Last Time

Corrections to the Elliptic Orbits – Elliptic Motion and Precession

- See here

0.001 degree per year is of order the precession rate

Planet | Calculation Today | Calculation in 1912

Table I. The ratio of the sun's mass to the planet's mass, the semimajor axis a_p, and the contribution to the precession of the perihelion of Mercury are given for each planet.

Planet	M/M_P	a_P (AU)	$\delta\gamma$ (arcsec/century) from Eq. (3.5)	$\delta\gamma$ (arcsec/century) from Eq. (4.14)	Doolittle[a] (arcsec/cent.)
Mercury	6 023 600	0.387 098 93	…	…	…
Venus	408 523.5	0.723 331 99	292.84	277.42	277.37
Earth+Moon	328 900.55	1.000 000 11	95.89	90.88	90.92
Mars	3 098 710	1.523 662 31	2.38	2.48	2.48
Jupiter	1 047.350	5.203 363 01	156.94	153.95	154.09
Saturn	3 498.0	9.537 070 32	7.57	7.32	7.32
Uranus	22 960	19.191 263 93	0.14	0.14	0.14
Neptune	19 314	30.068 963 48	0.04	0.04	0.04
Total			555.80	532.23	532.36

[a] Reference 1, p. 179, but corrected for current values of M/M_P.

Total = 532" per century, Observed value = 575" per century

500" per century = 0.0014 degrees / year

Summary of the Precession of the Perihelion

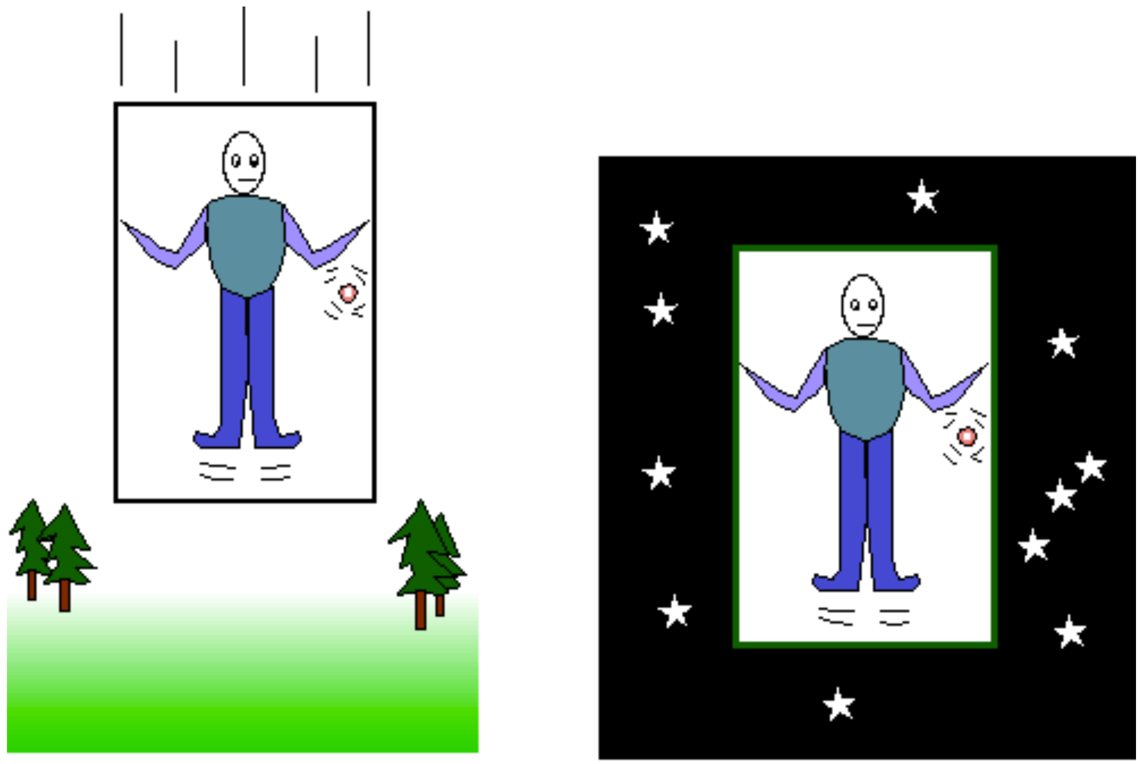
Source of Precession:	Value
Planetary Perturbations:	532”/century
Einstein:	43” /century
Total:	575” /century

Very good agreement with the Observed value 575” per century

Today

Equivalence Principle (Part 1)

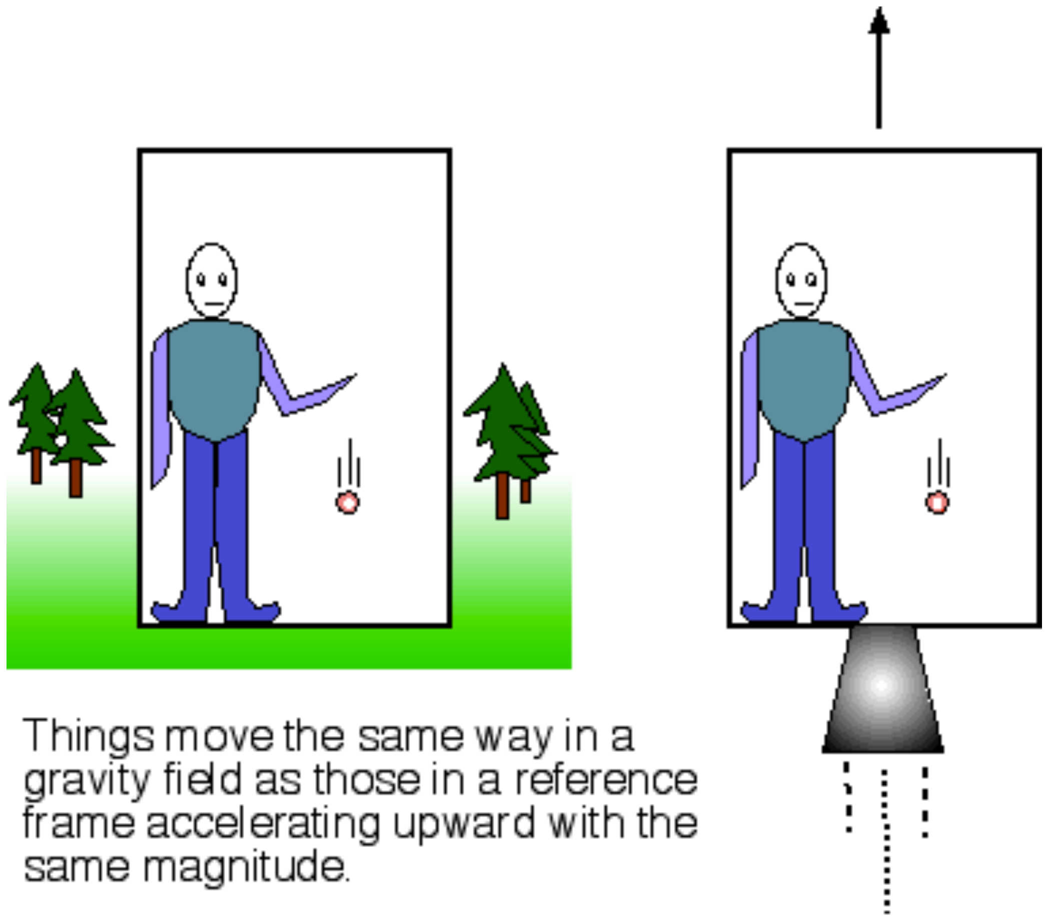
- A free falling observer, the elevator guy, will (in a small volume) experience the as if there were no gravitational forces.



Things falling freely in a gravity field all accelerate by the same amount, so they move the same way as if they were in a region of zero gravity — ``weightlessness''!

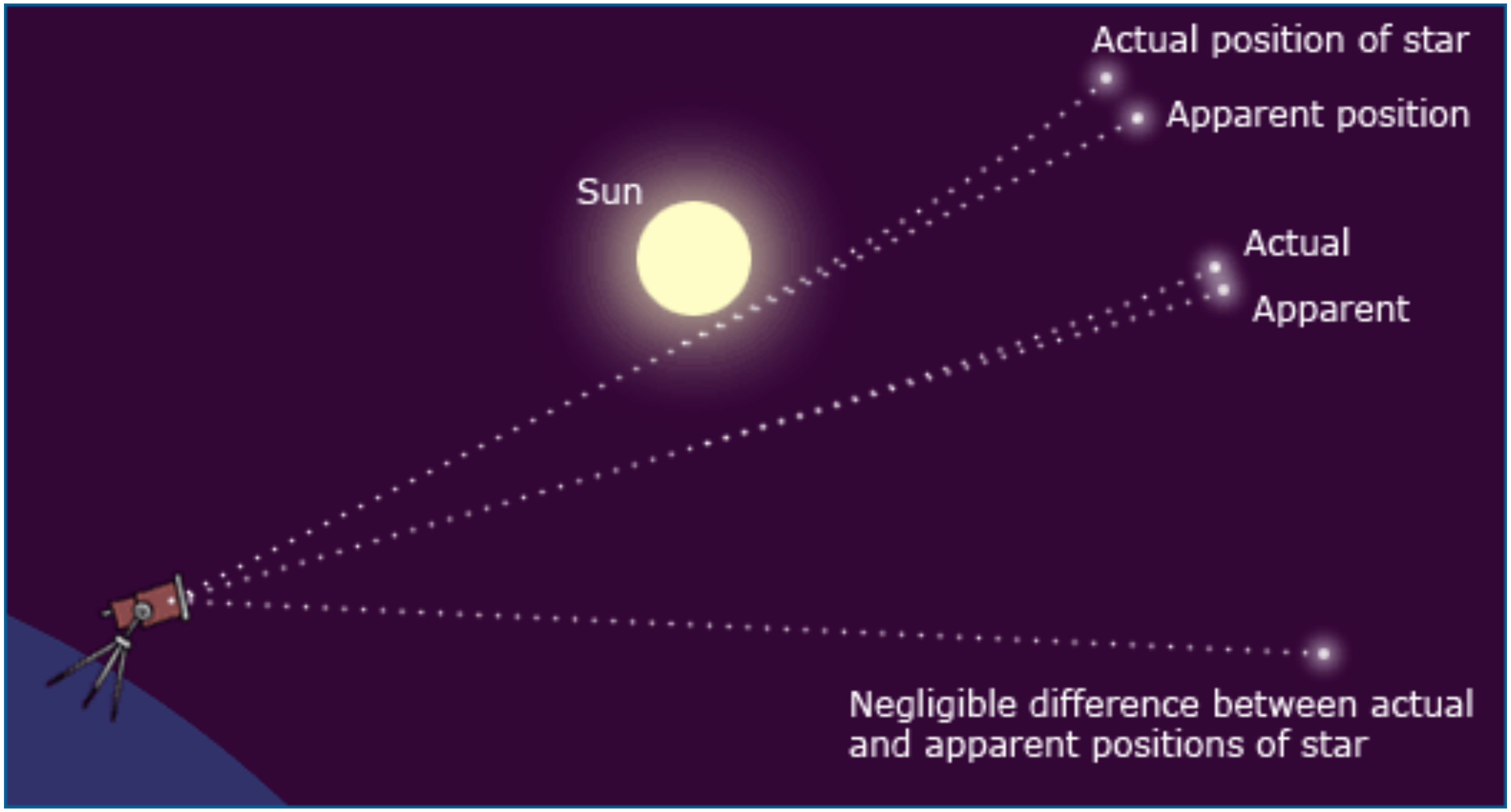
Equivalence Principle (Part 2)

- There is no experiment a person could conduct (in a small volume) that can distinguish gravitational forces from accelerated motion.



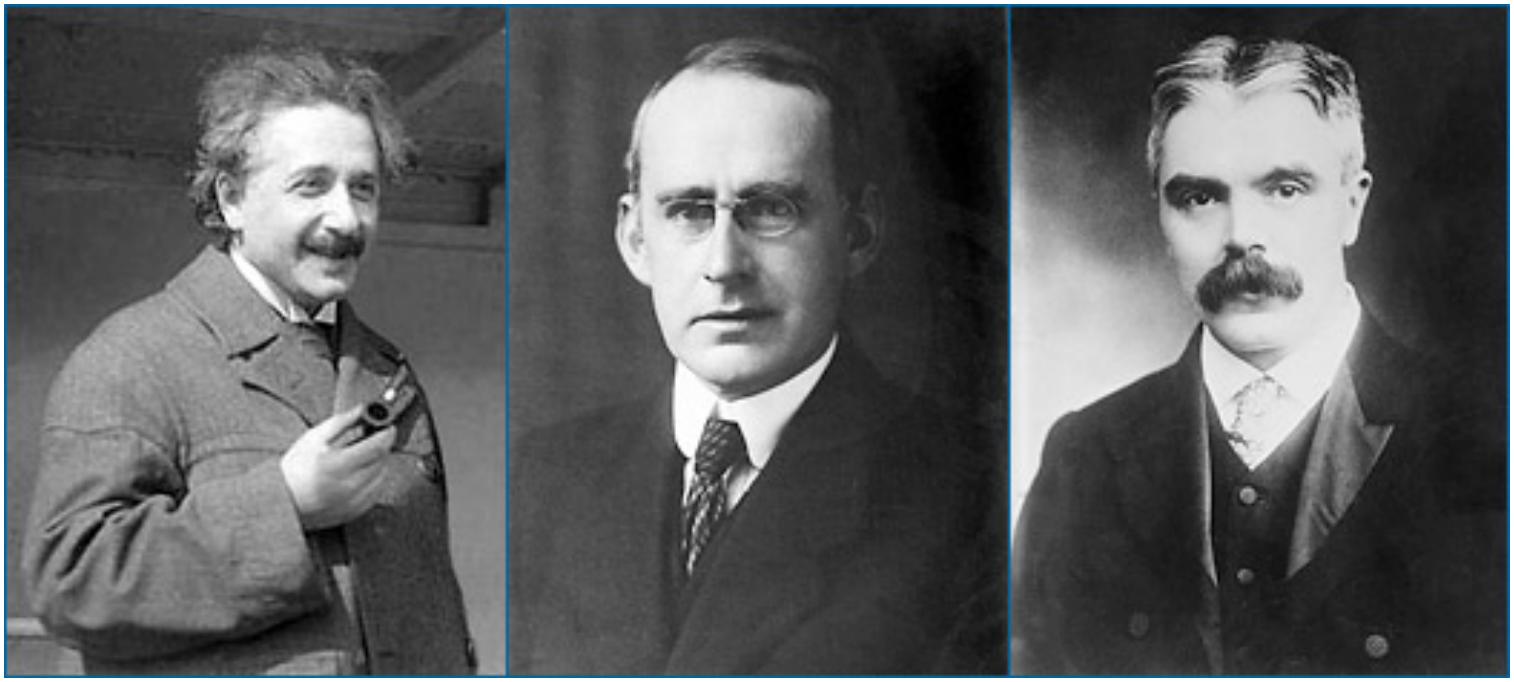
Measuring the bending of light

- Measure the deflection of starlight as it goes near the sun
- Compare angles between the stars during a solar eclipse, and at night at a different time of the year



source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04

The men of the 1919 measurement – Einstein,Eddington,Dyson

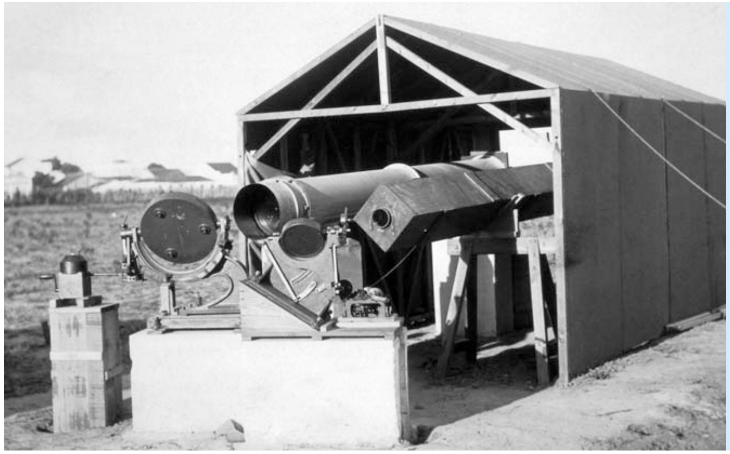


source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04

Eddington and Dyson travel to the tropics at Sorbal and Principe

source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04

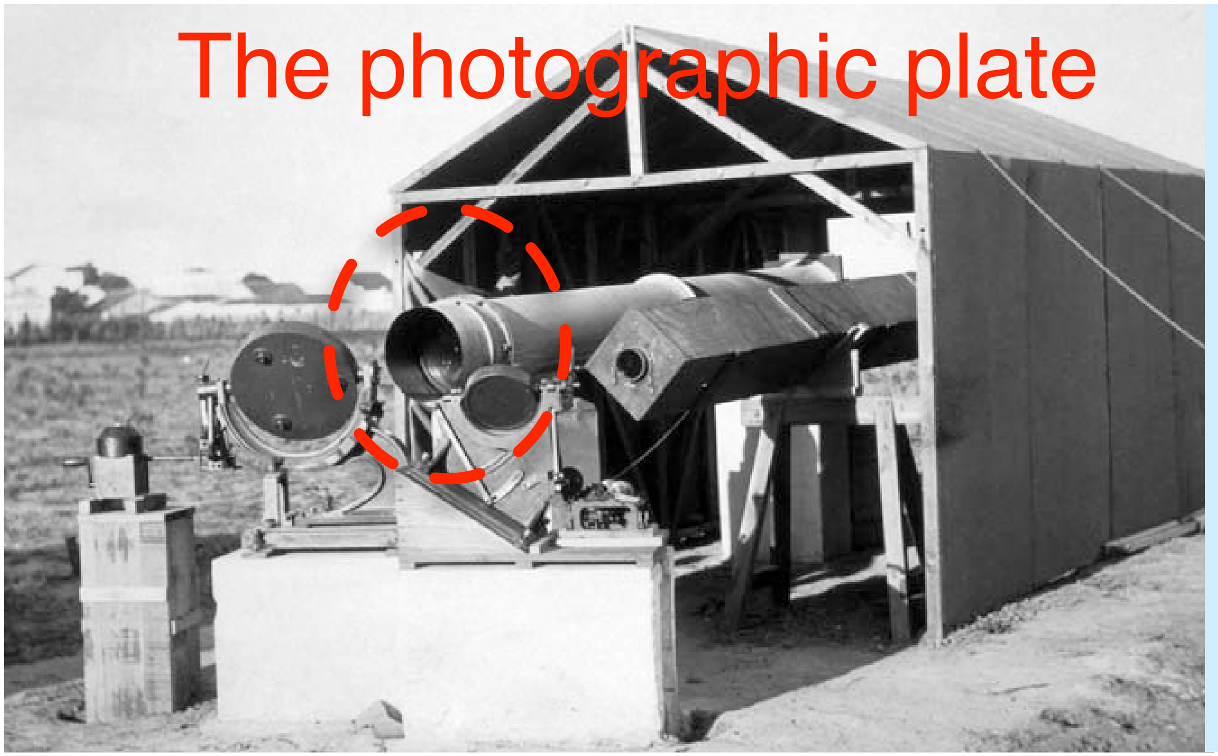
. . . And set up telescopes in the Tropics and at Cambridge



Instruments at Sobral, Brazil. The 4-inch lens is in the square tube on the right, and the astrographic lens, chosen for its wide field of view, is in the circular tube on the left. In front of the tubes are mirrors that are driven by a mechanism that keeps the stellar images at the same position on the plates during an exposure. The mirror on the left was the chief suspect in the poor-quality astrographic-lens images produced during the 1919 eclipse. (Courtesy of the Science Museum, London.)

source `http://undsci.berkeley.edu/article/0_0_0/fair_tests_04`

Record image on plate



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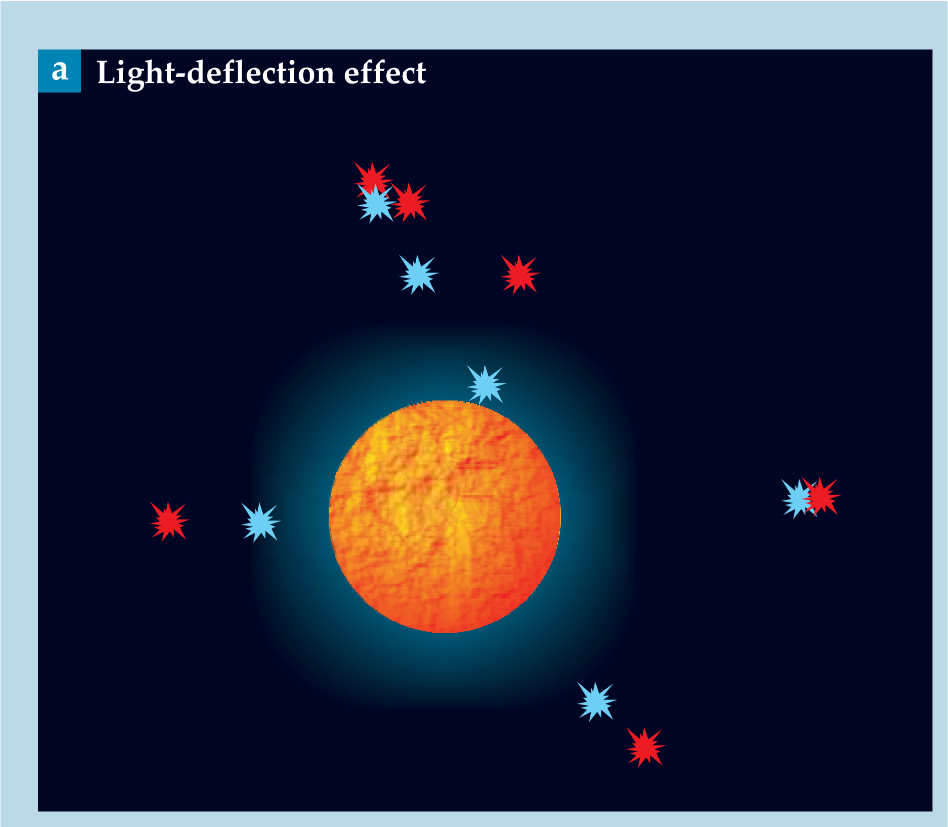
. . . And finally measure the deflection by reading the positions between the stars off of photographic plates with a micrometer and comparing to other plates

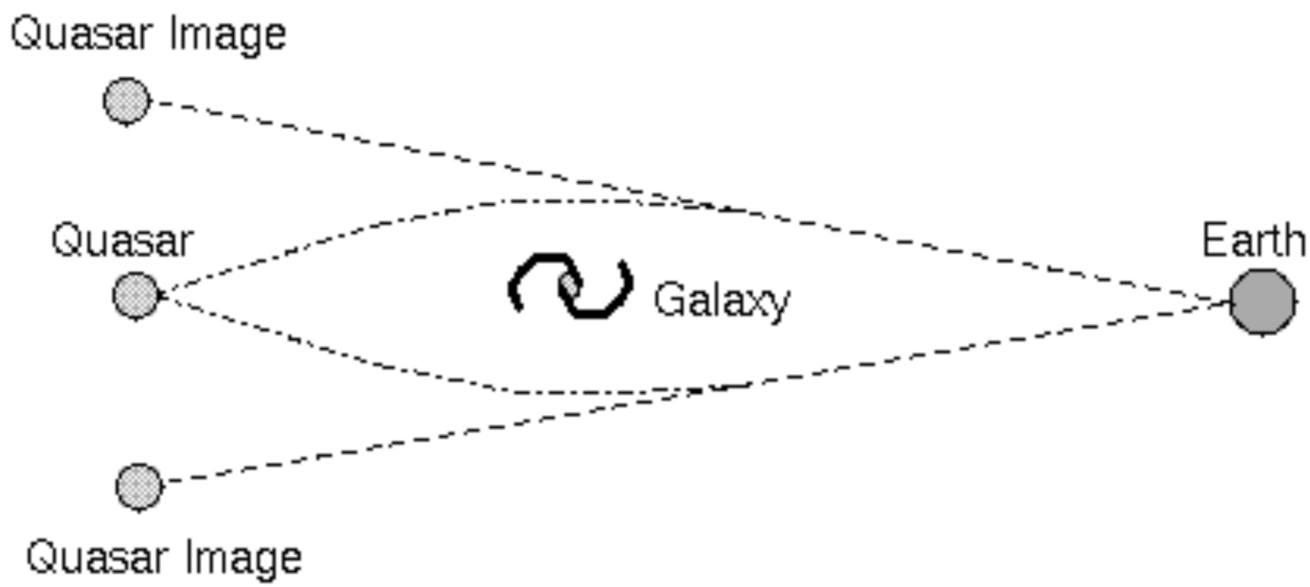


The experimetnal result agrees with Einstein's prediction of 1.7 arcsec

source http://undsci.berkeley.edu/article/0_0_0/fair_tests_04 and Physics Today article Kennefick

Gravitational Lensing in Observational Astronomy

- light from distant quasars bends around intermediate galaxy



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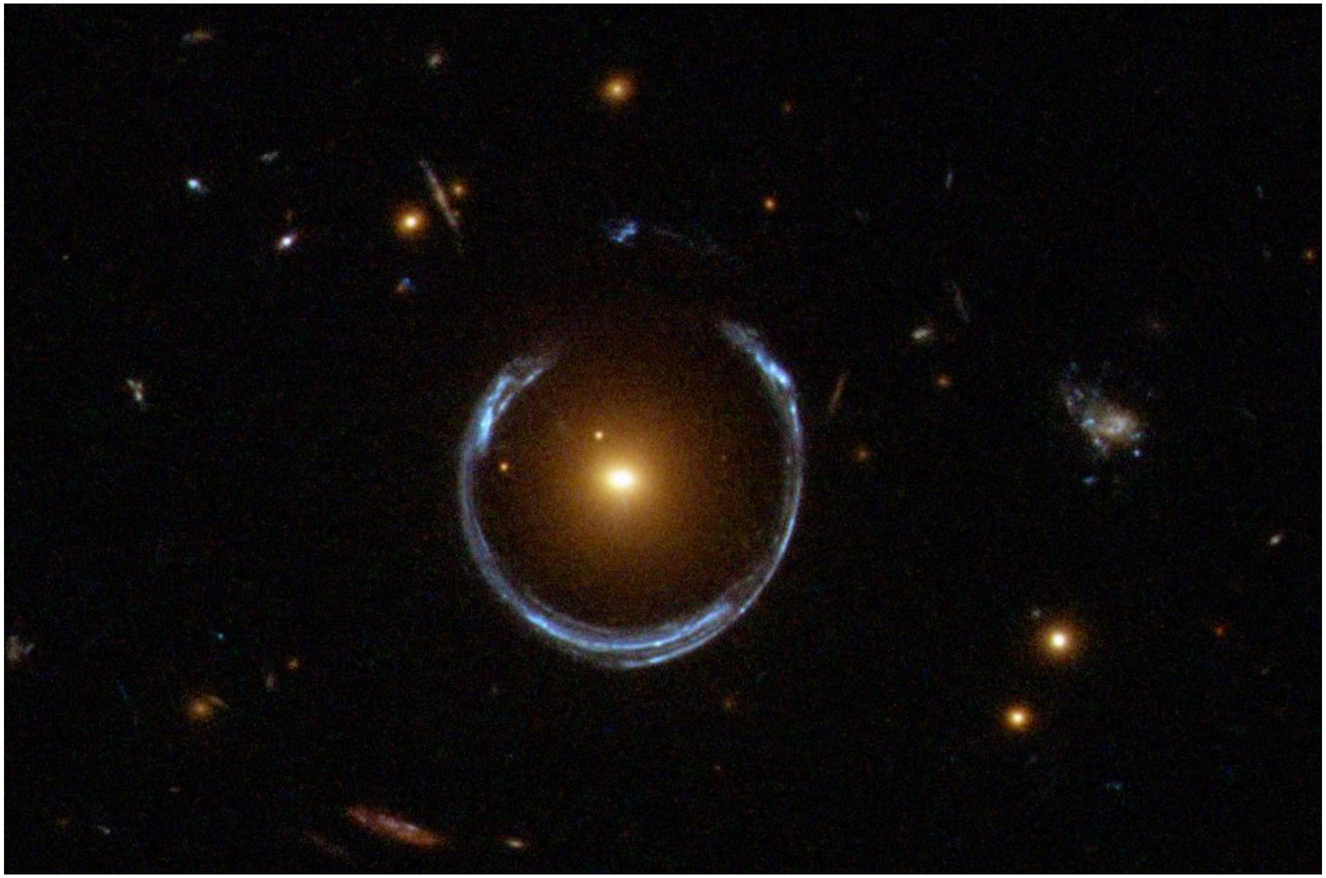
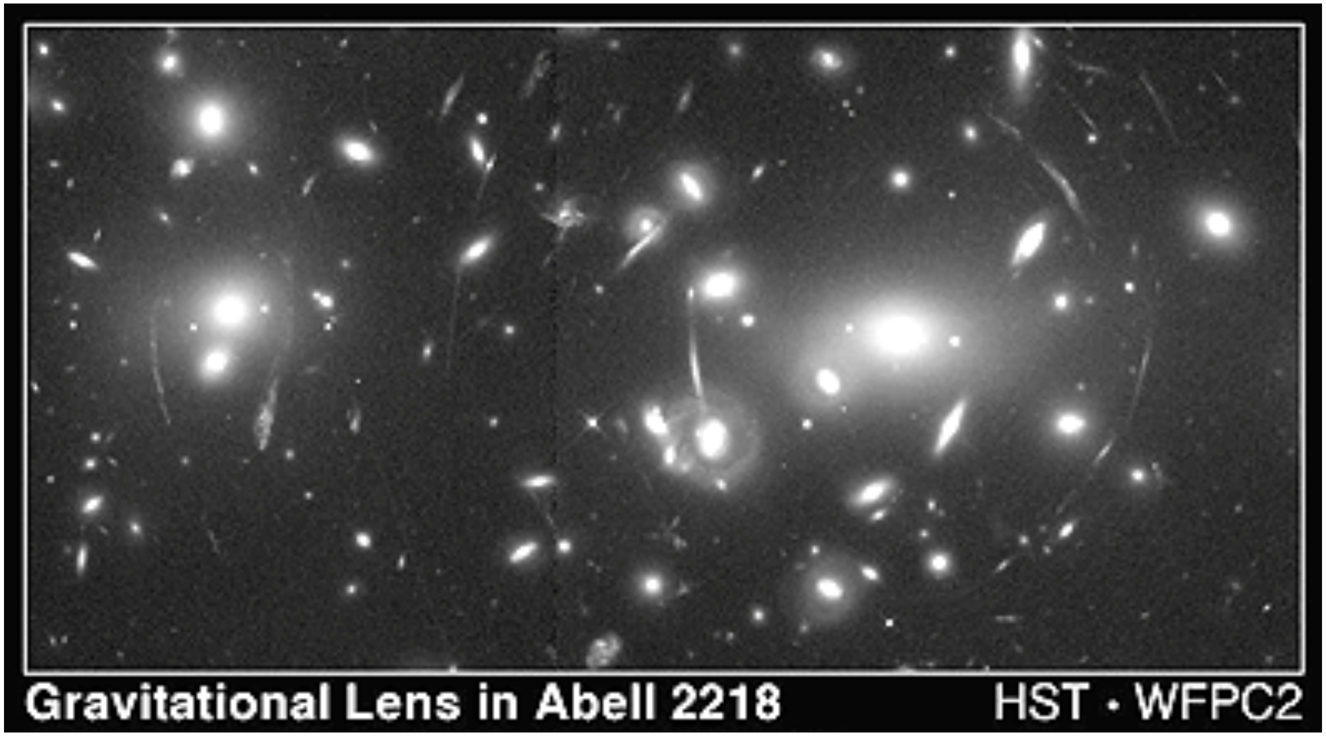
Gravitational Lensing in Observational Astronomy



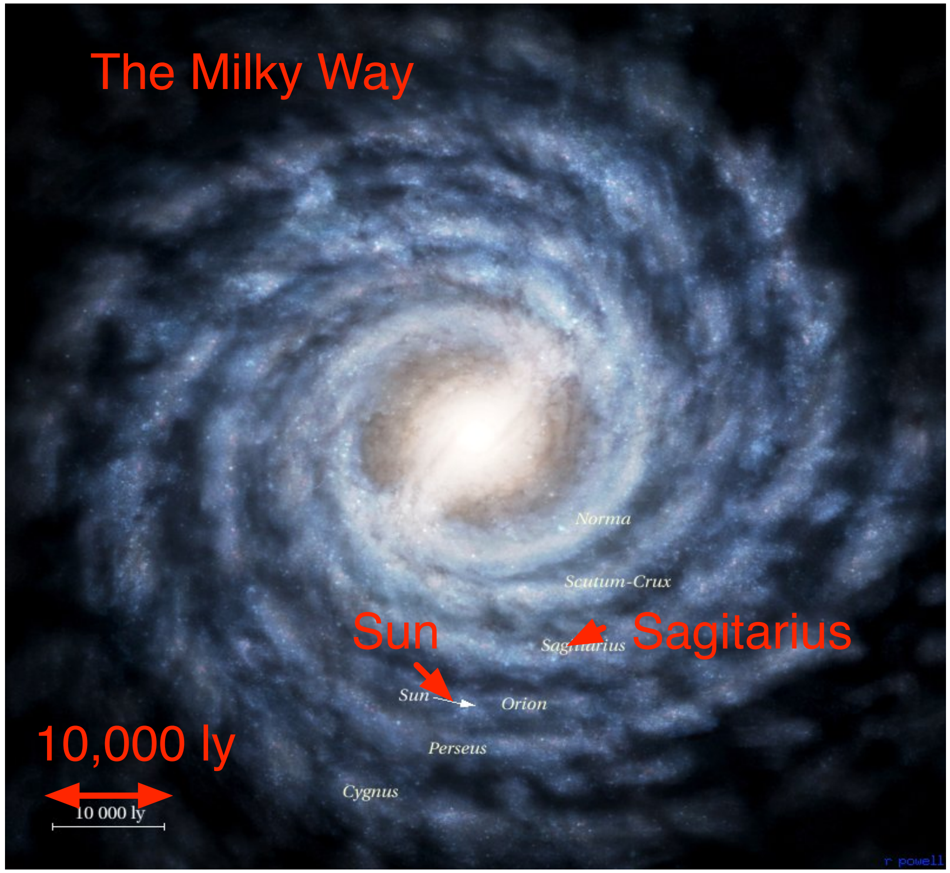
source – Wikimedia

More Pictures



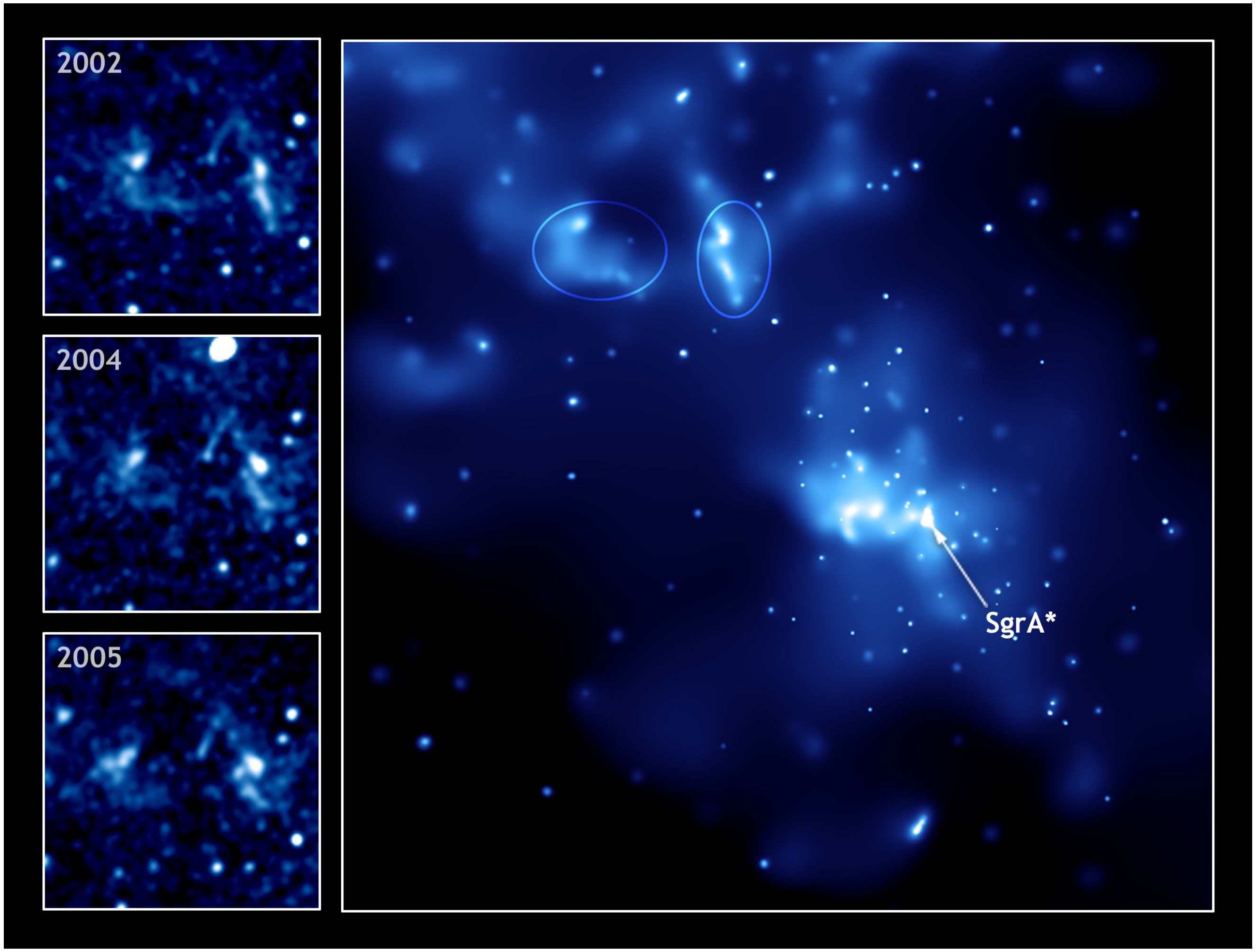
source – Wikimedia

Sagittarius A^* (in our galaxy) contains a suppermassive black hole



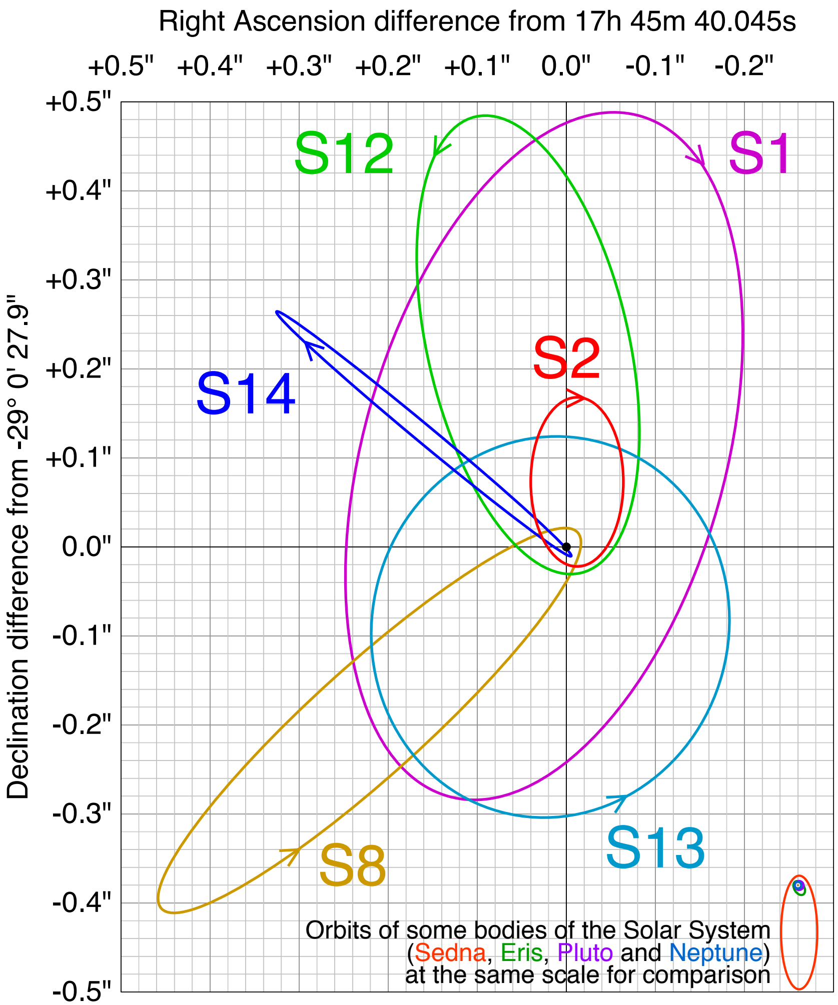
- We will look at the elliptic orbits of a few stars close to Sagittarius A
- The orbital radius of these stars is $R \sim 1000 AU \sim 0.01$ light years

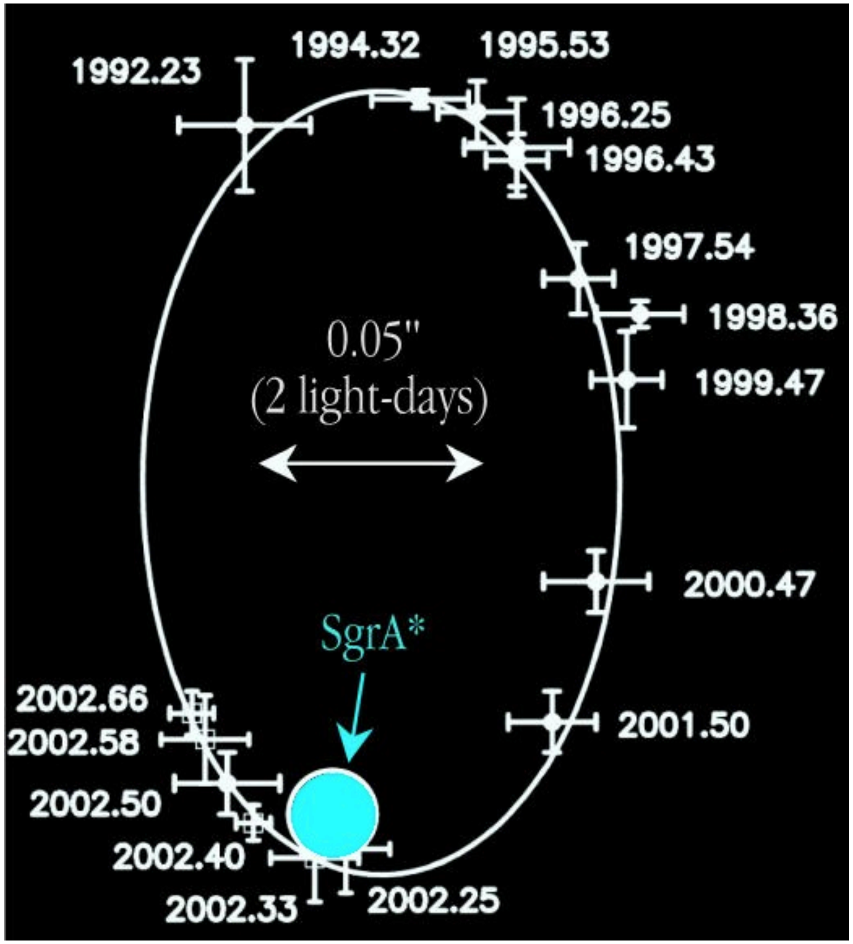
Sagittarius A^* (in our galaxy) contains a suppermassive black hole



- Look at the change in the image as a function of time (years) and look in different frequency bands (x-rays)

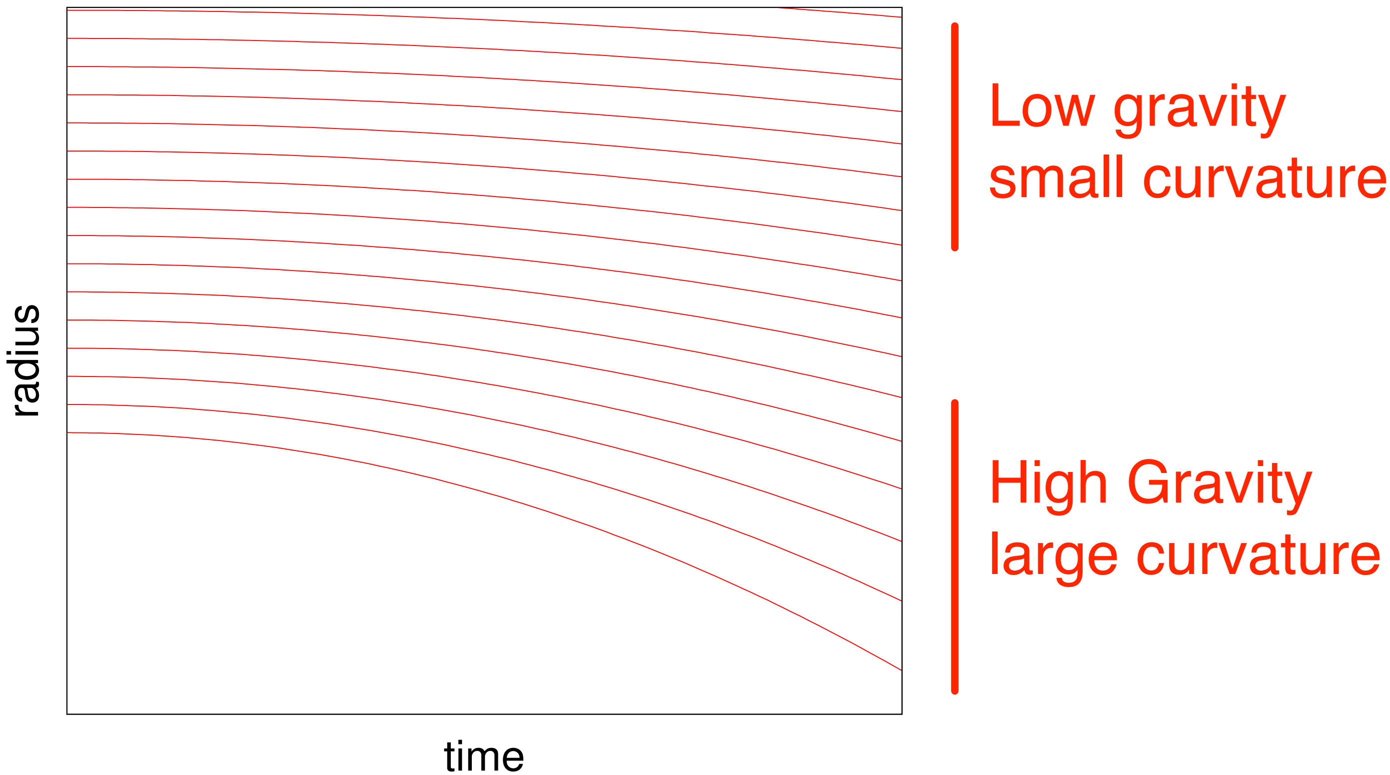
Orbits of six stars around the Sagittarius A^* in the center of our galaxy





From the orbital period and radius of the star, use Kepler's laws to find the mass of the SgrA^*

Note: 2 light days = 350 AU



Can view the problem of determining the forces of gravity, as a problem of finding how the coordinates of free falling observers change from point to point