



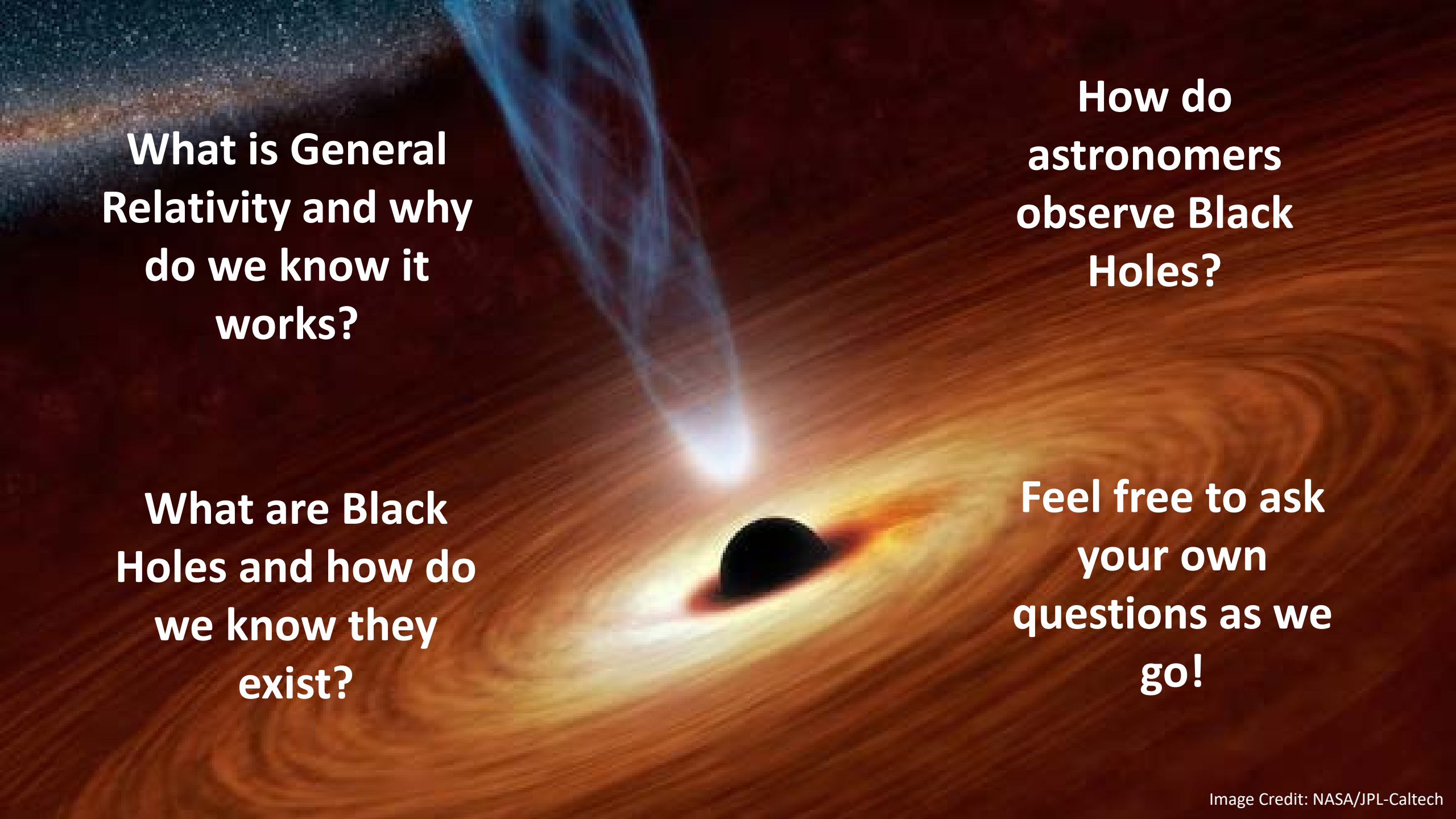
EXTREME ENVIRONMENTS: GRAVITY AND BLACK HOLES

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A black hole is depicted with a glowing accretion disk and a blue jet of light. The background is a dark, starry space. The text is overlaid on the image.

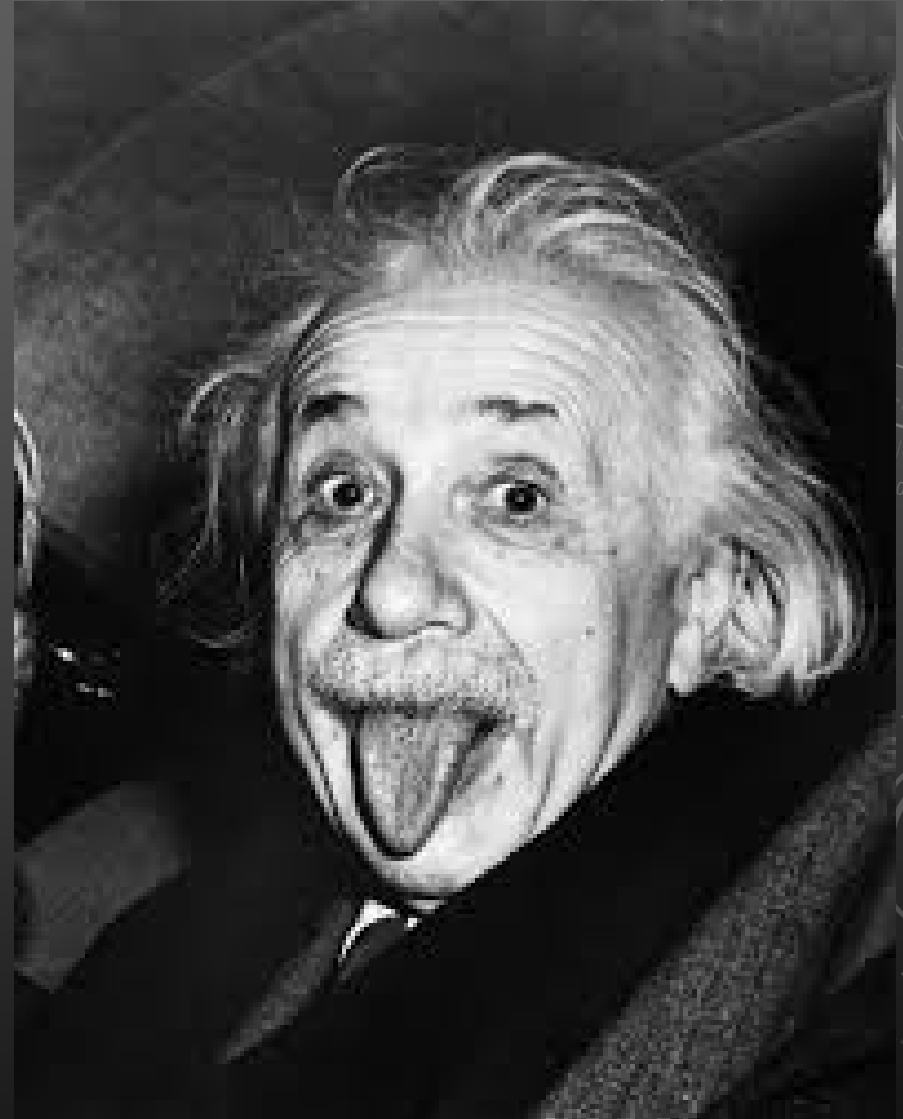
**What is General
Relativity and why
do we know it
works?**

**How do
astronomers
observe Black
Holes?**

**What are Black
Holes and how do
we know they
exist?**

**Feel free to ask
your own
questions as we
go!**

EINSTEIN'S THEORY OF
GENERAL RELATIVITY SAYS
GRAVITY IS THE RESULT OF
THE CURVATURE OF
SPACETIME



The background features several faint, light-gray technical diagrams. On the right side, there is a large circular diagram with concentric circles and radial lines, resembling a scale or a gauge, with numerical markings from 80 to 210. Below it is another circular diagram with dashed lines and arrows indicating a clockwise direction. In the bottom left corner, there are more circular elements, including a dashed line with an arrow pointing left. The overall aesthetic is clean and scientific.

GENERAL RELATIVITY TESTS: INSIDE OUR SOLAR SYSTEM

PRECESSION OF THE PERIHELION OF MERCURY



The background features several faint, light-gray technical diagrams. On the right side, there is a large circular diagram with concentric circles and radial lines, resembling a protractor or a scale for orbital parameters, with numerical markings from 80 to 210. Below it, another circular diagram shows a dashed elliptical path with arrows indicating direction. In the bottom left corner, there are more circular diagrams with arrows, suggesting orbital paths or precession. The overall theme is astronomical or mechanical.

THE SHIFTING ORBIT

~~PRECESSION OF THE PERIHELION~~

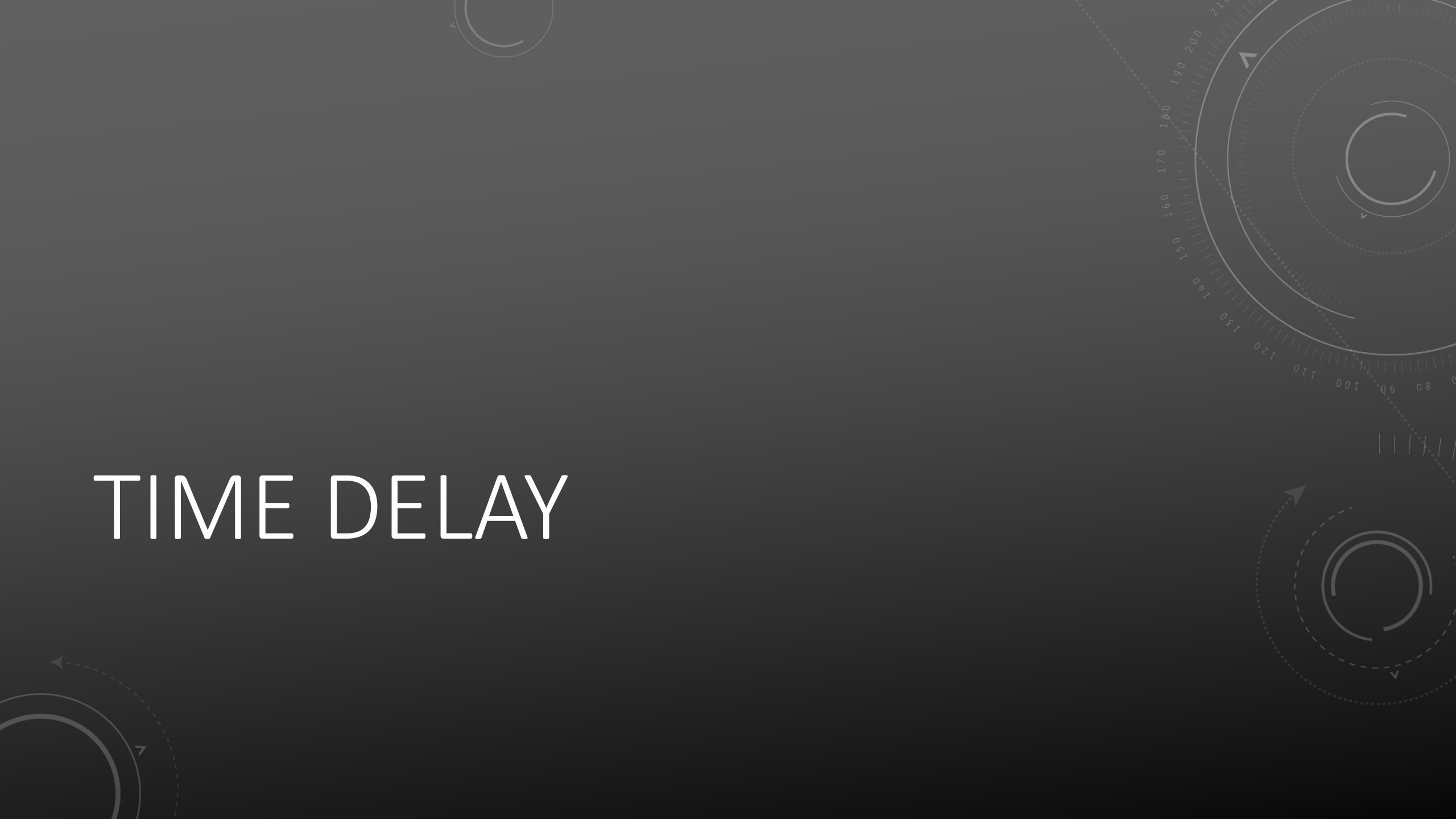
OF MERCURY

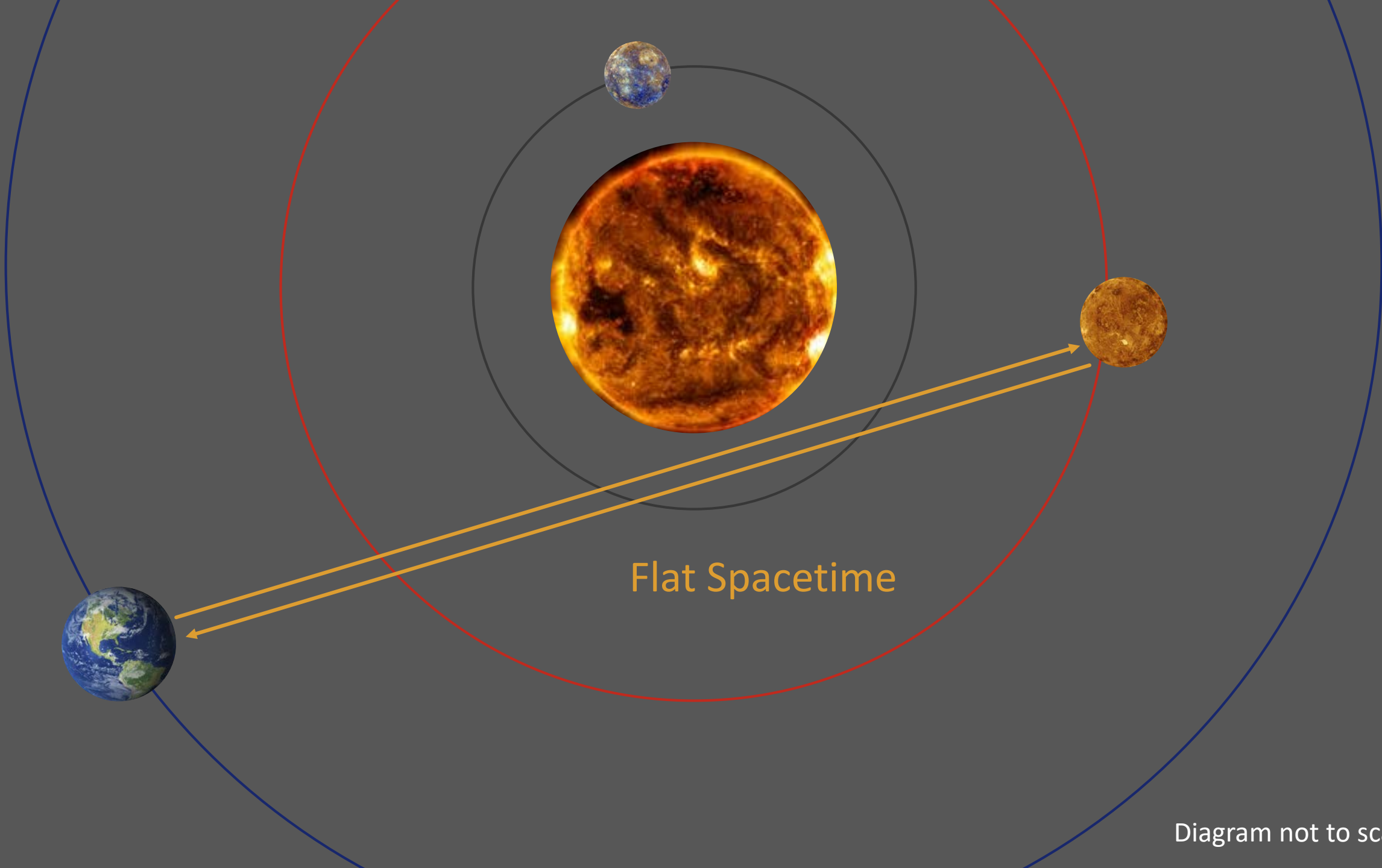


CLASSICAL ORBITAL MECHANICS THEORY COULDN'T MATCH
THE OBSERVATIONAL DATA

GR WAS THE MISSING PIECE

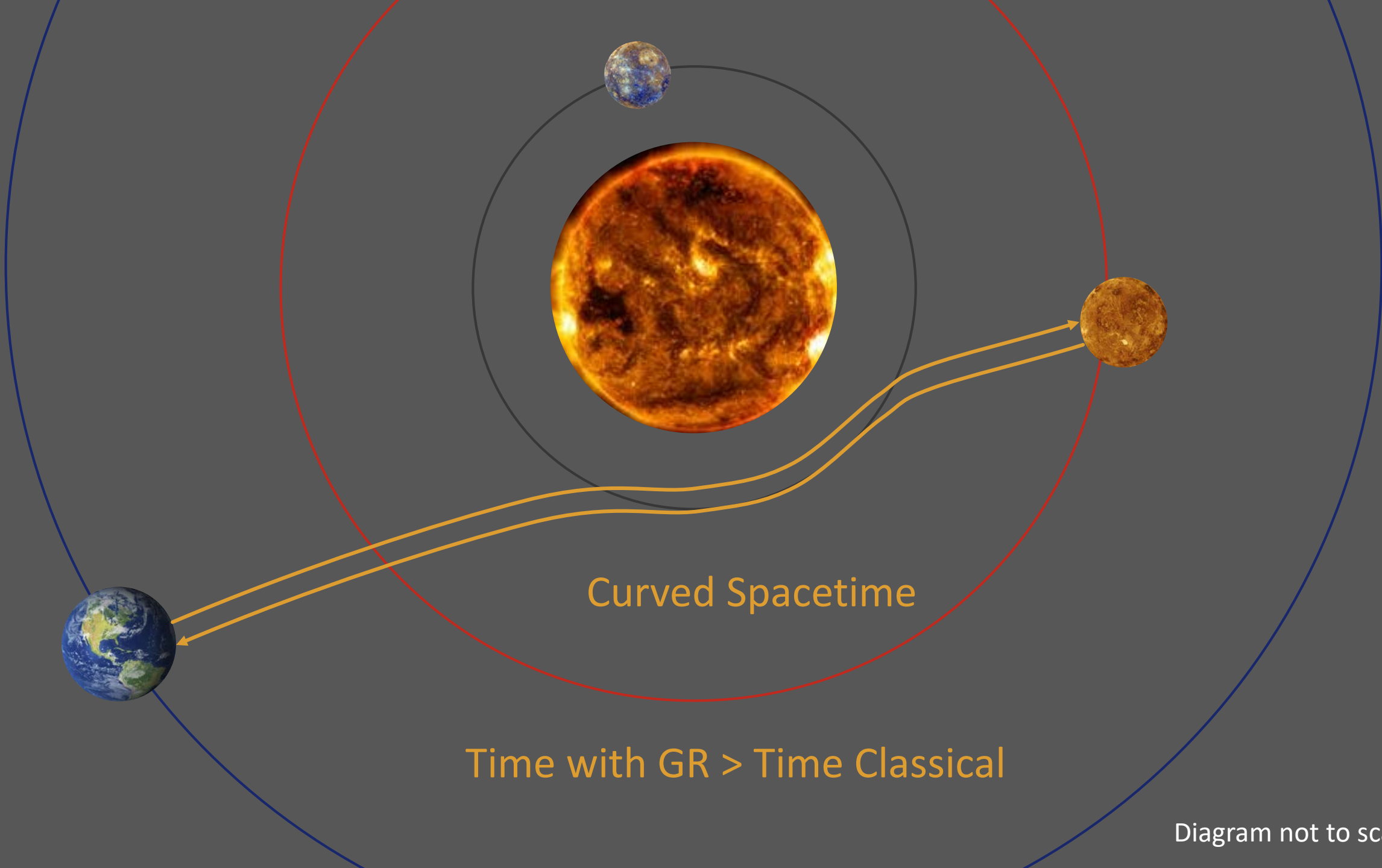
TIME DELAY





Flat Spacetime

Diagram not to scale!



Curved Spacetime

Time with GR > Time Classical

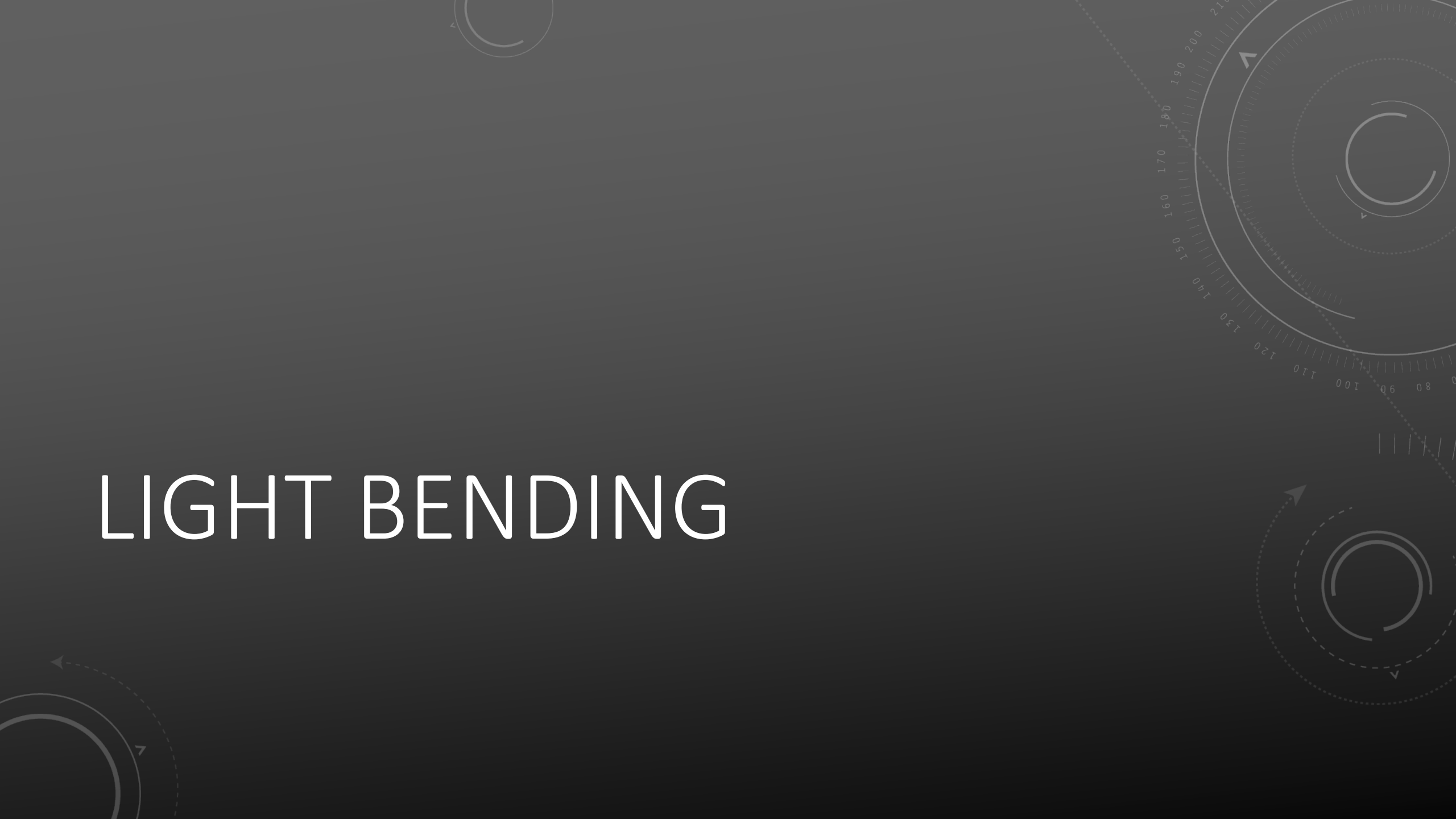
Diagram not to scale!

EVEN AROUND EARTH
TIME DILATION IS
IMPORTANT

NEED TO CONSIDER FOR
GPS SATELLITES TO WORK

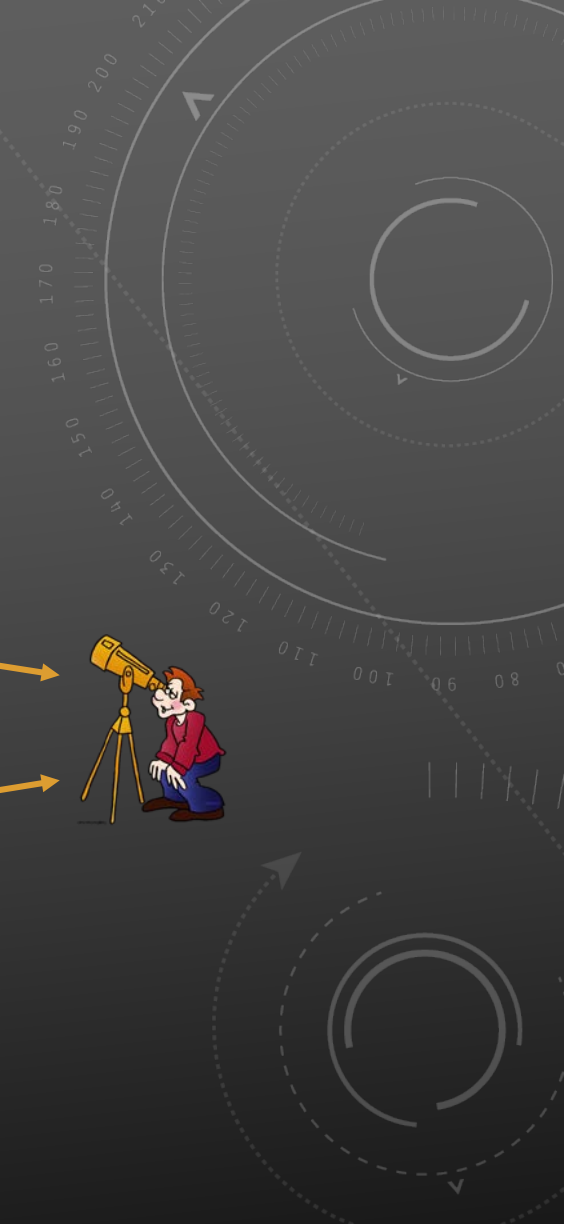
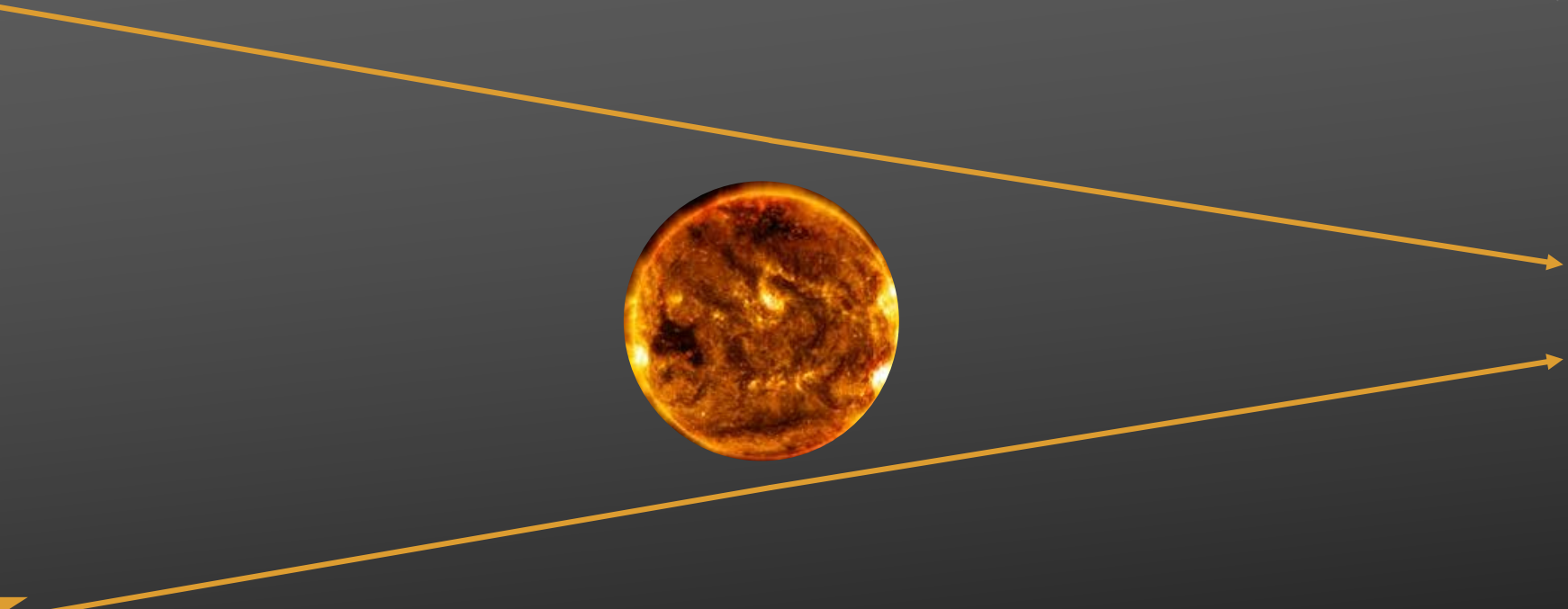


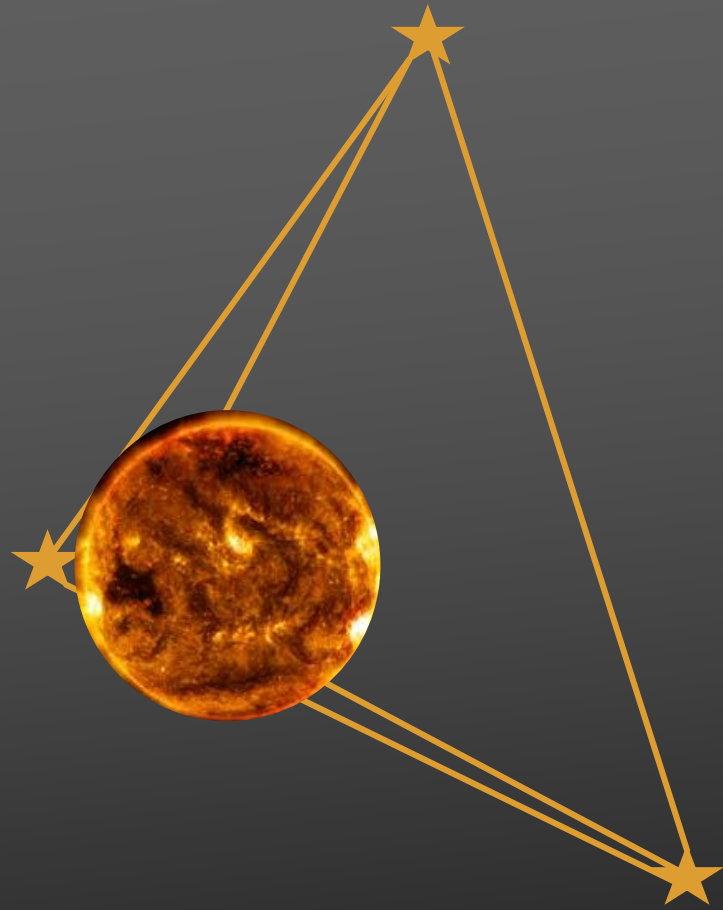
LIGHT BENDING





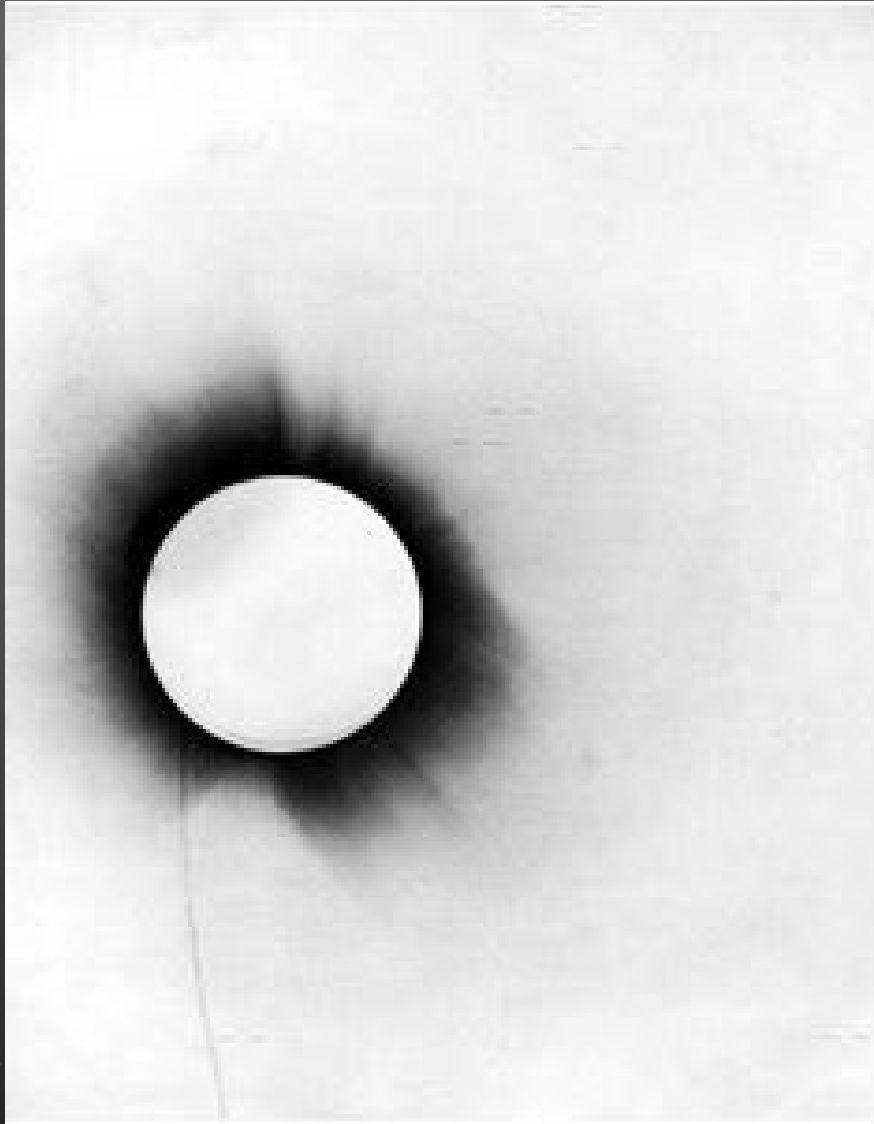






INSIDE OUR SOLAR SYSTEM

EDDINGTON'S
ECLIPSE
EXPEDITION



INSIDE OUR SOLAR SYSTEM

EDDINGTON'S ECLIPSE EXPEDITION



OUTSIDE OUR
SOLAR SYSTEM

GRAVITATIONAL
LENSING BY GALAXIES

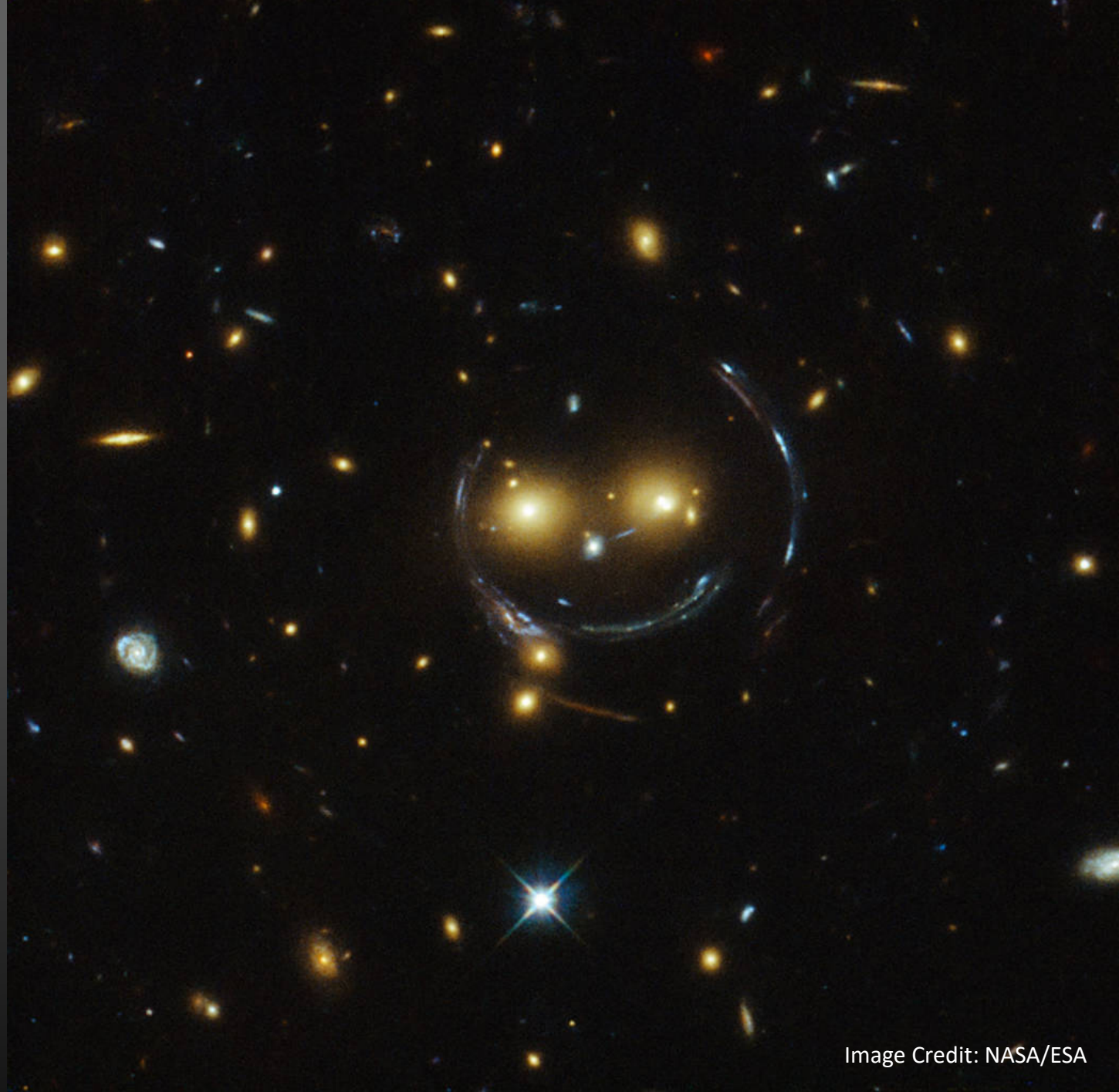


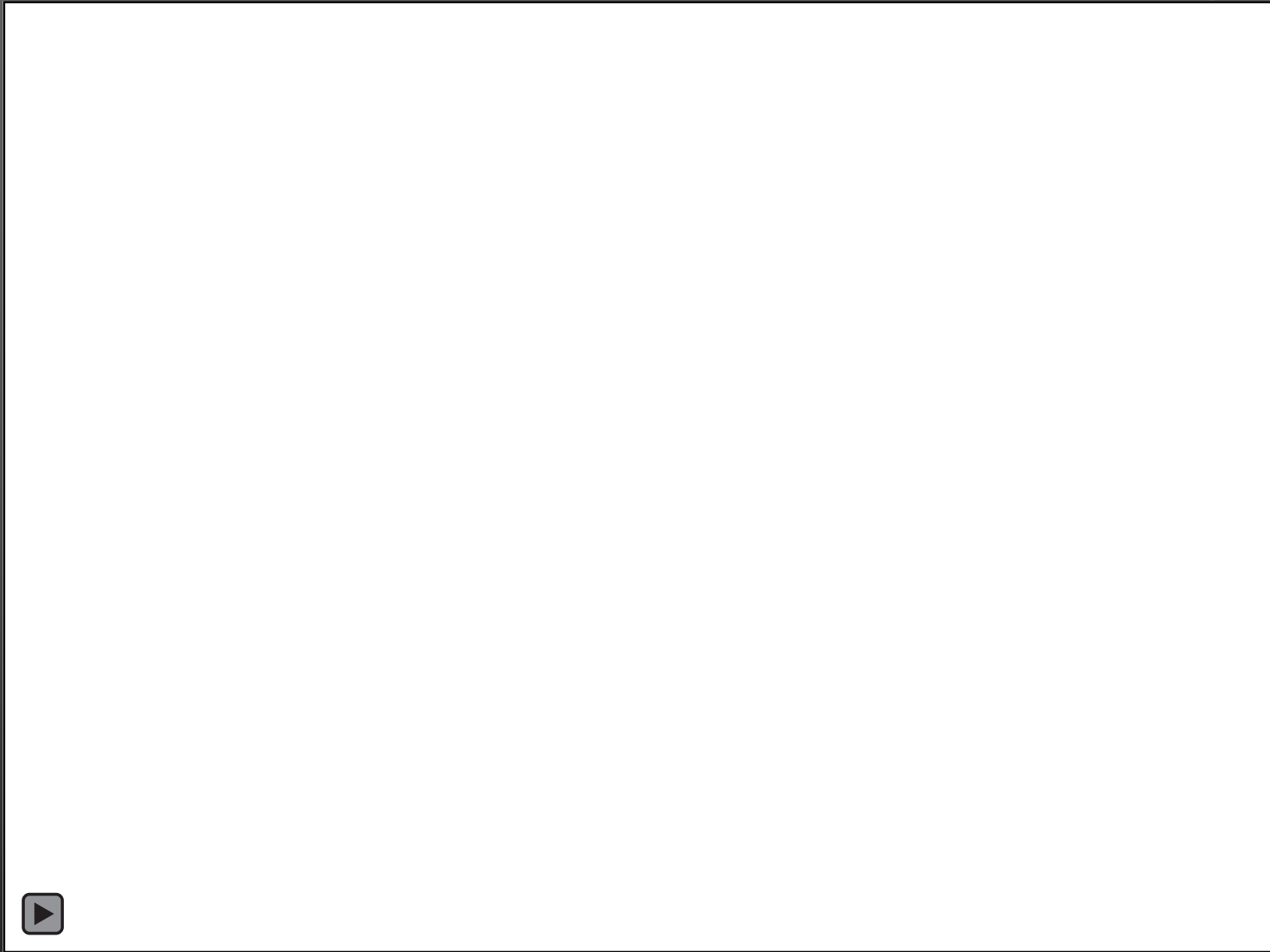
Image Credit: NASA/ESA

The background features several faint, light-gray technical diagrams. On the right side, there is a large circular diagram with concentric rings and radial lines, resembling a scale or a gauge, with numerical markings from 80 to 210. Below it is another circular diagram with dashed lines and arrows. In the bottom left corner, there are more circular elements, including a dashed line with an arrow pointing left. The overall aesthetic is technical and scientific.

GENERAL RELATIVITY TESTS: OUTSIDE OUR SOLAR SYSTEM

HULSE TAYLOR BINARY PULSAR







OBSERVED ORBITS OF PULSARS GETTING SMALLER

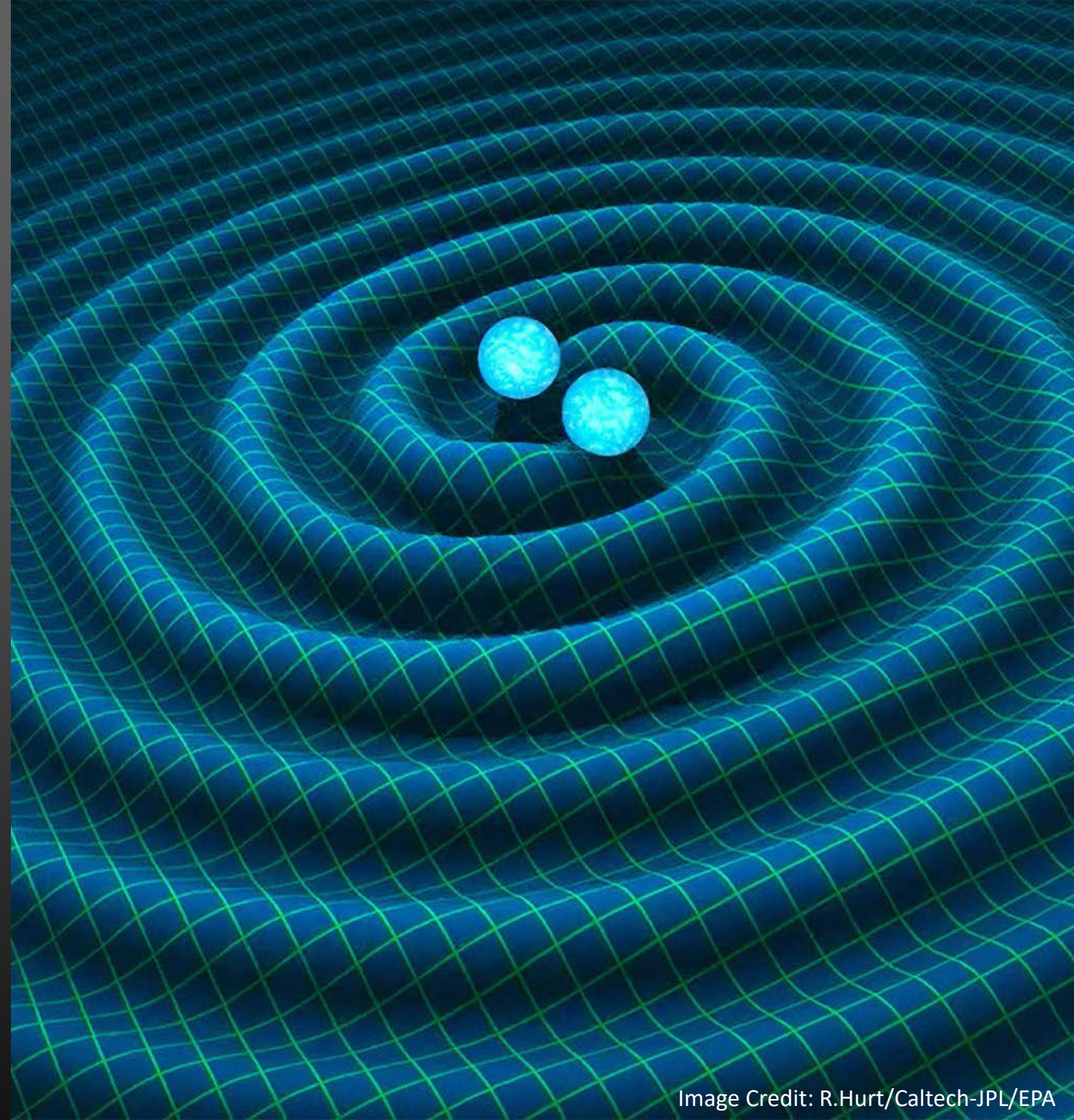
ENERGY CARRIED AWAY BY GRAVITATIONAL WAVES

GRAVITATIONAL WAVES

The background features several faint, light-gray circular and semi-circular elements. On the right side, there is a large circular scale with numerical markings from 80 to 210 in increments of 10. Several arrows are scattered throughout the image, some pointing clockwise and others counter-clockwise, suggesting motion or rotation. The overall aesthetic is technical and scientific.

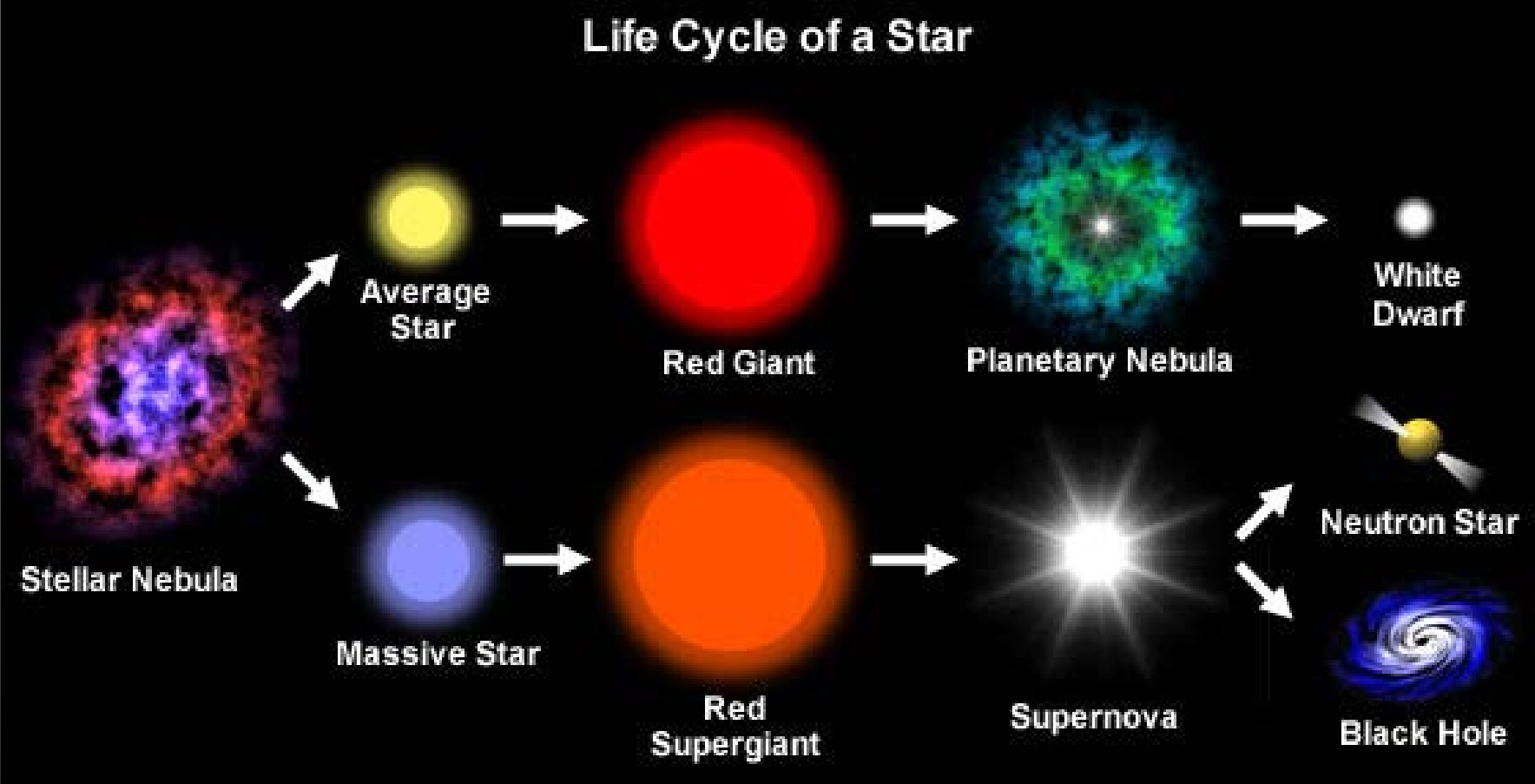
OBSERVED FROM
MERGERS OF DENSE
OBJECTS

FIRST DETECTED BY
LIGO IN 2016



BLACK HOLES





Stellar Mass Black Holes:
~5-30 Times the Mass of the Sun

Event Horizon →
Point of No Return

Supermassive
Black Holes:
~1,000,000 – 1,000,000,000
Times the Mass of the Sun

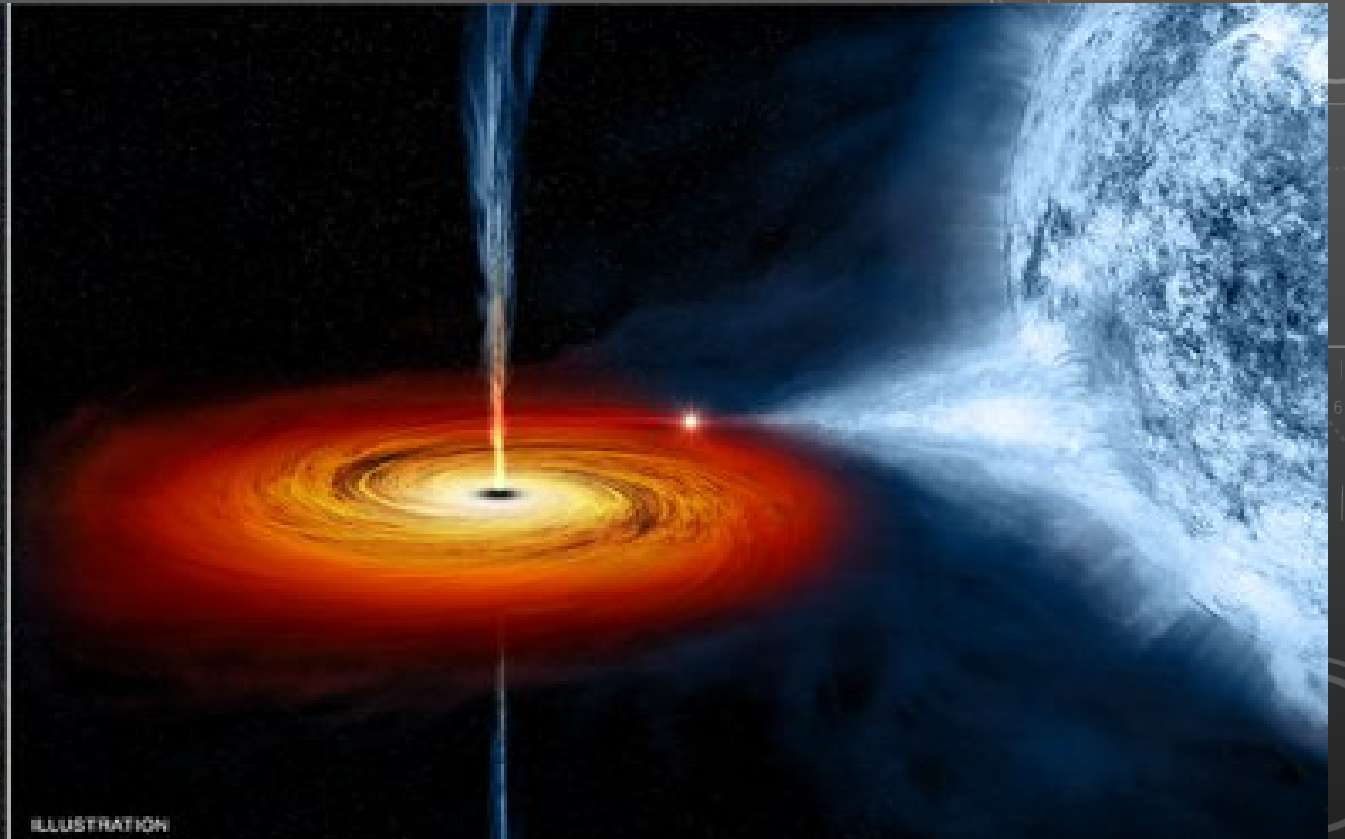
Event Horizon Size
Depends on the
Black Hole Mass

Observed by
Looking at the
Stuff Getting
Sucked In

DO THEY EXIST?

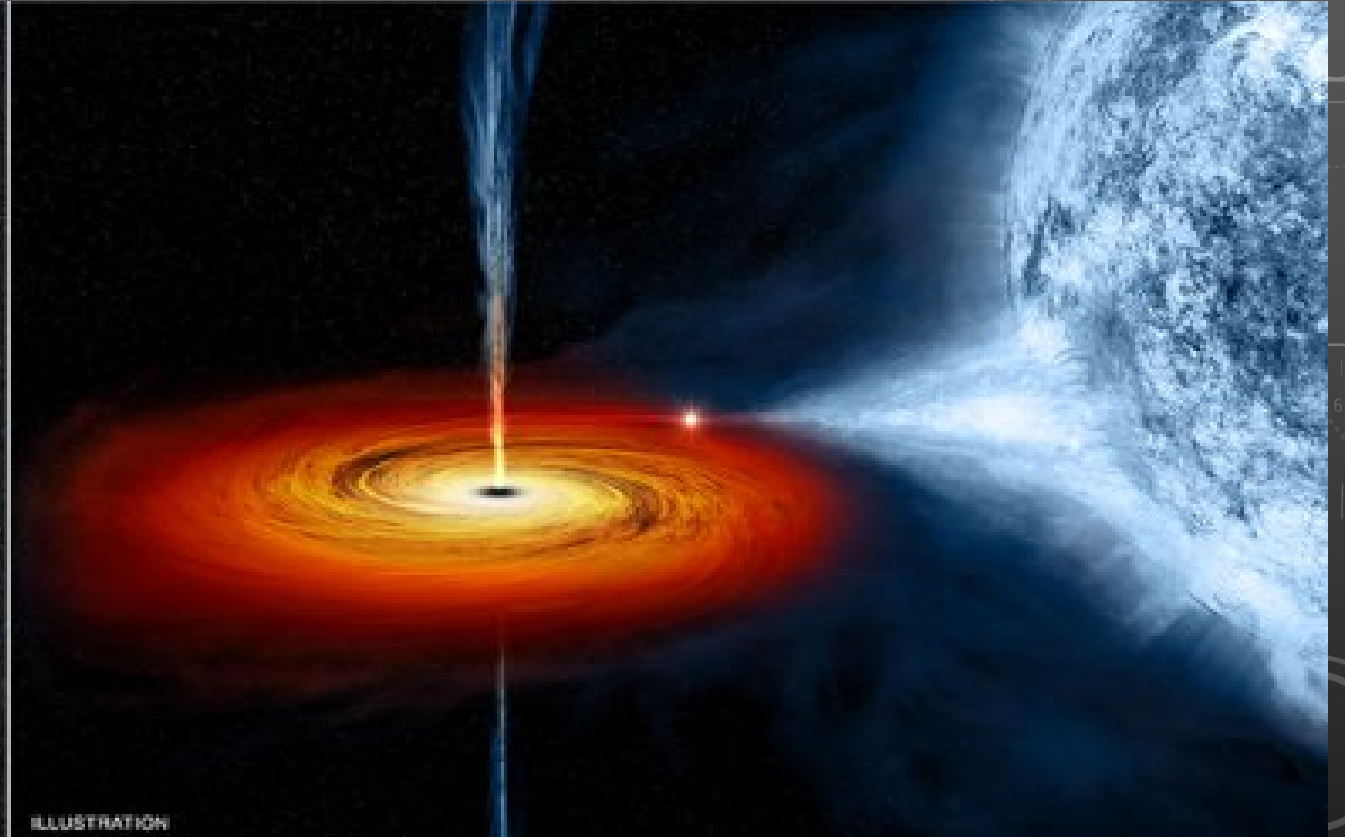
The background is a dark gray gradient. It features several faint, light gray geometric elements: a large circular scale on the right side with numerical markings from 80 to 210; a smaller circular scale at the bottom right; and various dashed and solid lines, arcs, and arrows scattered across the frame, suggesting a technical or scientific theme.

CYGNUS-X1



14.8 TIMES THE MASS OF THE SUN

CYGNUS-X1



VERY BRIGHT IN THE X-RAYS

The background is a dark gray color with several faint, light gray technical diagrams. On the right side, there is a large circular diagram with concentric circles and radial lines, resembling a scale or a gauge. Below it, there is another circular diagram with dashed lines and arrows. In the bottom left corner, there is a partial circular diagram with arrows. The overall aesthetic is technical and scientific.

IS CYGNUS-X1 A BLACK HOLE?

STEPHEN HAWKING - NO

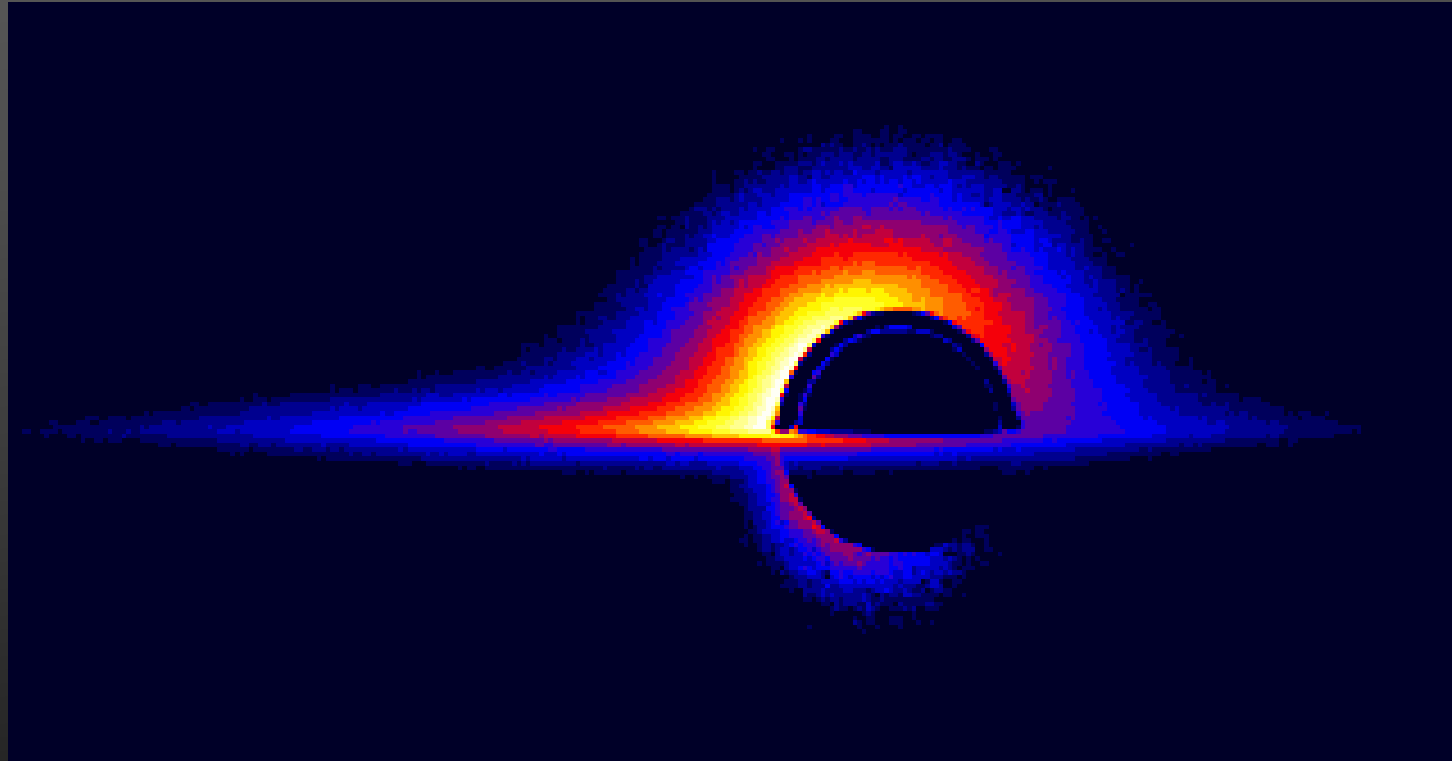


KIP THORNE - YES

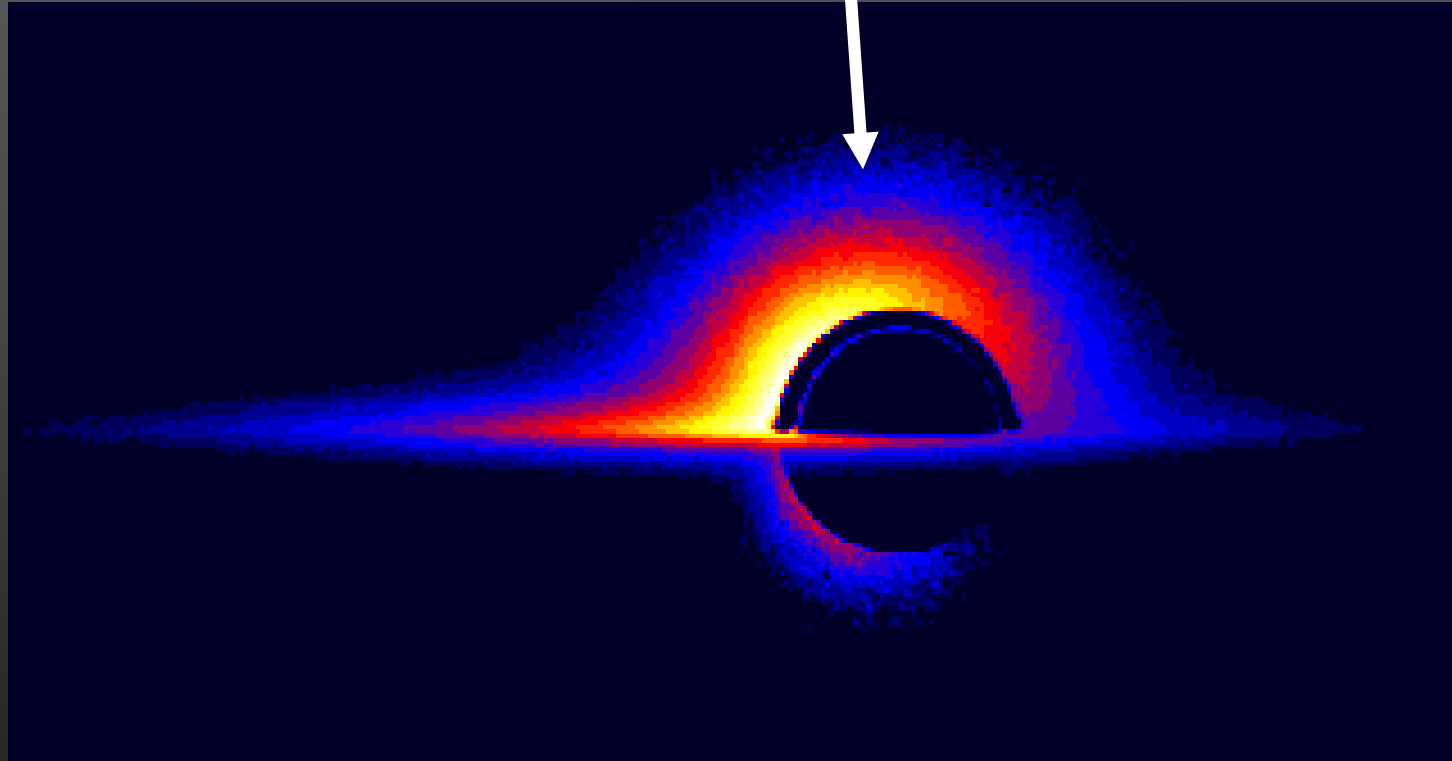
GENERAL RELATIVITY AND BLACK HOLES



EMISSION FROM A BLACK HOLE ACCRETION DISK SEEN EDGE ON



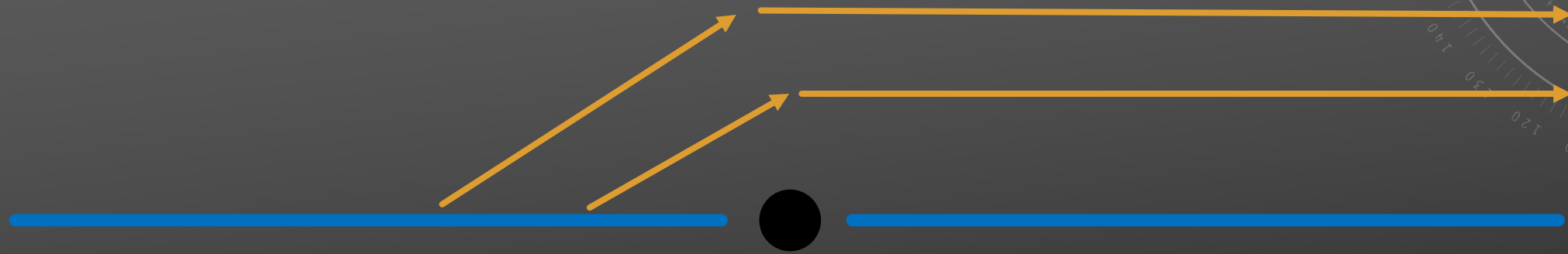
IF WE ARE LOOKING AT THE DISK EDGE ON
WHAT IS THIS AT THE TOP?



WITHOUT GENERAL RELATIVITY



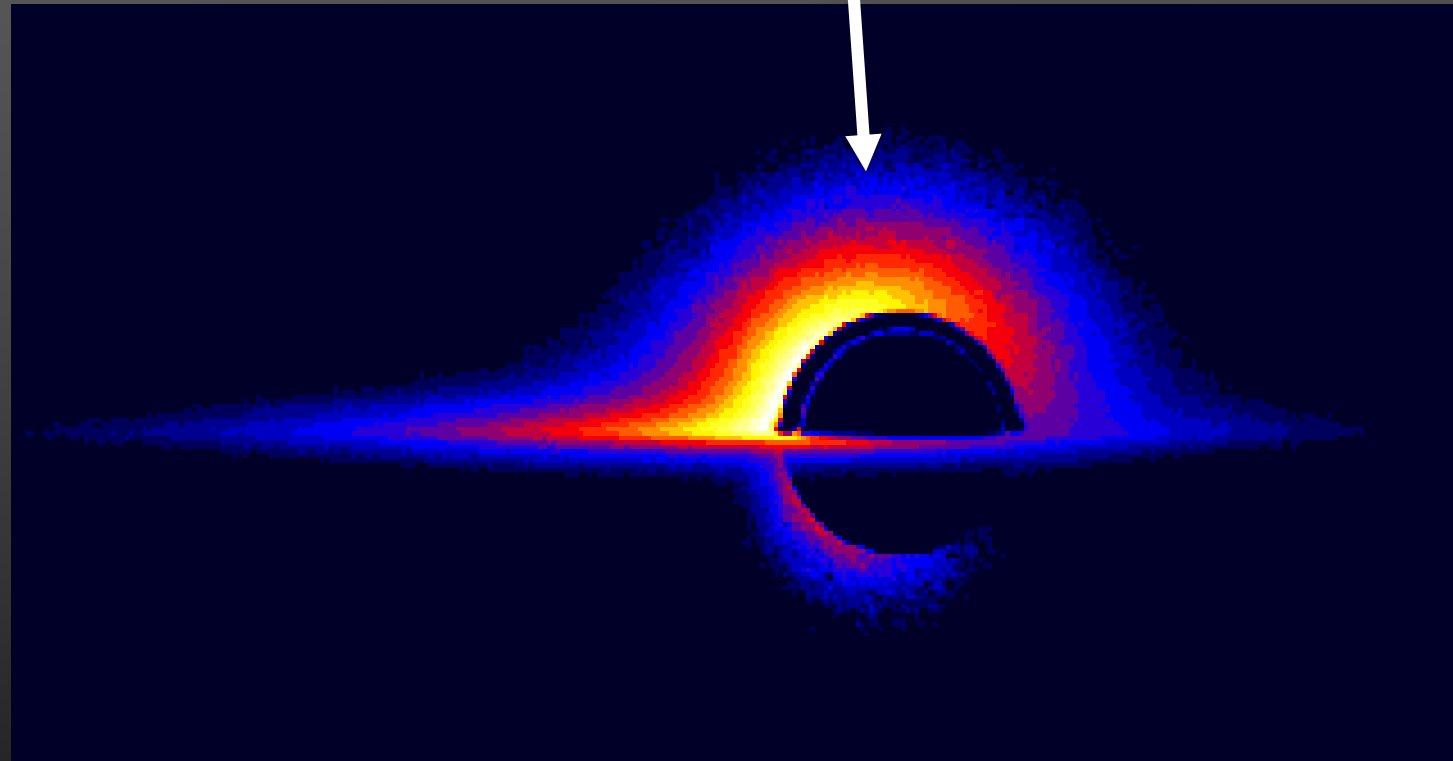
WITH GENERAL RELATIVITY



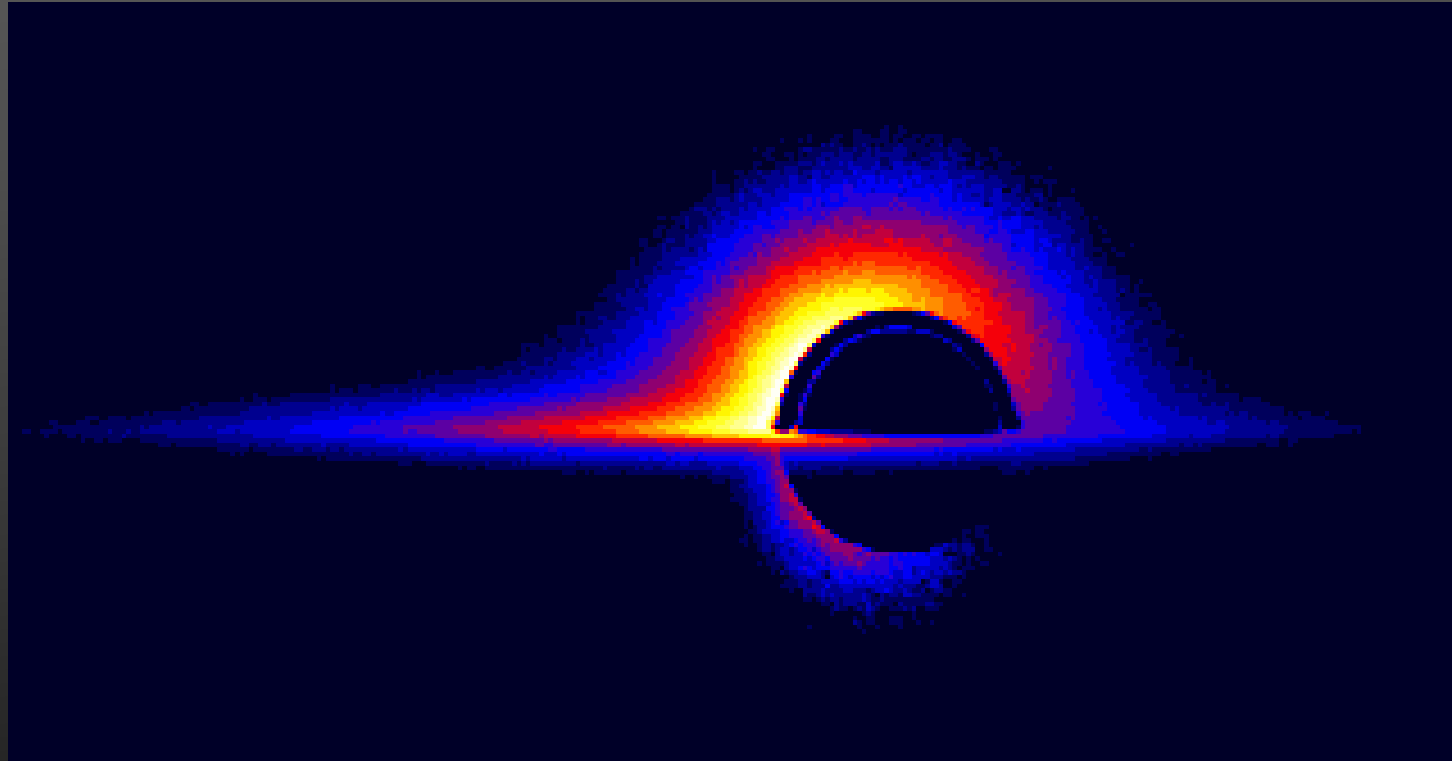
We Are Here

LIGHT BENDING

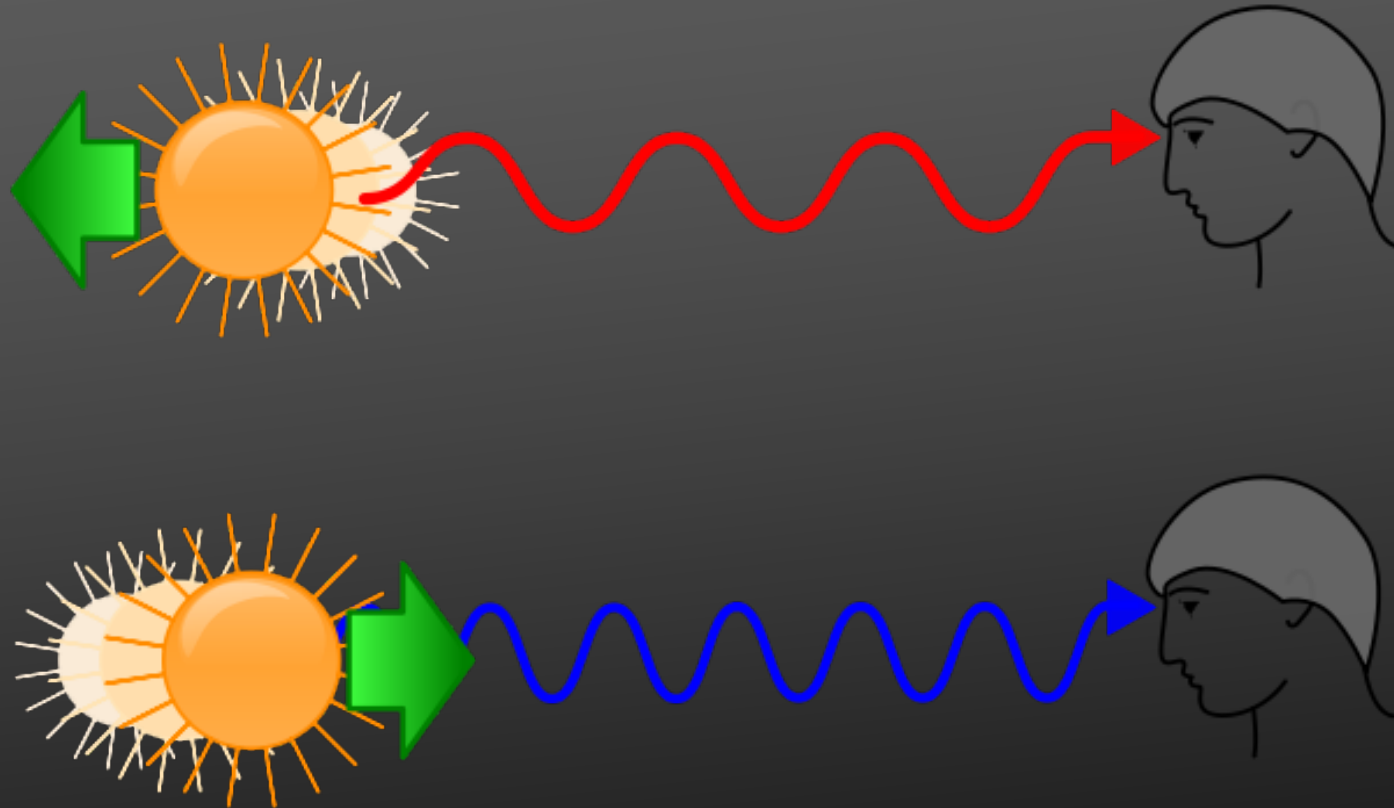
SEEING THE FAR SIDE OF THE DISK



WHY IS THE LEFT SIDE BRIGHTER
THAN THE RIGHT?

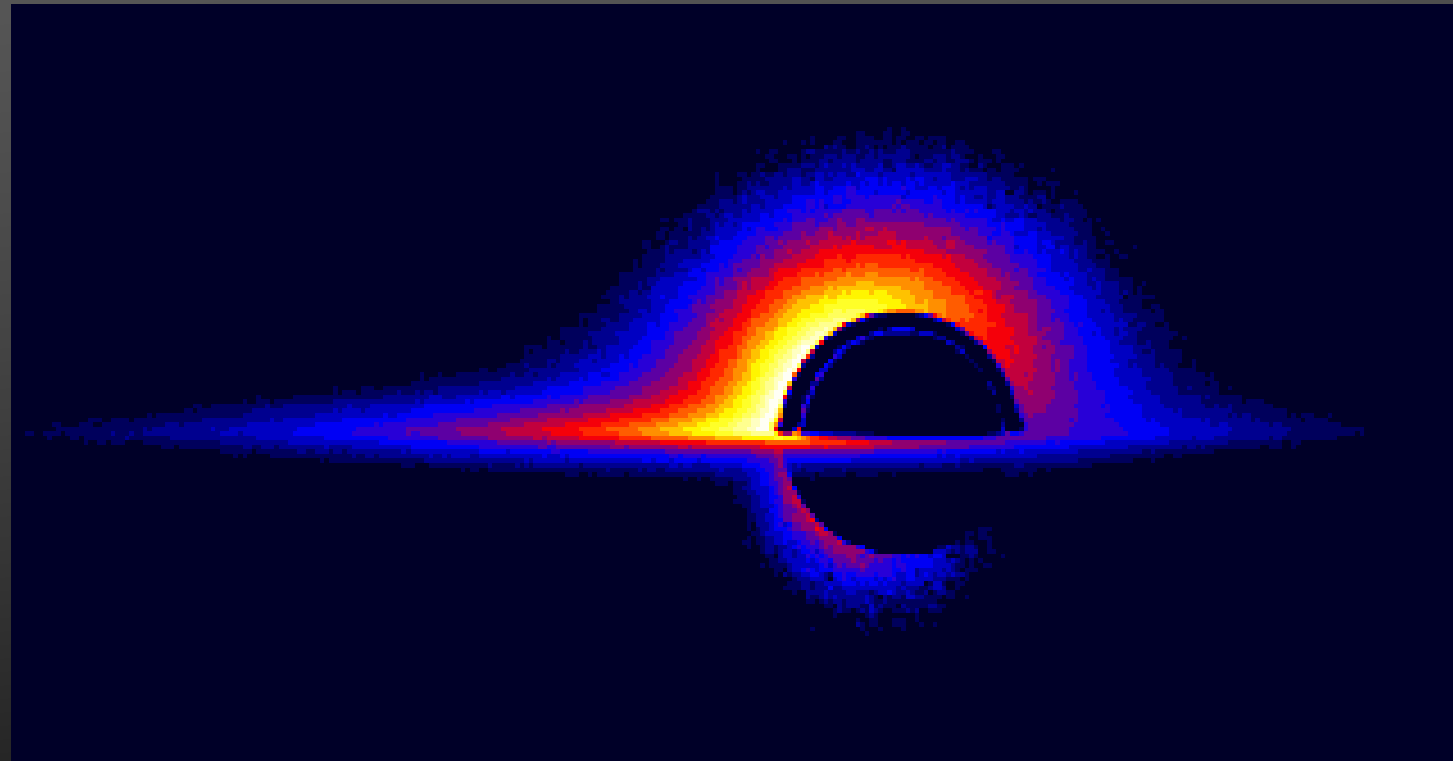


THE DOPPLER EFFECT



THE DISK IS SPINNING

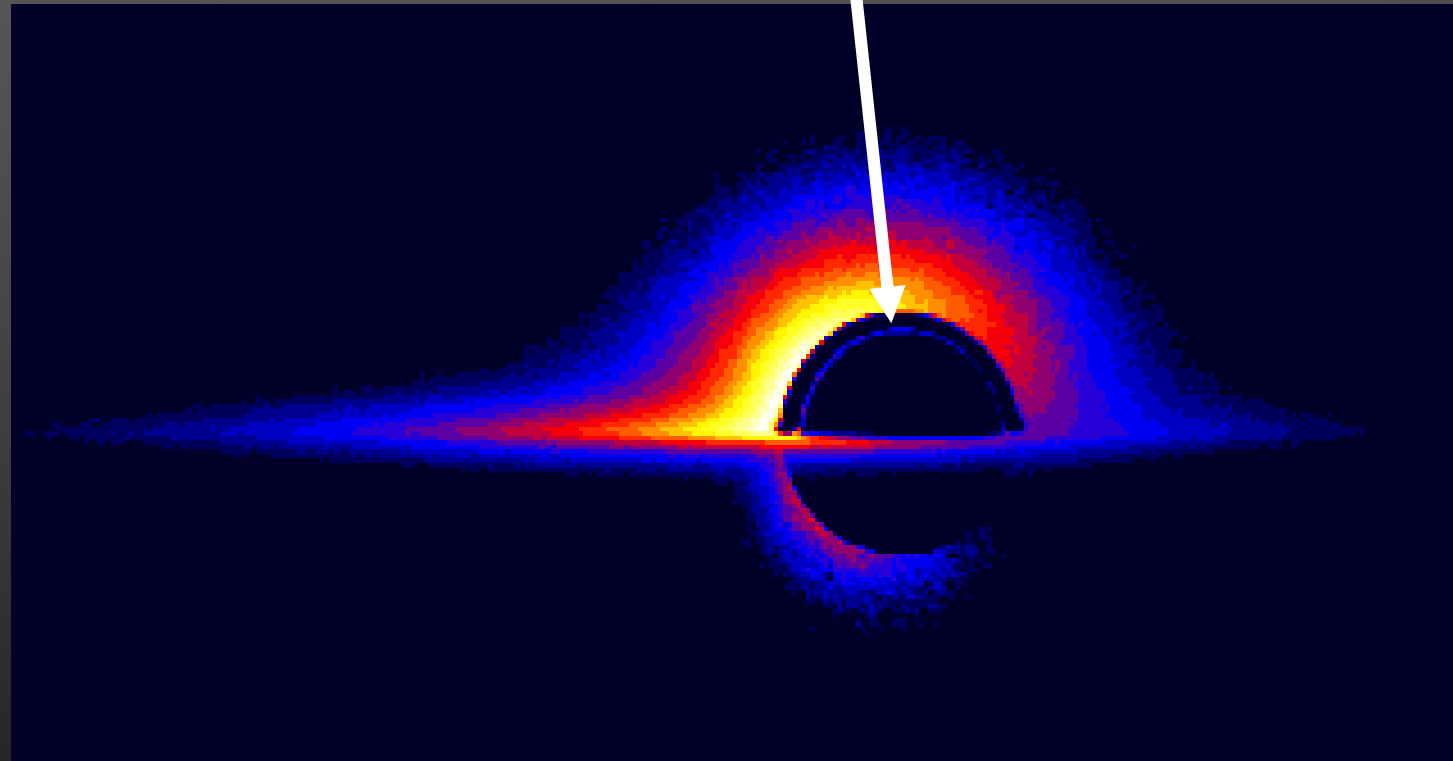
Moving Towards
Us:
More Energy



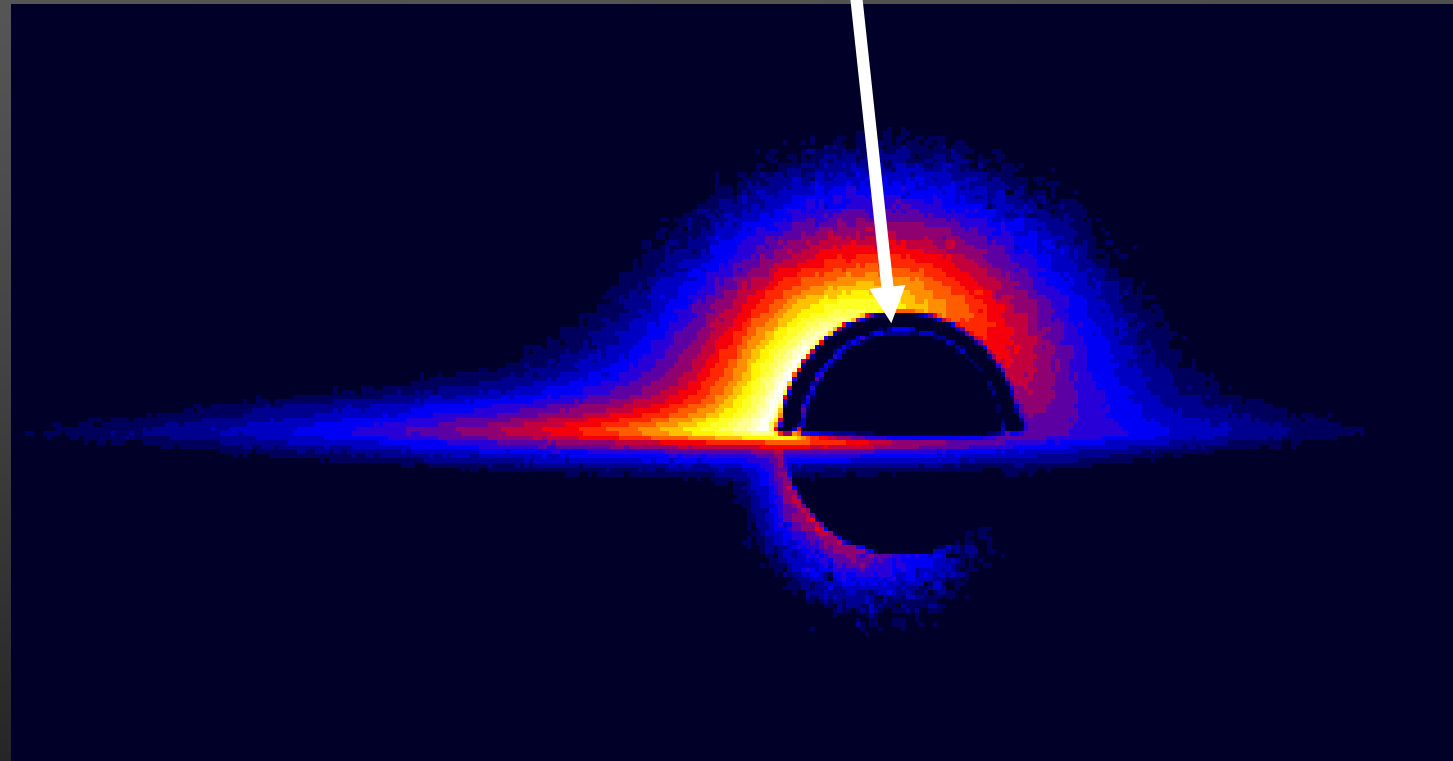
Moving Away
From Us:
Less Energy



WHAT IS THIS RING?



PHOTON RING – PHOTONS GETTING SLINGSHOT AROUND THE BLACK HOLE



The background is a dark gray color with several faint, light gray technical diagrams. On the right side, there is a large circular diagram with concentric circles and radial lines, resembling a scale or a gauge, with numbers from 80 to 210. Below it is another circular diagram with dashed lines and arrows. In the bottom left corner, there are more circular diagrams with arrows. The text is centered in the middle of the image.

WHAT WOULD HAPPEN IF YOU
WENT INTO A BLACK HOLE?

TIME



**For You: Everything
would seem normal**

**For Us On Earth:
You would slow down until you
reach the event horizon – then
you would freeze in time**

FORCE

A full-page background image showing a space scene. On the left, a black hole is depicted as a swirling vortex of colorful light (purple, blue, yellow, red) with a dark center. On the right, an astronaut in a white spacesuit with a large life-support backpack is floating in space, looking towards the black hole. The background is a dark, starry space.

For small black holes
you would get pulled
apart before you
reached the event
horizon

As you get close tidal
forces get more extreme
SPAGETTIFICATION!

HOW DO WE OBSERVE BLACK HOLES?





Ground Based Astronomy



Space Based Astronomy



Scientific Ballooning



Thank You!
Questions?