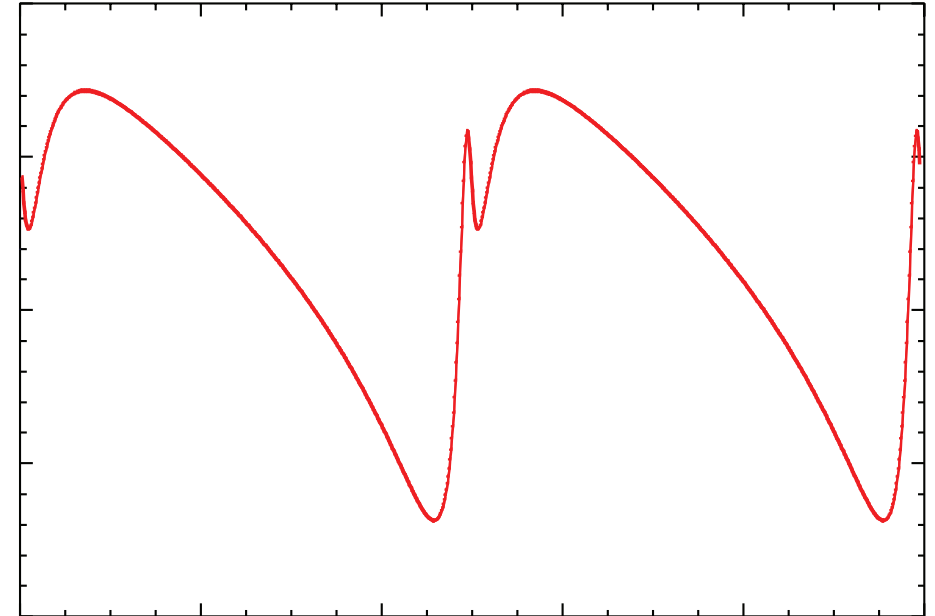
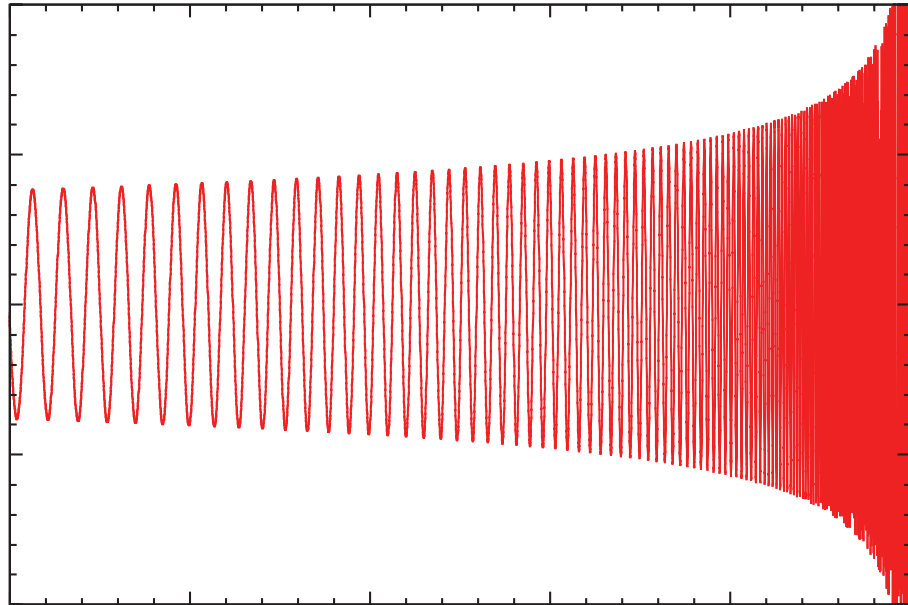
5 million kilometer laser interferometer in space

Binary Black Holes



- Half of all stars we see in the sky are binaries
- If stars evolve into black holes, then binary star systems can evolve into **binary black holes**!

Waveform Zoology



- Gravitational waves **encode astrophysical information!**
- They aren't good for making pretty pictures! :-)

The Songs of Gravity

10 M_{sun} BH + 10,000 M_{sun} BH
circular orbits

10 M_{sun} BH + 10,000 M_{sun} BH
eccentric orbits

More information, reading

- ALBERT EINSTEIN: www.aip.org/history/einstein/
- LISA: lisa.nasa.gov
- BLACK HOLES AND TIME WARPS (Kip S. Thorne)
- EINSTEIN'S UNFINISHED SYMPHONY (Marcia Bartusiak)
- EXPLORING BLACK HOLES (Ed Taylor/John Wheeler)

