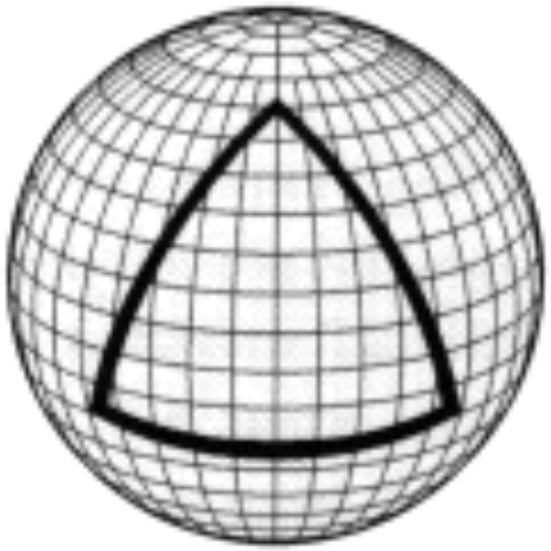
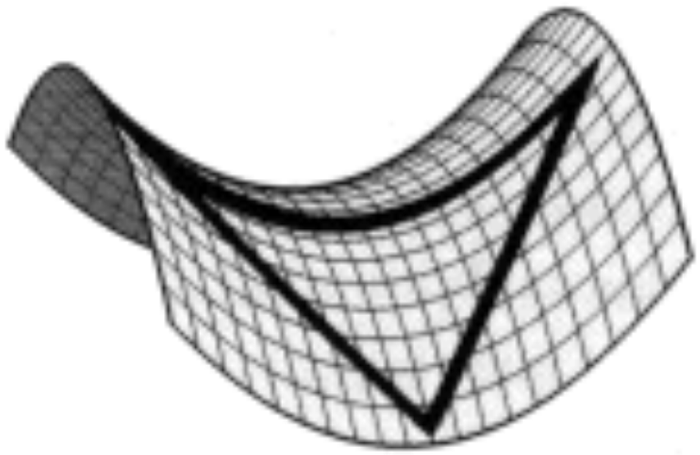
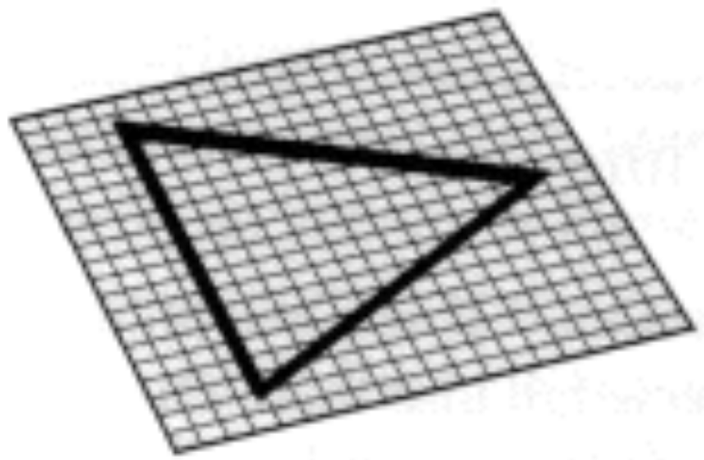
interior angles of a triangle...180 degrees?



Positive Curvature

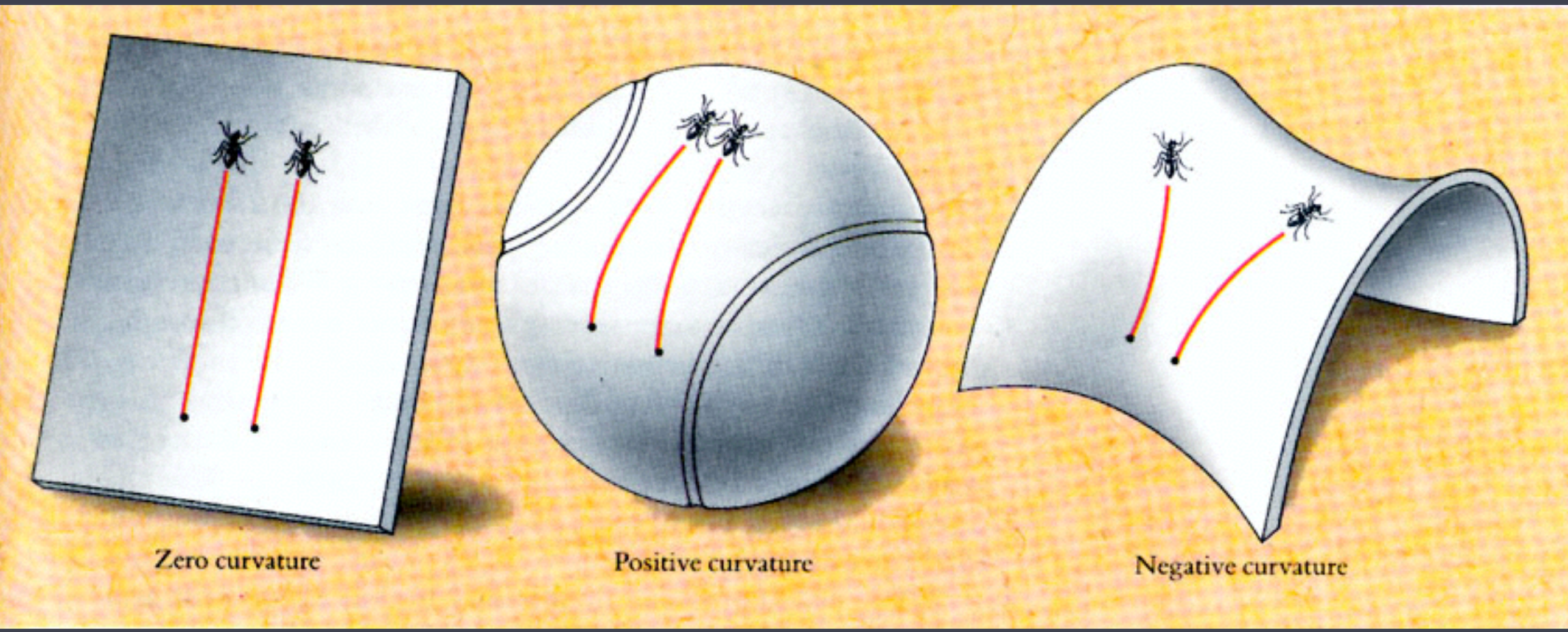


Negative Curvature

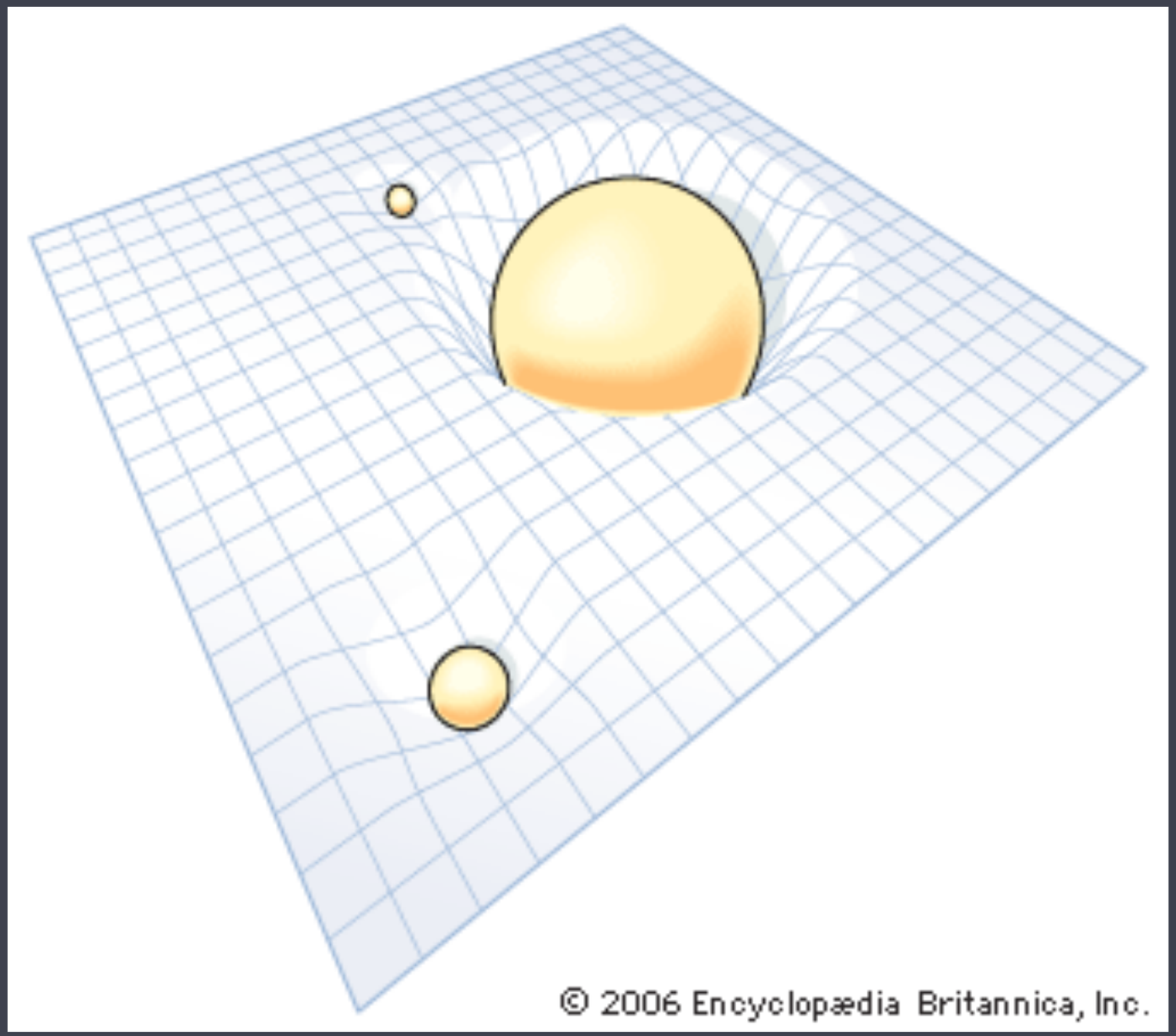


Flat Curvature

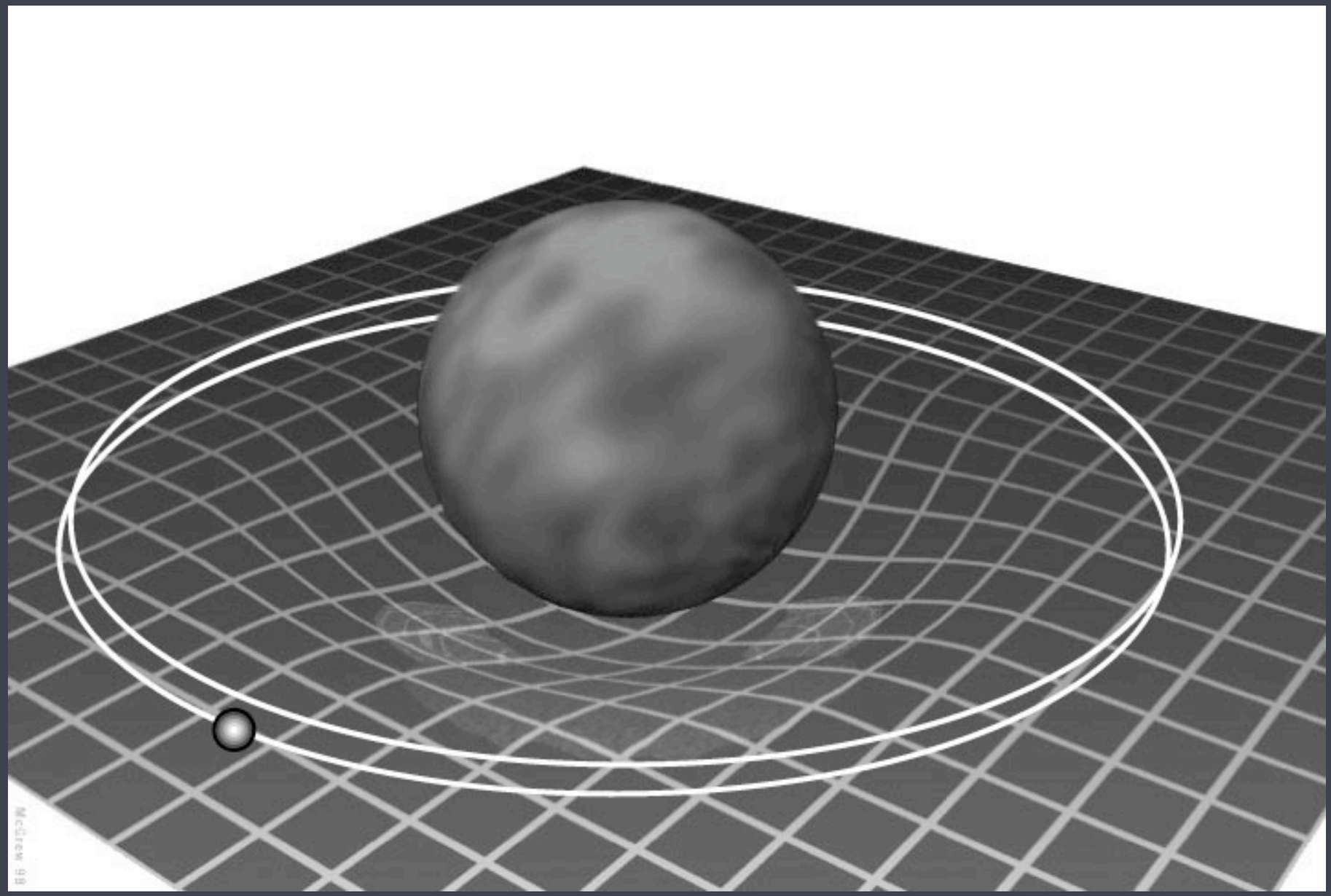
parallel lines?



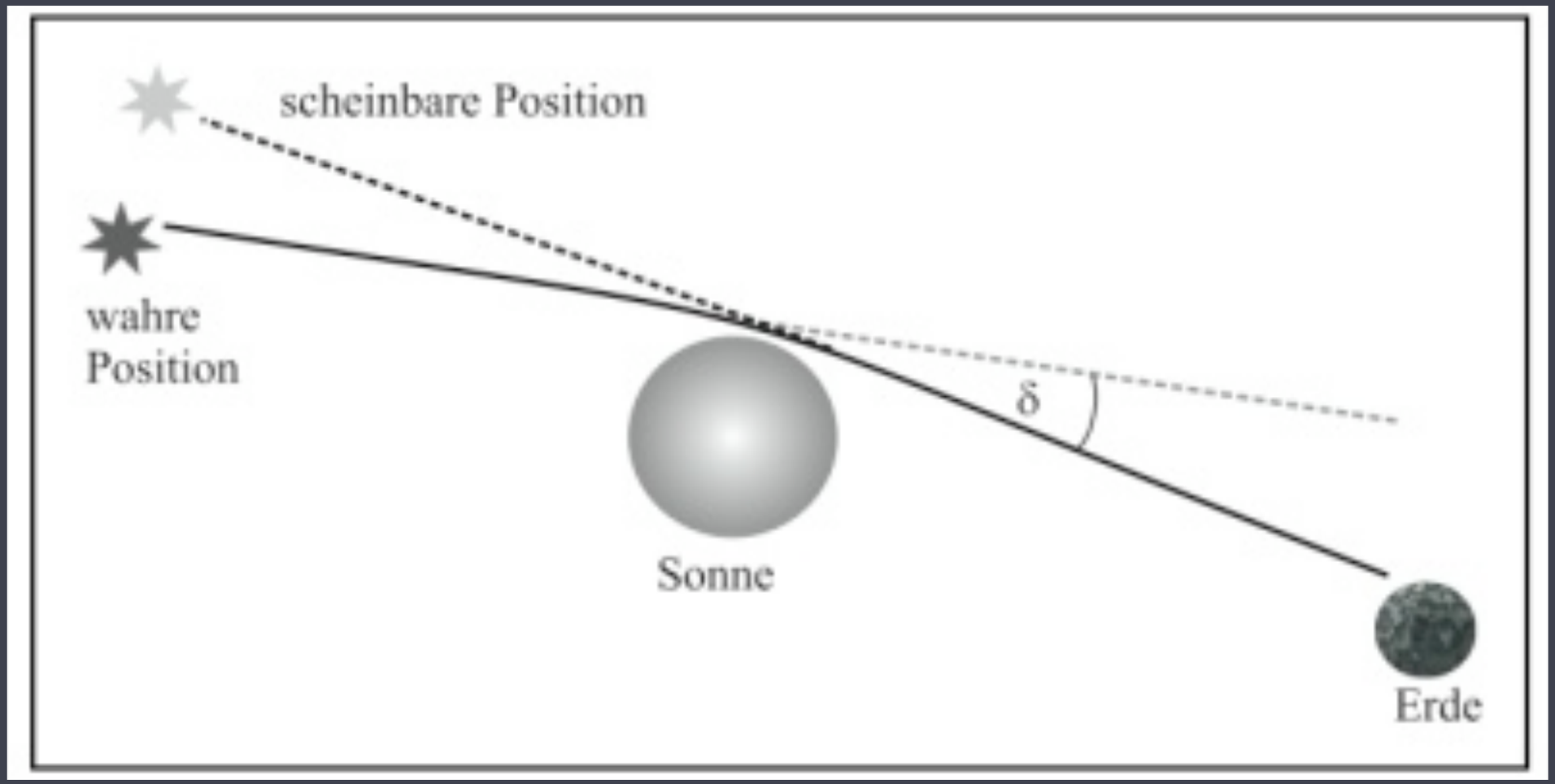
mass curves space *locally* too



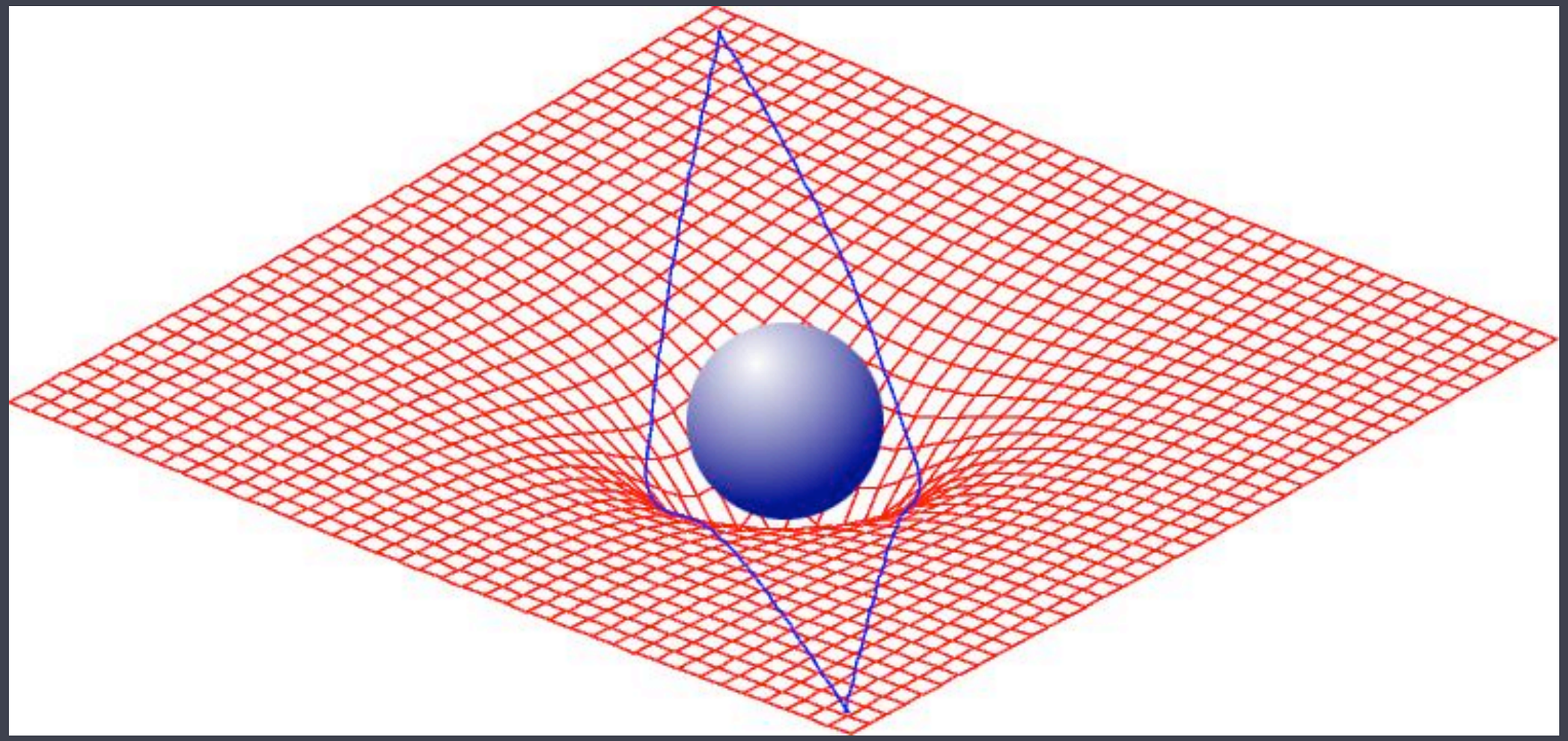
Orbits can be understood in terms of curved space

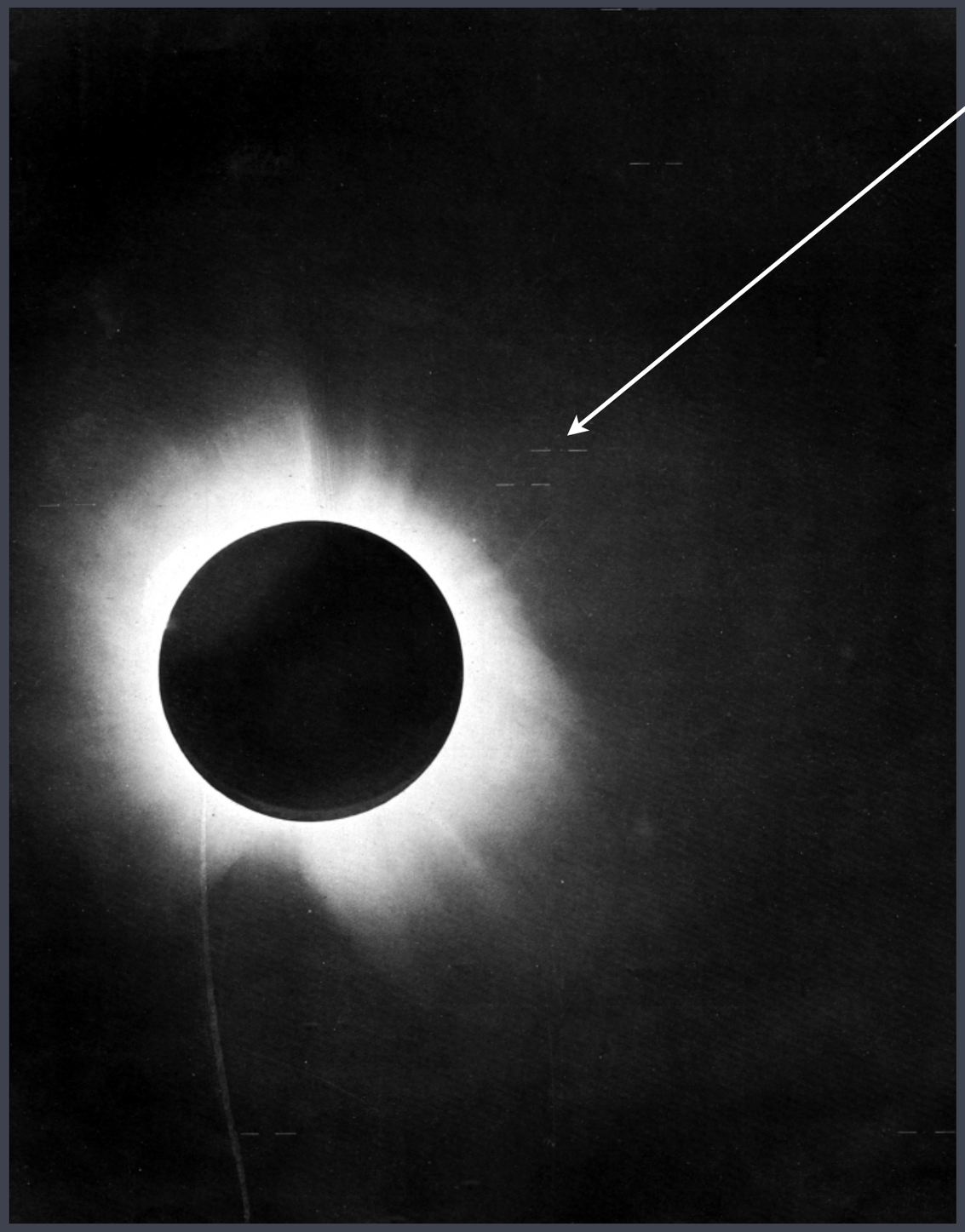


Prediction: the Sun bends starlight that passes near it



Einstein's view is that light is just following the shortest path (geodesic) in curved spacetime





1919 eclipse expedition confirms the bending of starlight by the Sun… quantitative agreement with Einstein (2 times bigger effect than Newton)

Actual Position of the Star

Apparent Position of the Star

Distance from the Earth to the Stella Background is more than 93,000,000,000,000 miles.

THE SUN

Distance from the Earth 93,000,000 miles

This Diagram shows the proportional Displacement of the Stars in relation to the distance from the Sun.

The amount of Displacement is exaggerated about 600 times

Apparent Position :
Actual Position :

THE SUN

AFRICA

Principe I.

Sobral

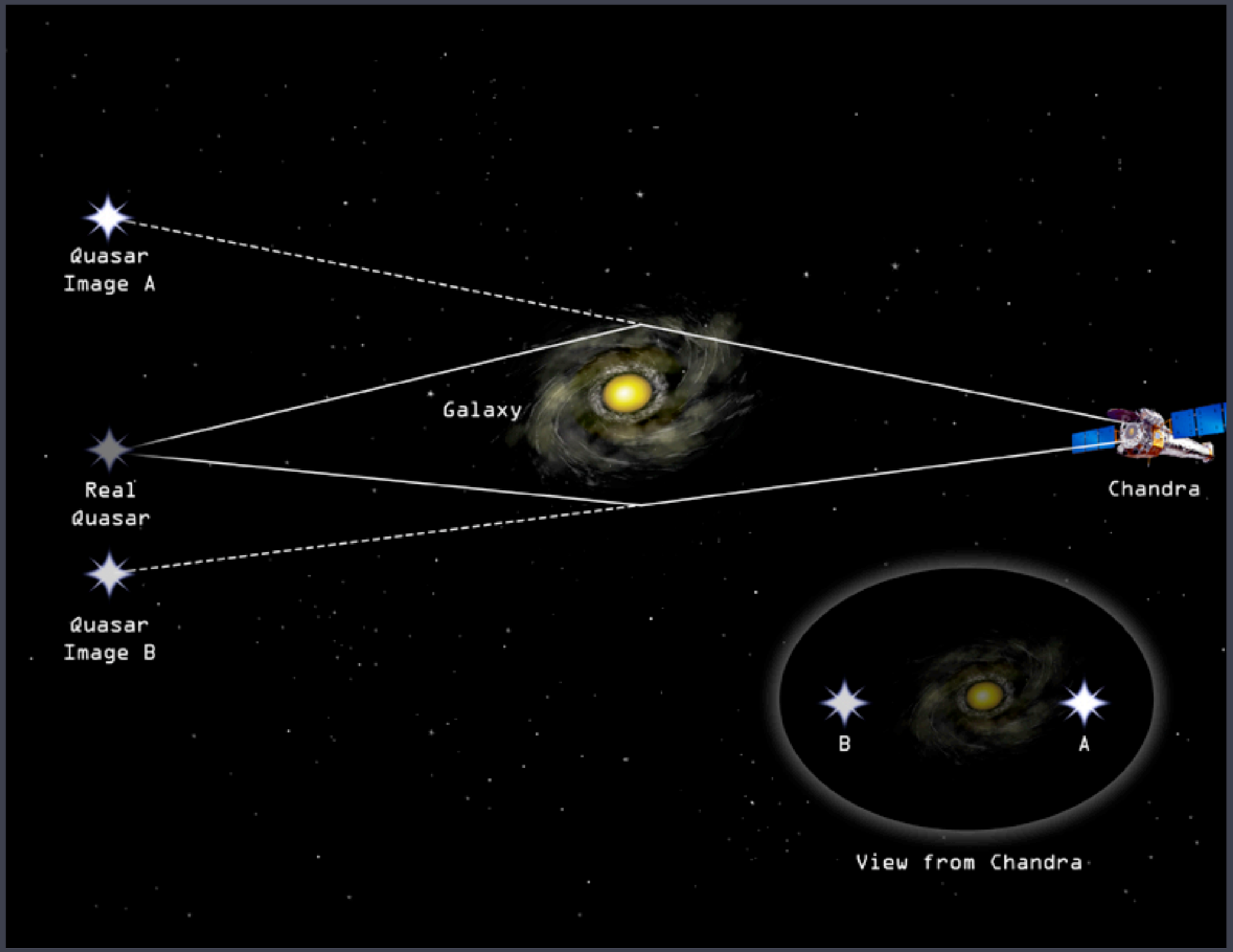
SOUTH AMERICA

ATLANTIC OCEAN

Showing Path of Total Eclipse of May 28-29, 1919, and positions of the two Observation Stations.

THE OBSERVATION STATION AT SOBRAL, IN BRAZIL

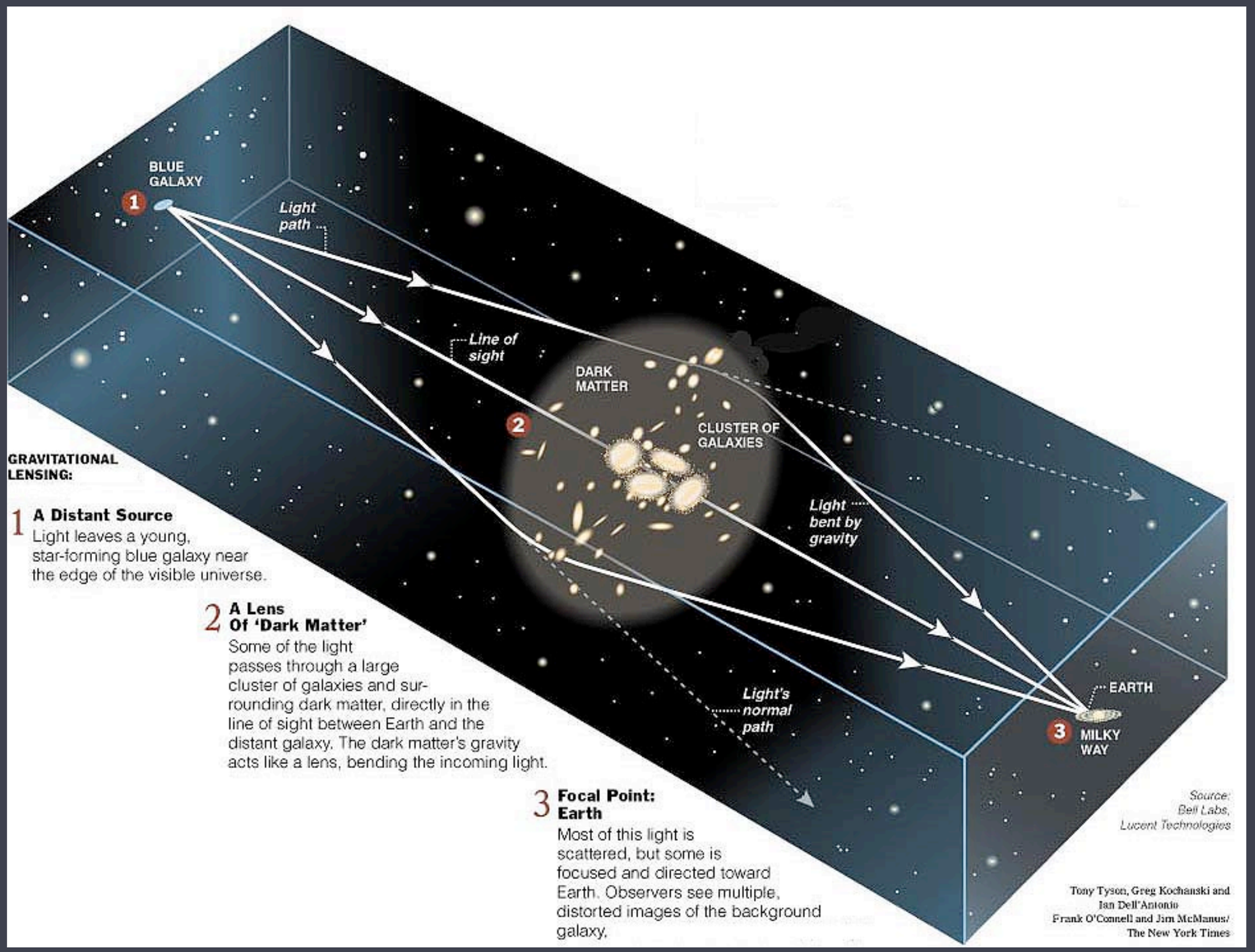
The Corona


Quasar
Image A
Galaxy
Real
Quasar
Chandra
Quasar
Image B
B
A
View from Chandra

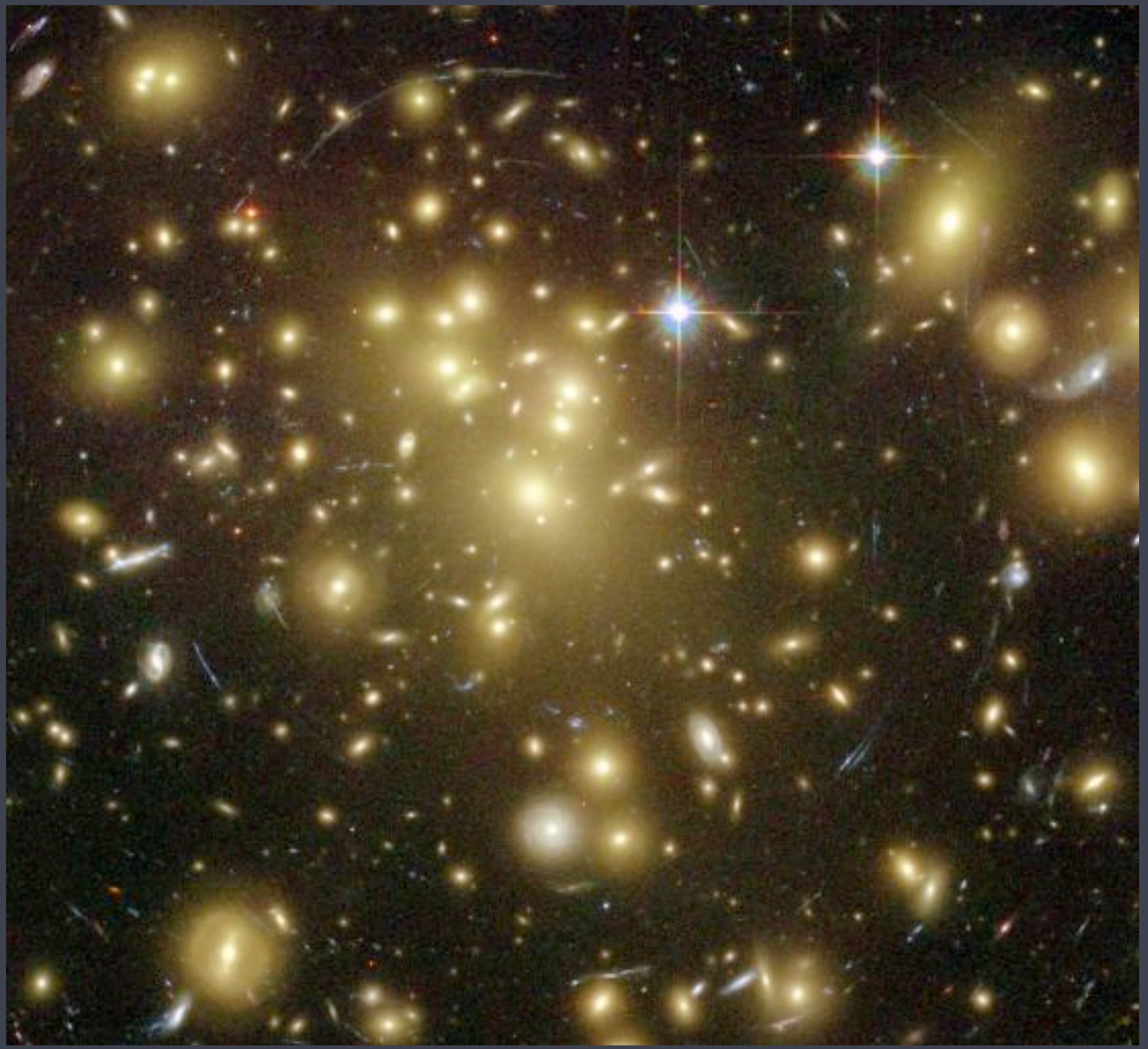
“Einstein Cross” - quadruply lensed galaxy (as some of you pointed out, if the alignment were perfect, you’d get a ring)

Smithsonian building on the Washington Mall, with a Saturn-mass black hole halfway between the building and the observer

galaxy clusters are the largest single entities in the universe; we'd like to measure the mass in galaxy clusters to sample Ω_m on these scales



foreground galaxy cluster lensing background galaxies



by modeling the observed lensing, the mass distribution in the cluster can be determined along with the total mass of the cluster: this "weighs" both regular baryonic matter *and* dark matter

purple is x-ray emission from hot (> million K) gas

most baryonic matter in the universe is this hot, cluster gas