GW PAC GRAVITATIONAL WAVE Physics and Astronomy Center

CALIFORNIA STATE UNIVERSITY FULLERTON

Visualizing the Curvature of Spacetime: Vortex and Tendex Lines of Merging Binary Black Hole Systems

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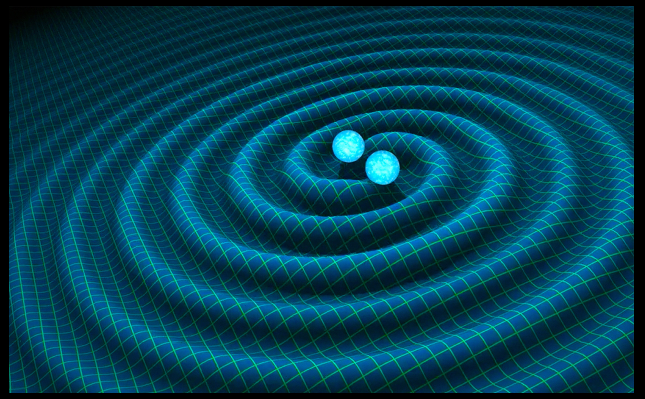
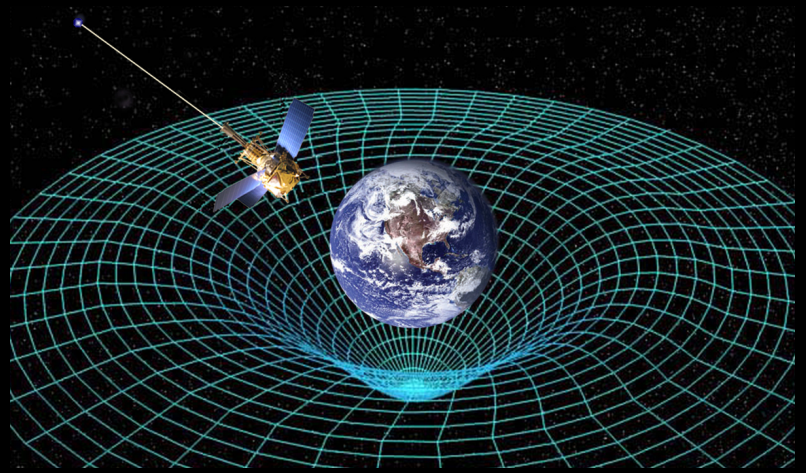
- 1915, Albert Einstein - theory of general relativity - gravity is actually the curvature of space and time
- Also predicted gravitational waves, ripples in space and time
- Said they would never be seen
- However in 2015, LIGO detected two black holes colliding
- What if we want to know what happens to the spacetime surrounding as the black holes collide?



Courtesy of Nasa

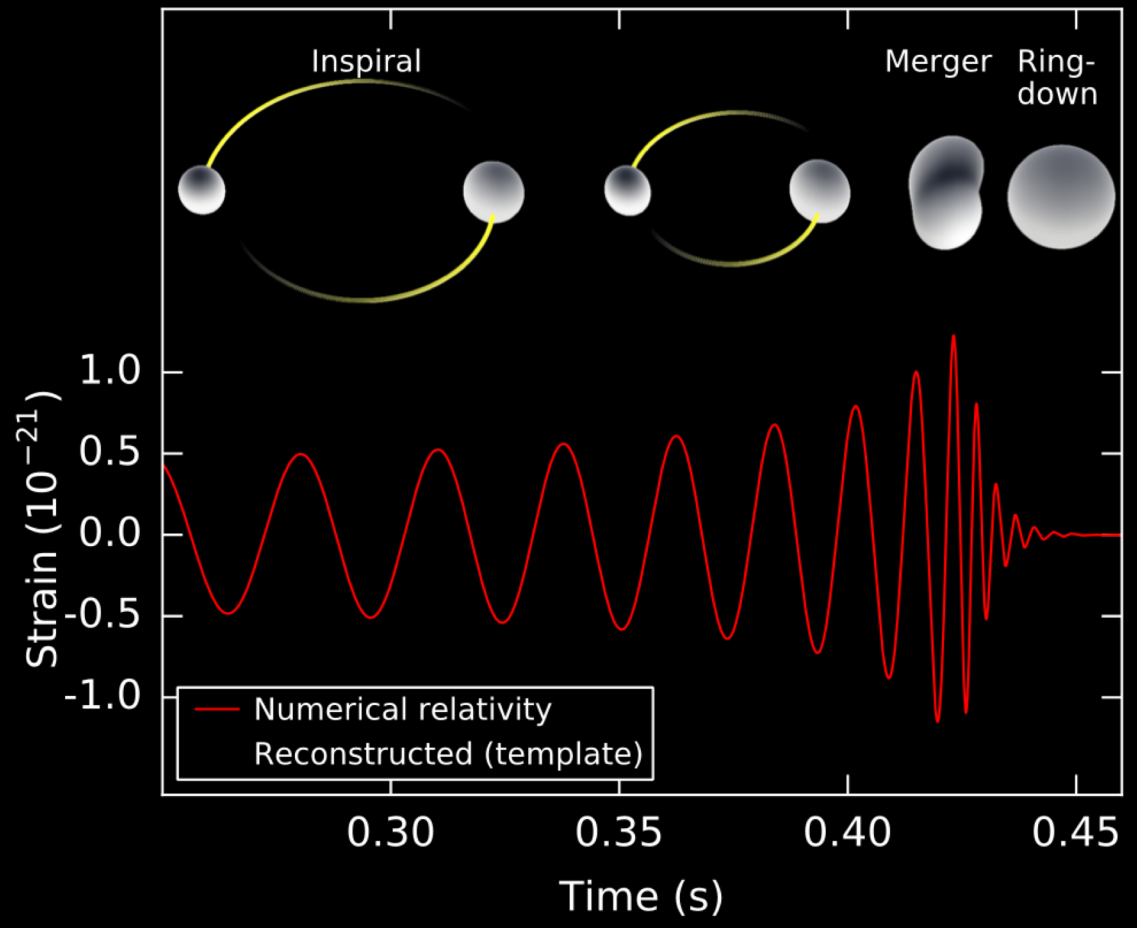


Courtesy of LIGO

Numerical Relativity

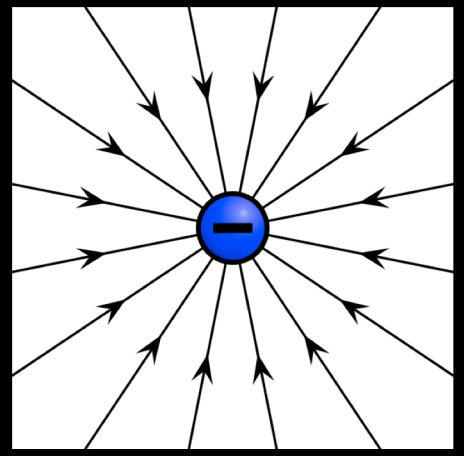
- We model the curvature of spacetime around merging black holes using SpEC, which solves Einstein's equations on our super computer.

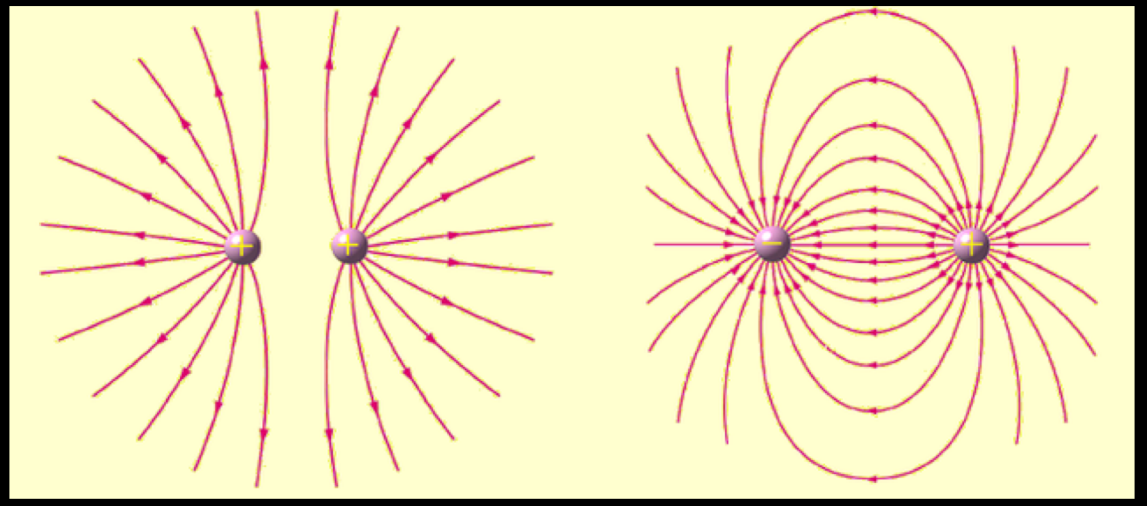
- First solves for initial conditions and then solves time dependent equations, taking steps in time

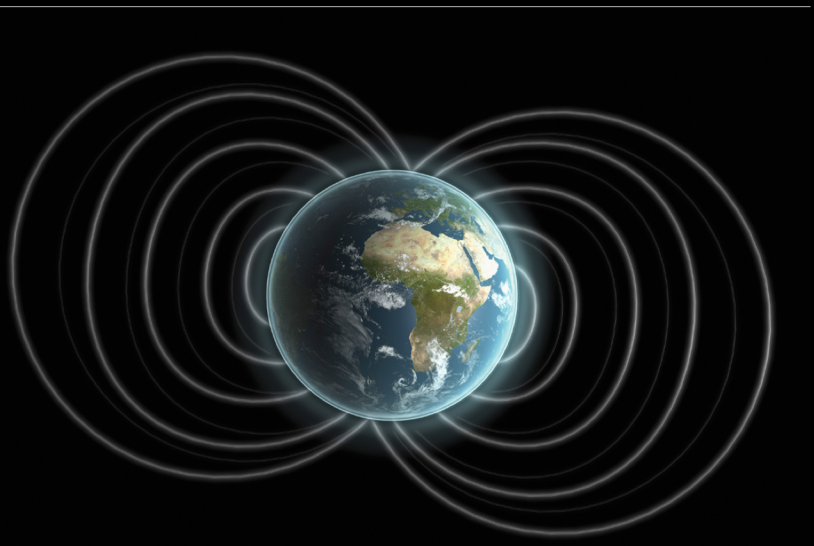


Electric and magnetic field lines

- Visualize electric and magnetic fields
- Electric field lines
  - Single charge
  - 2 charges
- Magnetic field lines

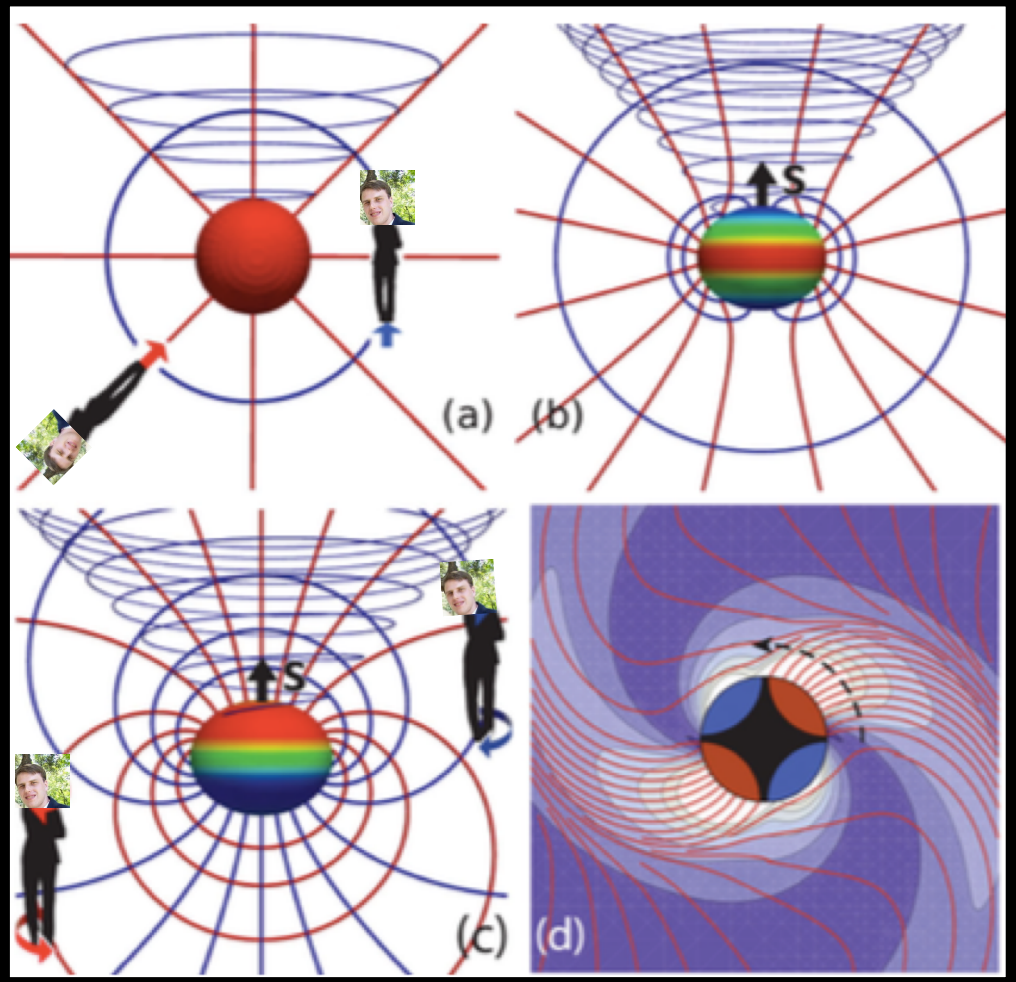




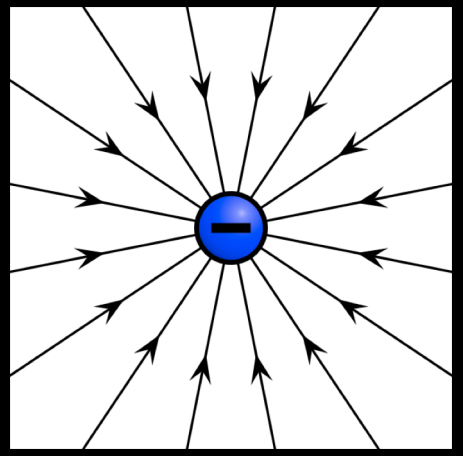


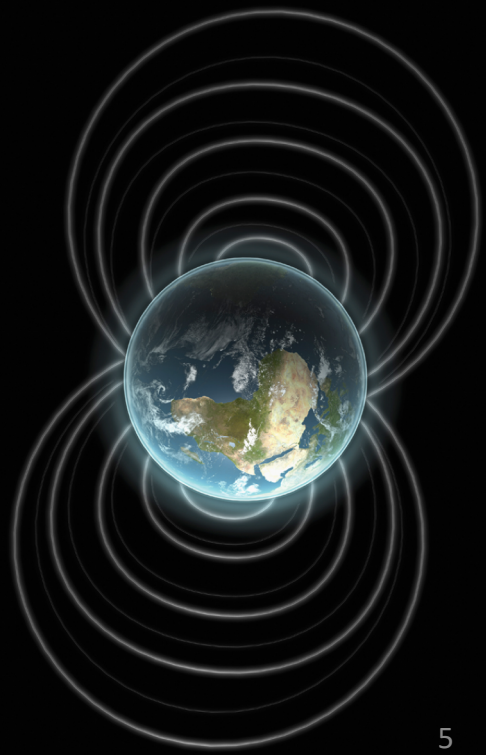
- Tendex Line - analogous to electric field lines; tidal gravity acts on an observer
- Vortex Line – analogous to magnetic field lines; along which vorticity will act

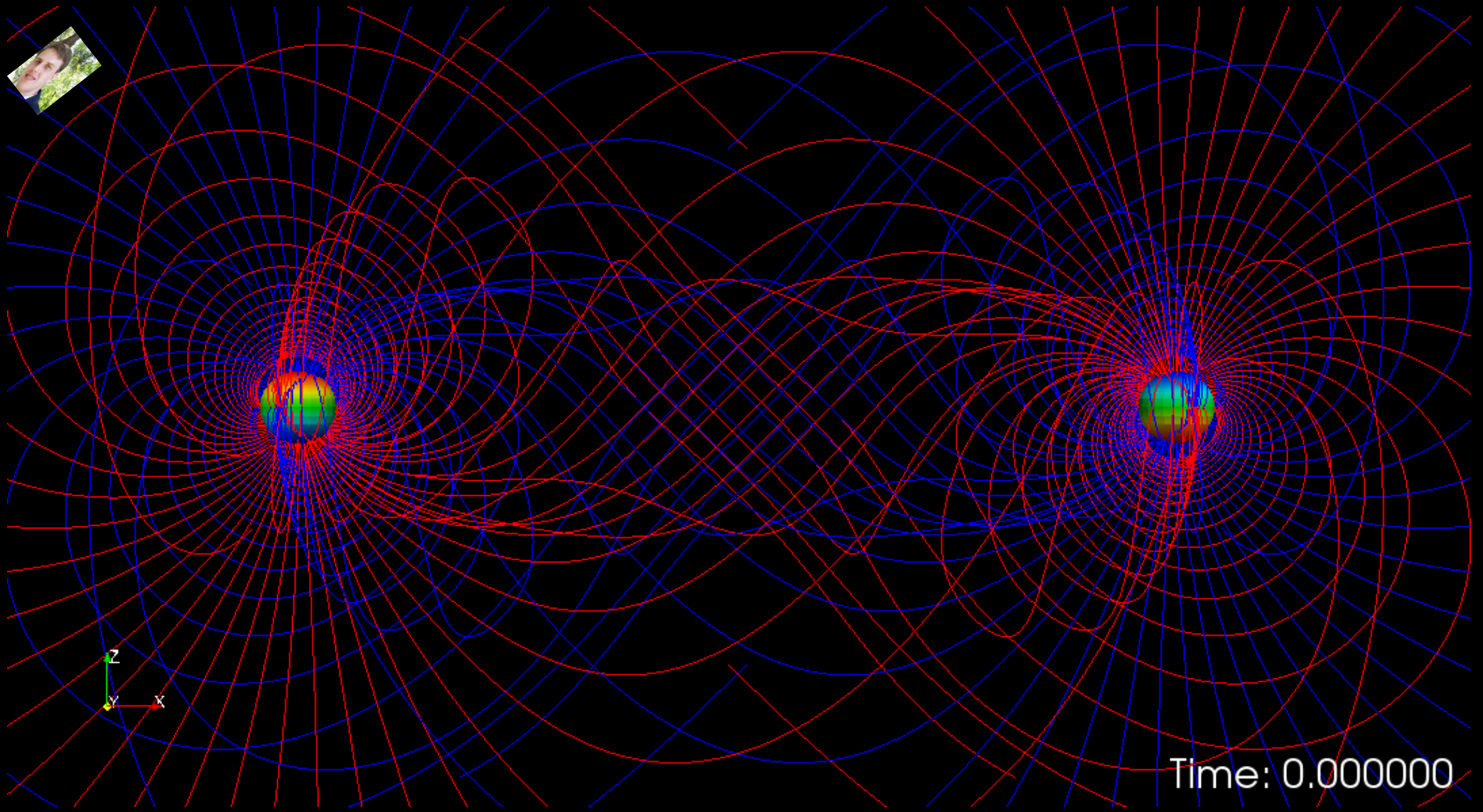
Vortex and Tendex Lines

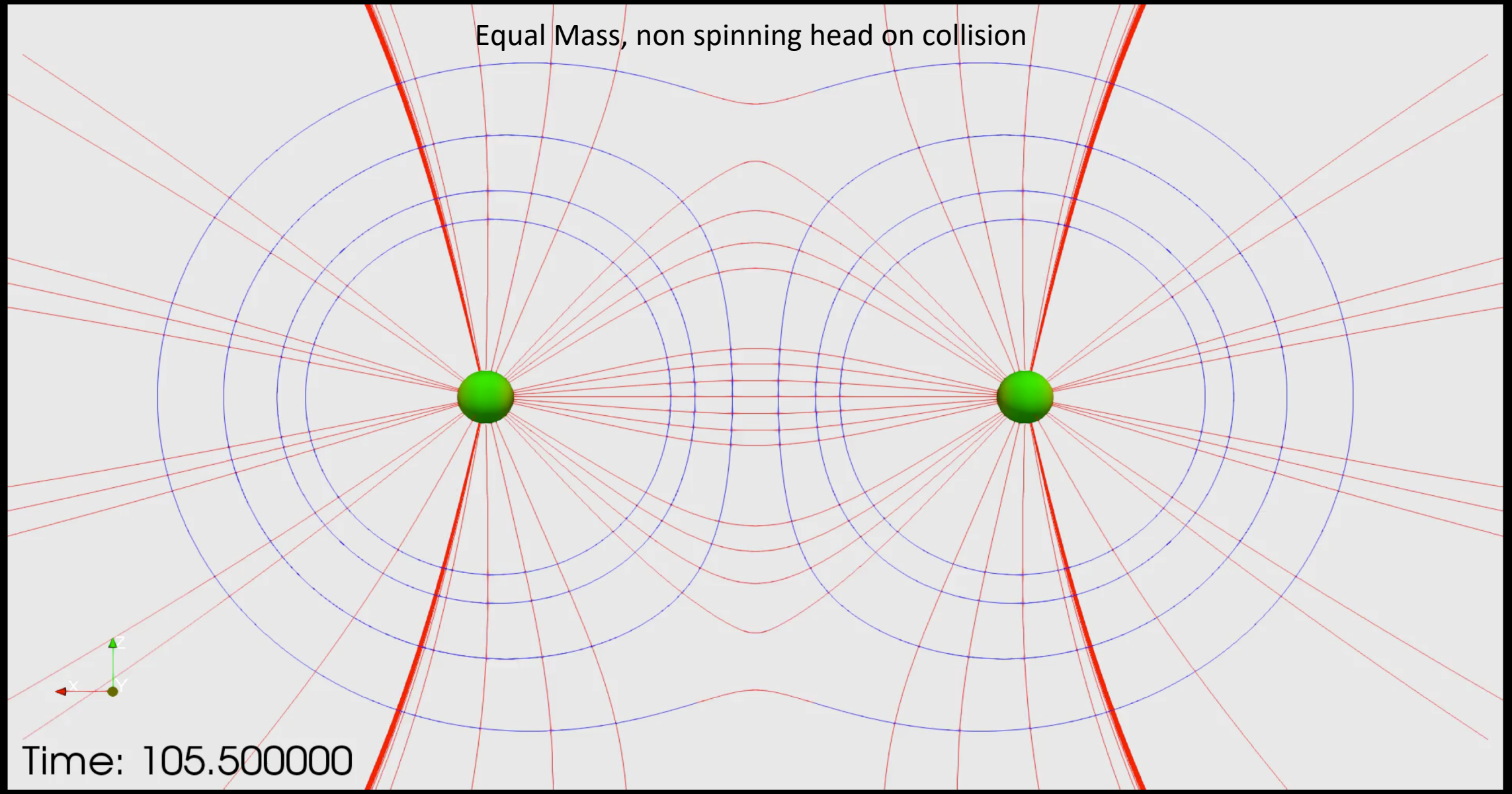


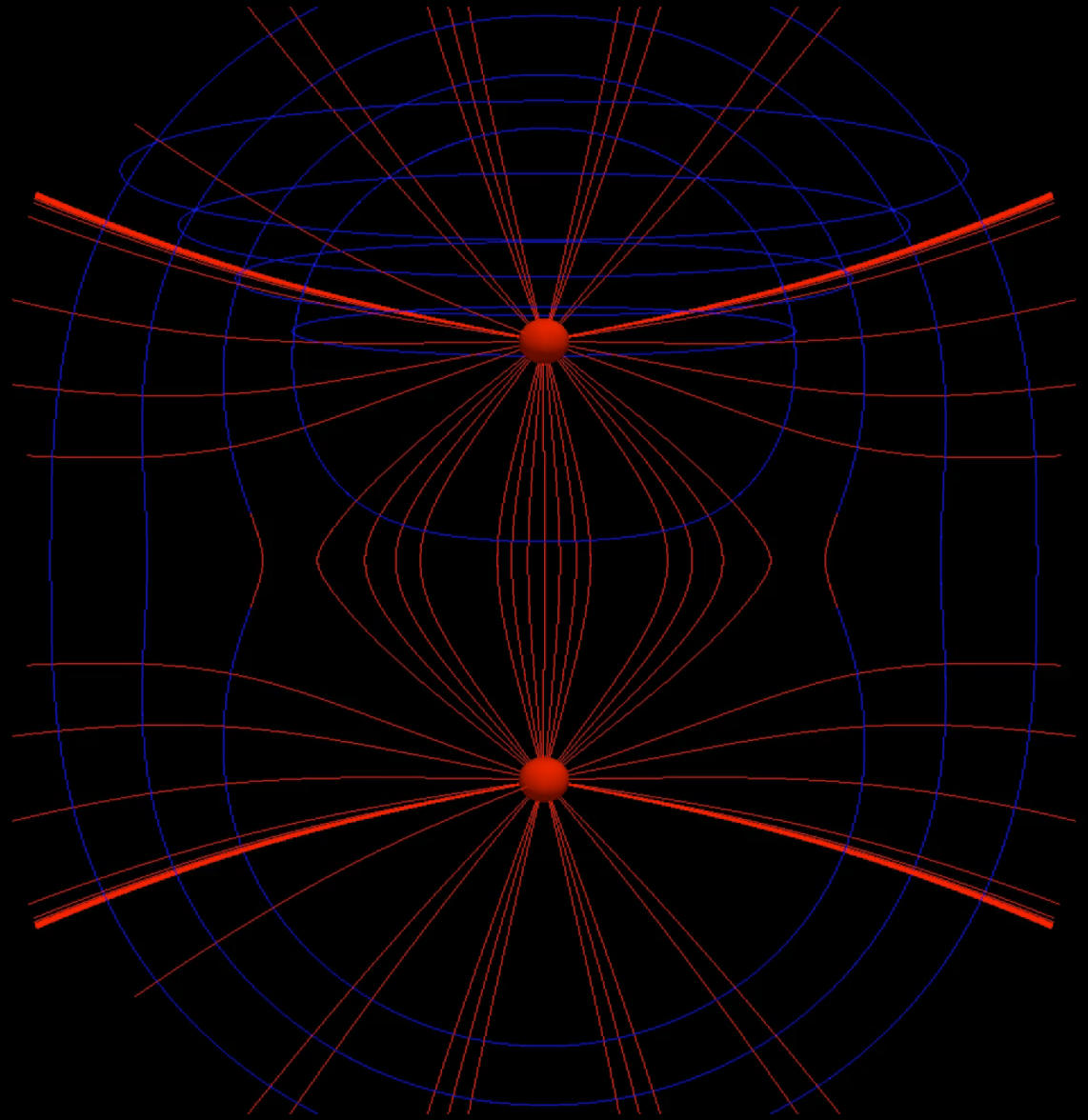
PRL 106, 151101 (2011)



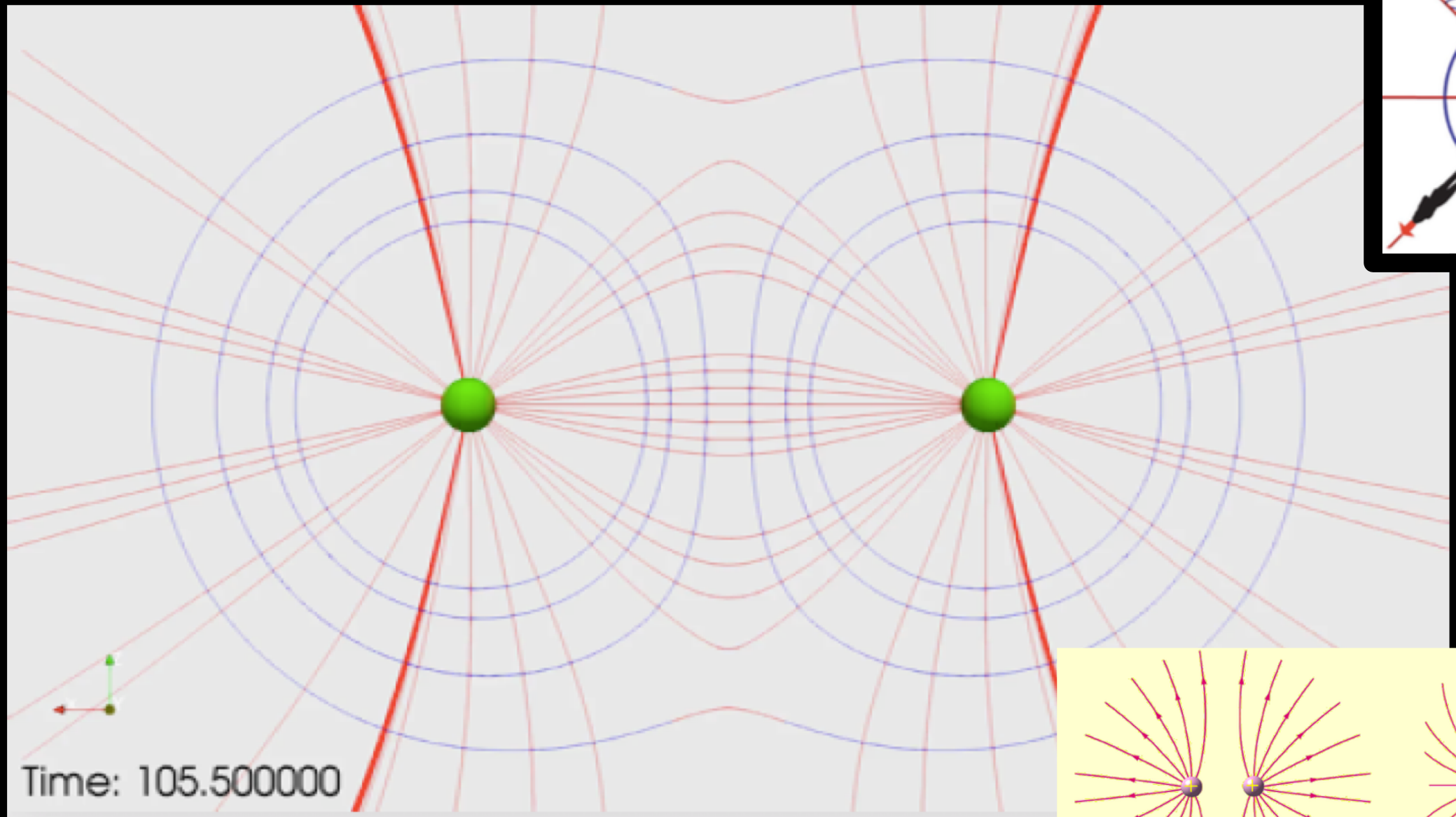


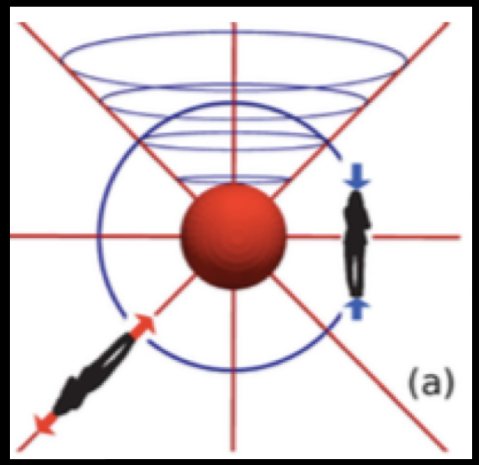

Z
Y
X
Time: 0.000000

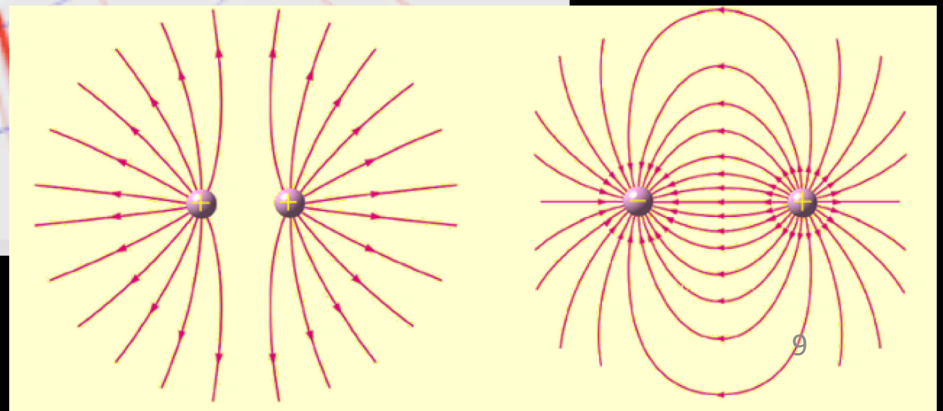

Equal Mass, non spinning head on collision
Time: 105.500000

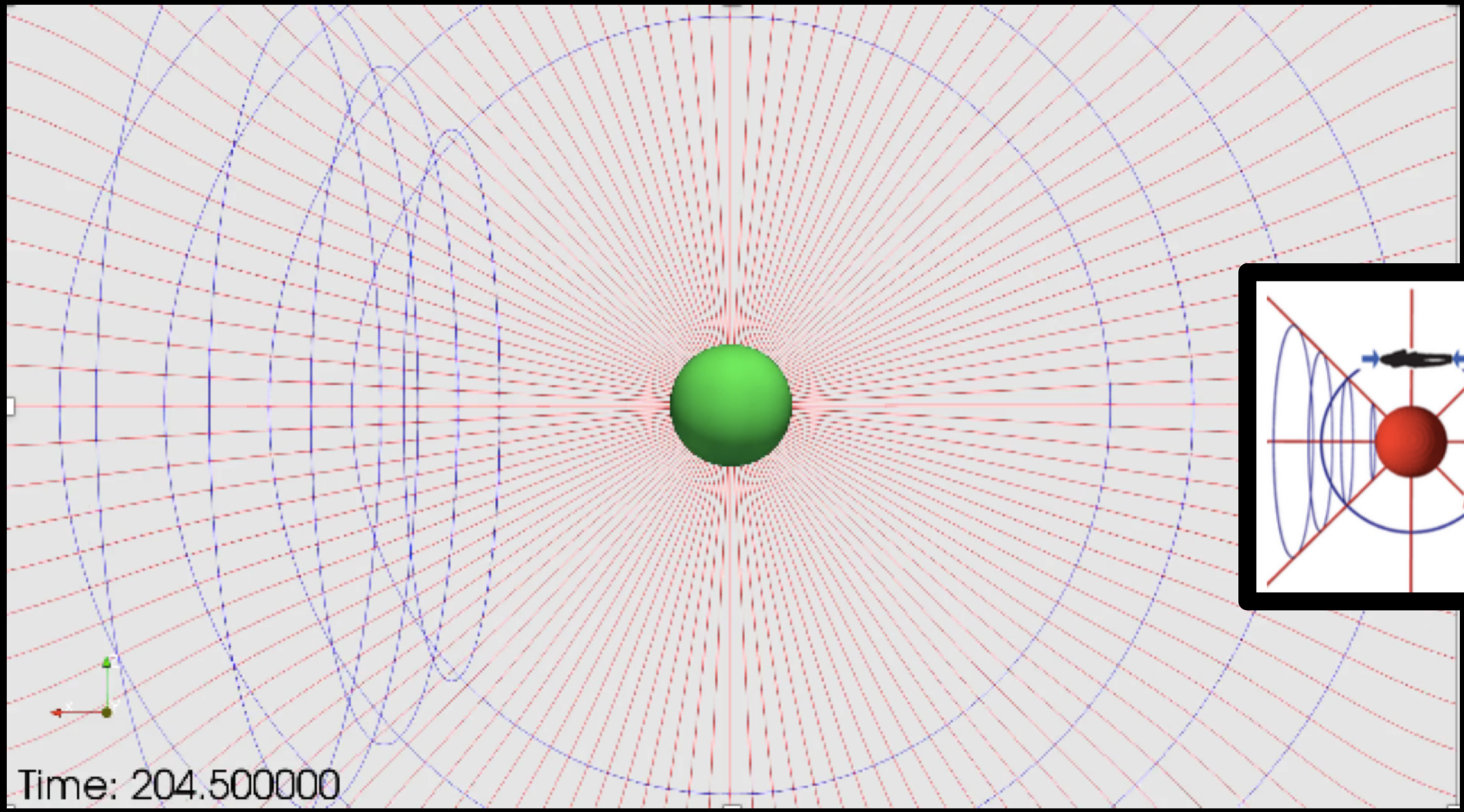


Equal Mass, non spinning head on collision


Time: 105.500000

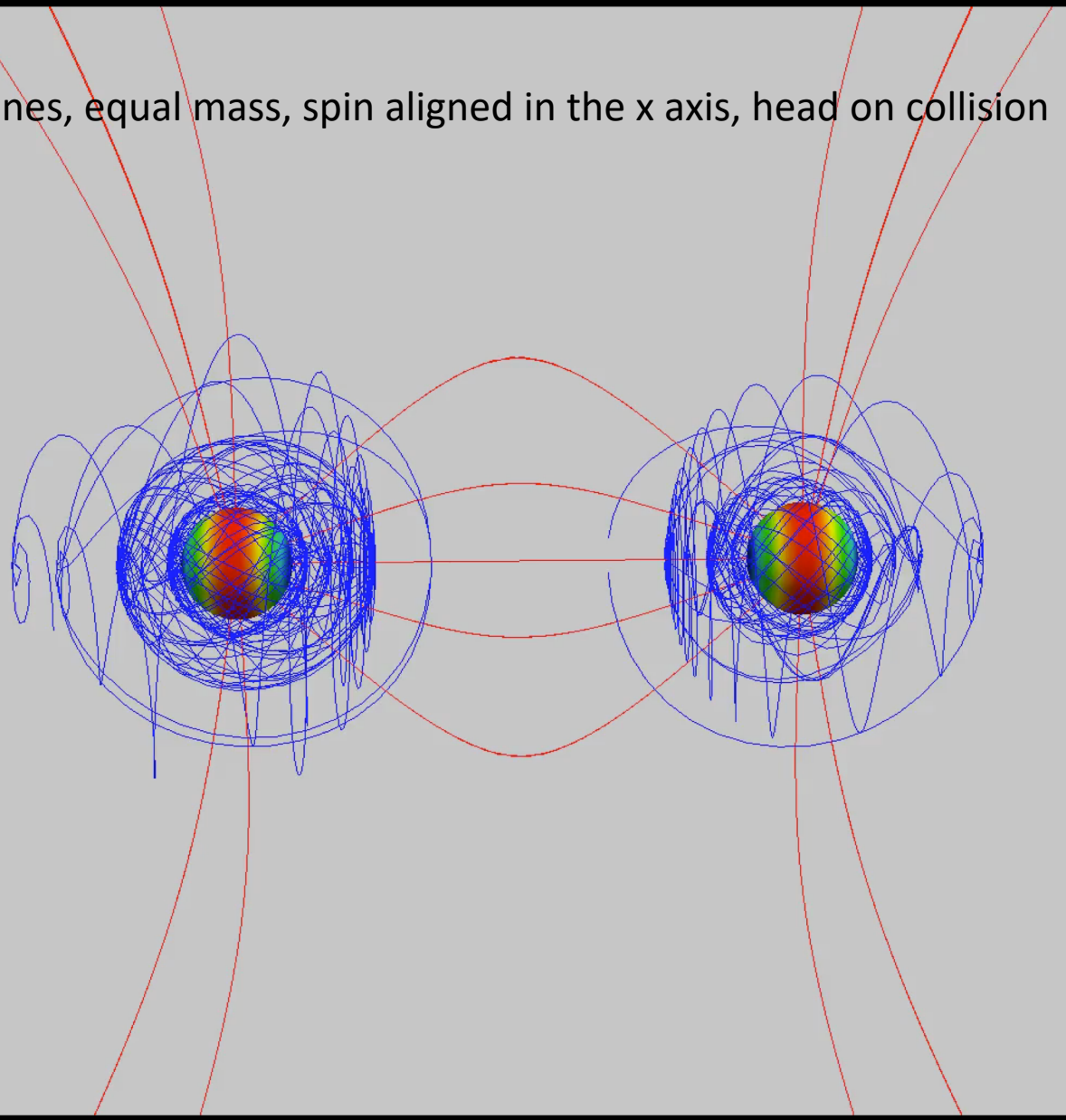

(a)



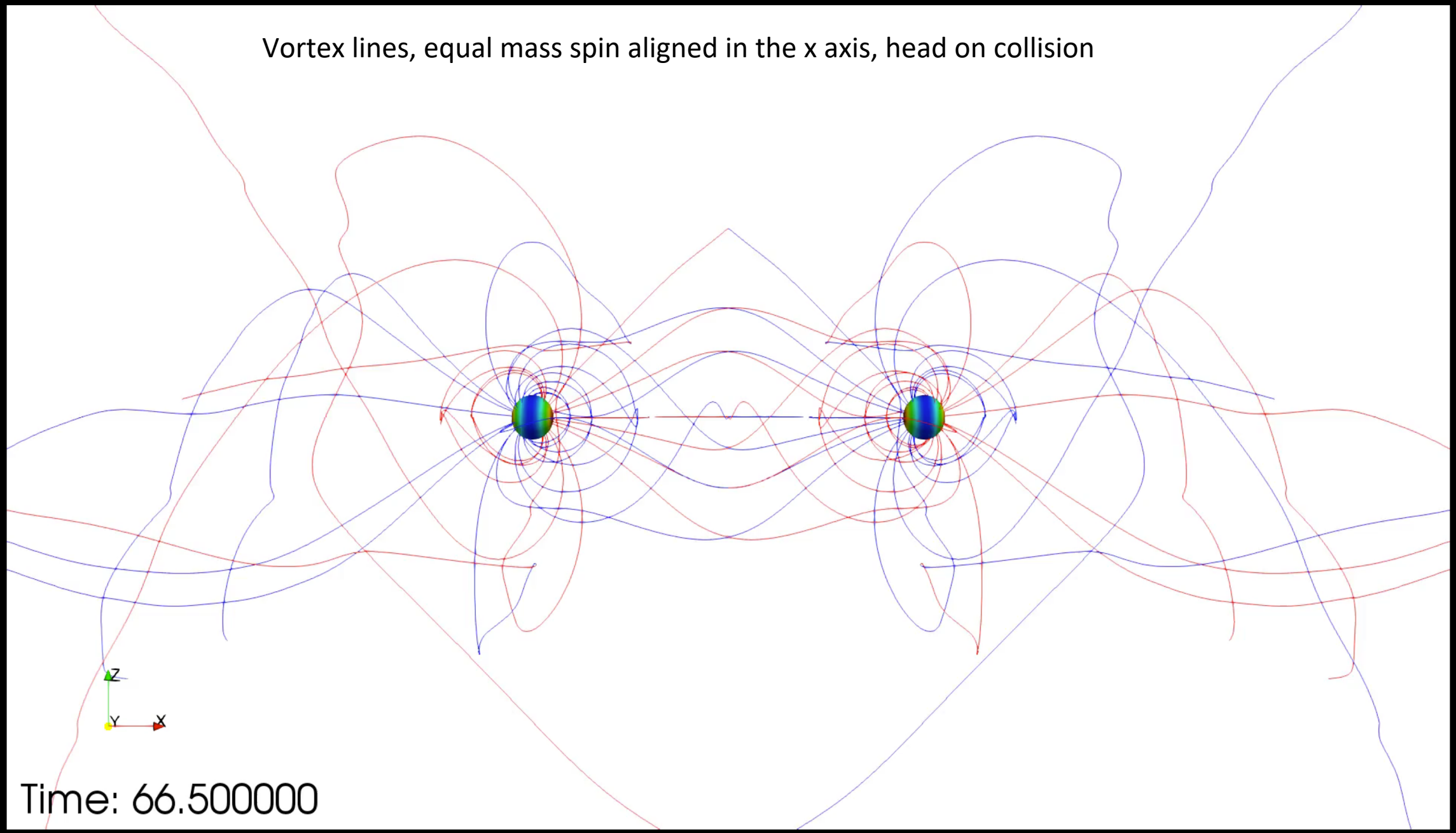

Time: 204.500000

(a)

Tendex lines, equal mass, spin aligned in the x axis, head on collision



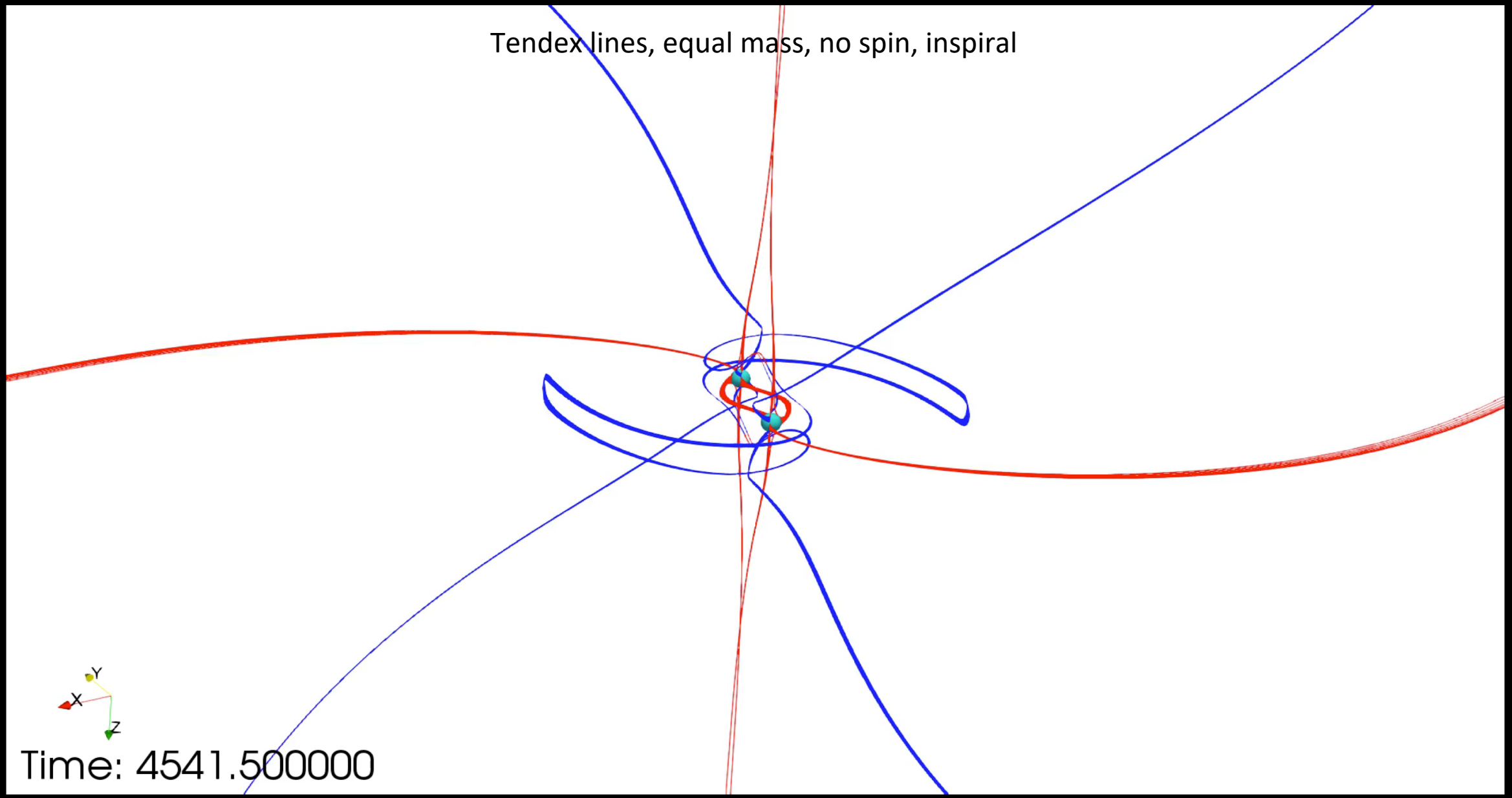
Vortex lines, equal mass spin aligned in the x axis, head on collision



Conclusion

- Generate accurate descriptions of warped space times around merging binary black holes
- Move onto spinning inspirals

Tendex lines, equal mass, no spin, inspiral



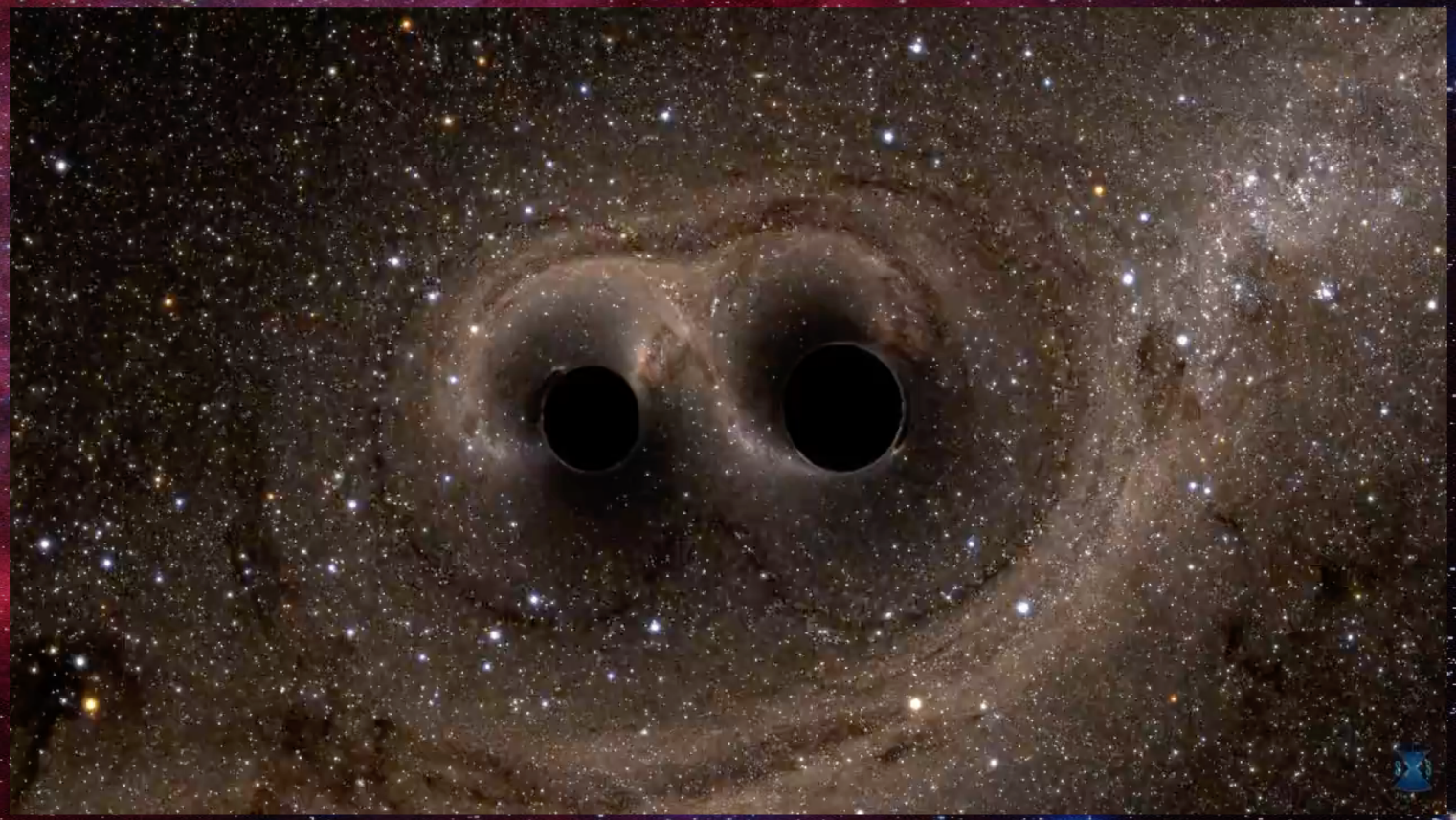
Methods

- The Weyl describes the curvature of spacetime outside a blackhole
- The Weyl tensor can be split into two different parts, the electric and magnetic part.
- Electric part – describes tidal gravity.
- Magnetic Part – describes differential frame dragging
- Electric/Magnetic part have three orthogonal eigenvectors which can be depicted by their integral curves
- Tendex/Vortex lines are tangent to the eigenvectors
- We call the eigenvalue of one of these lines its tendicity/vorticity.

PHYSICAL REVIEW D 84, 124014 (2011)

What Are Black Holes

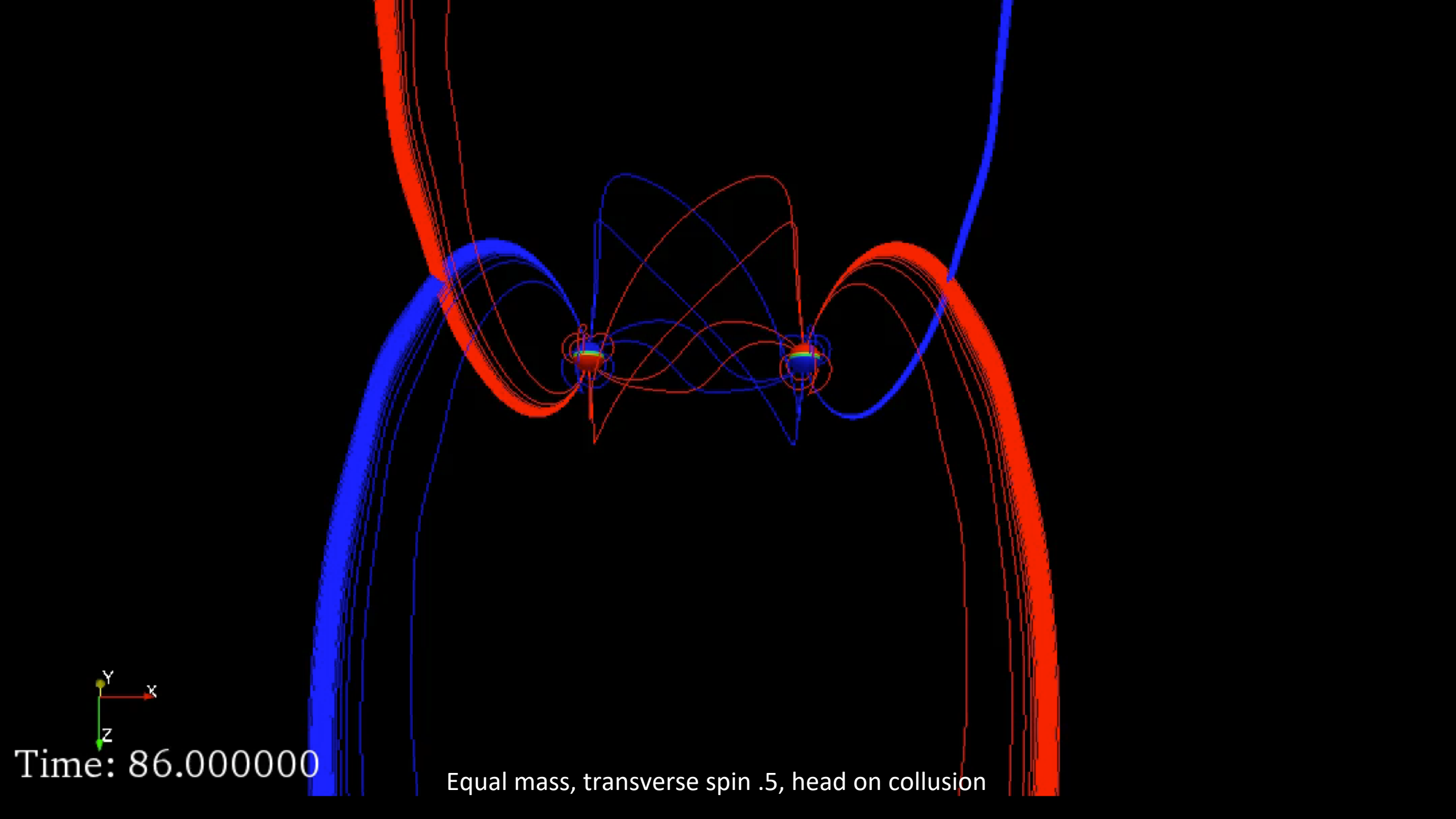
- Formed when a massive star can no longer support the processes that occur at its core
- Collapses into a black hole
- So massive, anything that enters that, not even light, can escape



Courtesy of SXS

Black Holes Detected

- In 2015, the laser interferometer gravitational wave observatory detected two black that crashed into each other 1.3 billion years ago.
- Masses – 29 M and 36 M
- 3 M worth of energy released
- First detection of gravity waves
- Through the detection, we can find out these properties



Equal mass, transverse spin .5, head on collusion