

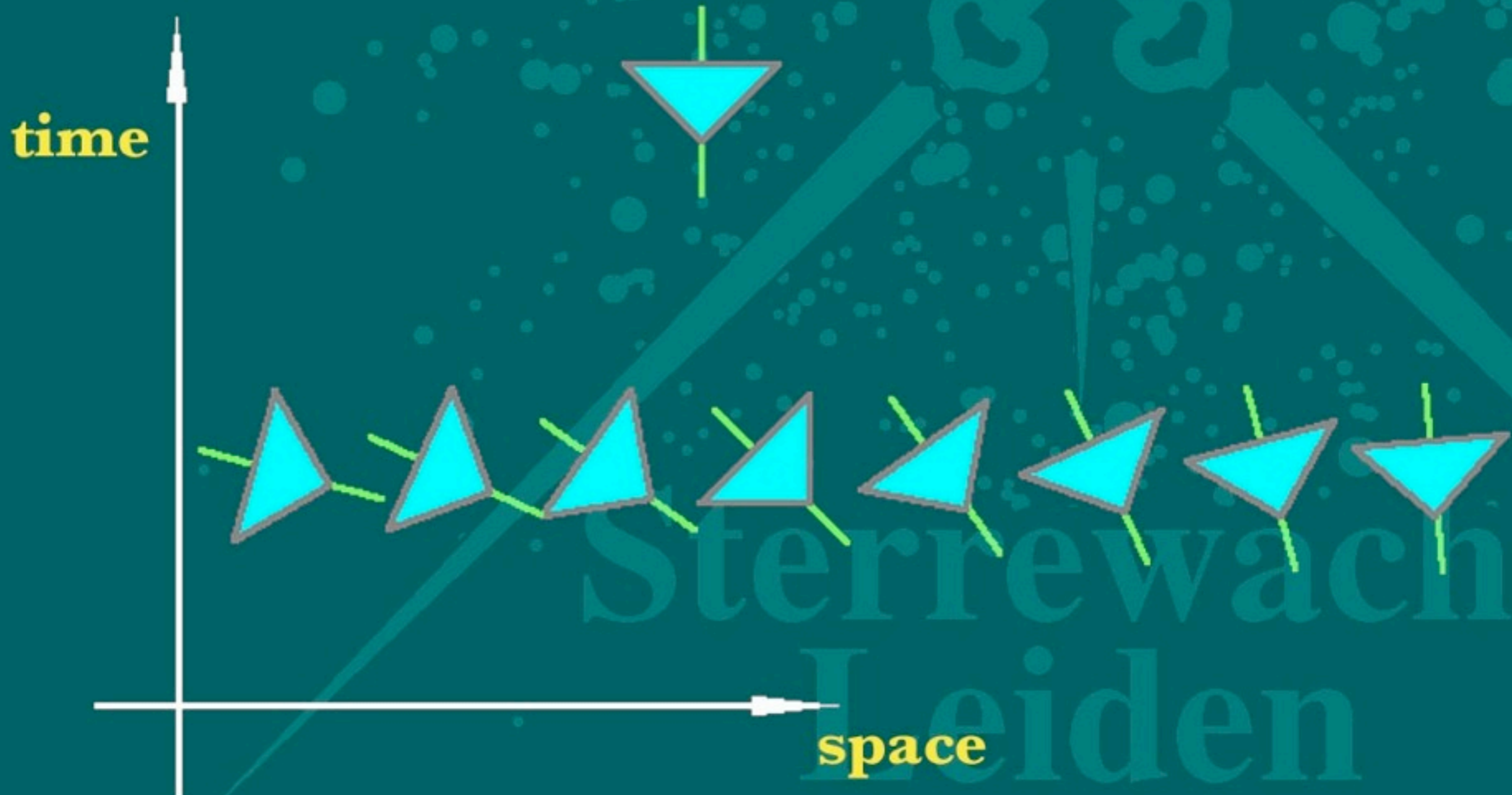
What's cooking

- (Non)relativistic behaviour
 - ◆ Consequences of $v=Hr$
 - ◆ $v \sim c$ and acceleration \rightarrow GRT
 - ◆ Metric theory, metric tensor
 - ◆ Second-order derivatives
 - ◆ Connection with Newton \rightarrow Einstein Eqs
- The connection with Lagrangian theory: local Lorentz symmetry
- H&I specialization: Friedmann Equations

Local Light Cones

- Example: the Schwarzschild Black Hole

Building Spacetime with Light Cones



Sterrewacht
Leiden

$$ds^2 = \left(1 - \frac{1}{r}\right) c^2 dt^2 - \left(1 - \frac{1}{r}\right)^{-1} dr^2$$

If α is the angle between the axis of the light cone and the direction of the global t -axis, we have

$$\tan \alpha = \frac{1}{1 - 2r}$$

Sterrewacht
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Schwarzschild Black Hole



Leiden

$$ds^2 = \left(1 - \frac{1}{r}\right) c^2 dt^2 - \left(1 - \frac{1}{r}\right)^{-1} dr^2$$

Path of a light ray: $ds = 0$, so that

$$ds \propto \sqrt{\frac{r}{r-1}} dr$$

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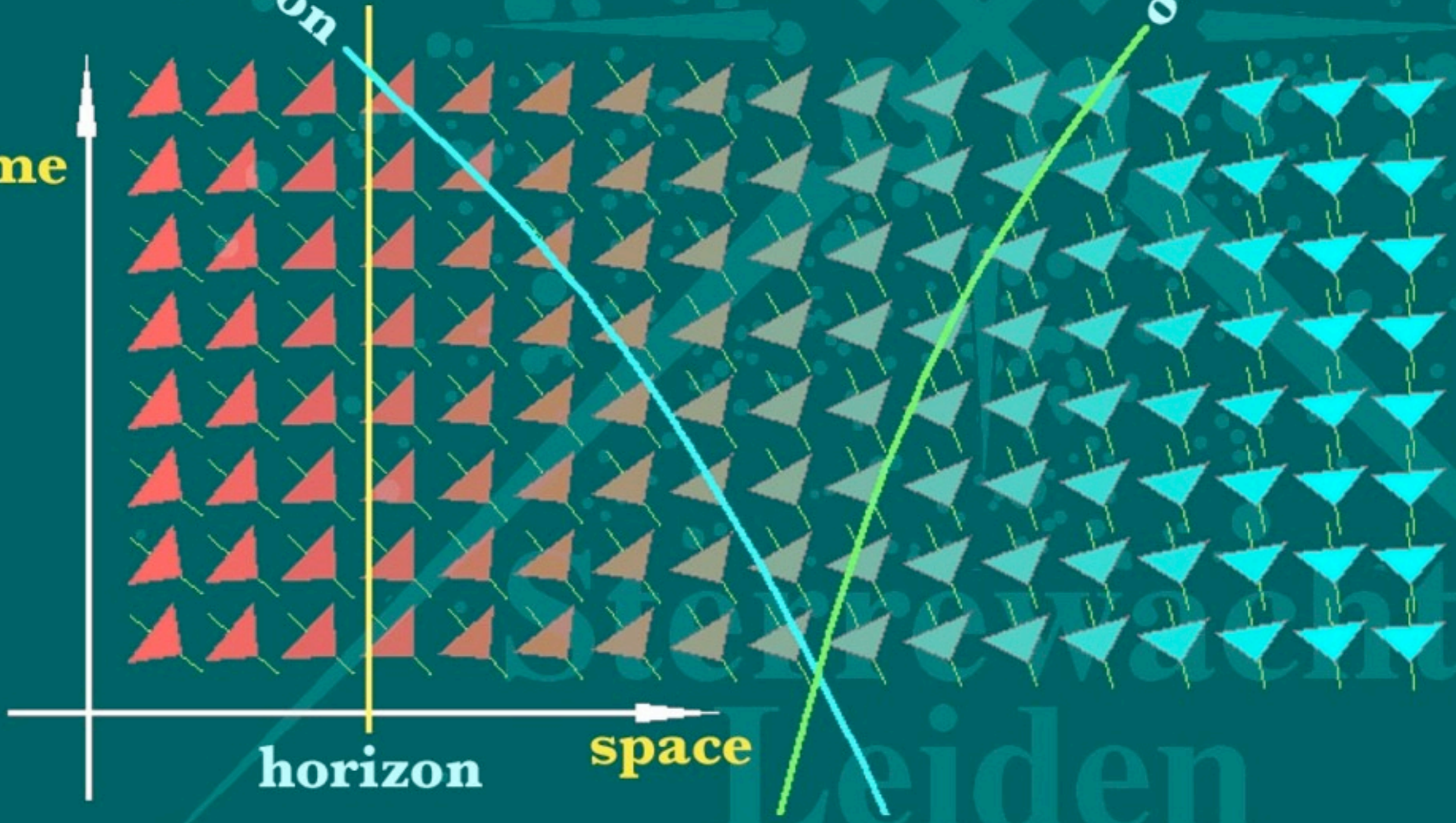
time

free motion

outgoing light

horizon

space



Leiden

$$ds \propto \sqrt{\frac{r}{r-1}} dr$$

$$r = (\cosh \chi)^2$$

$$ds = 2 (\cosh \chi)^2 d\chi$$

$$s = \sinh \chi \cosh \chi + \chi$$

$$s = \sqrt{r^2 - r} + \log(2r - 1 + 2\sqrt{r^2 - r})$$

Light Paths

time



space

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Light Paths

time



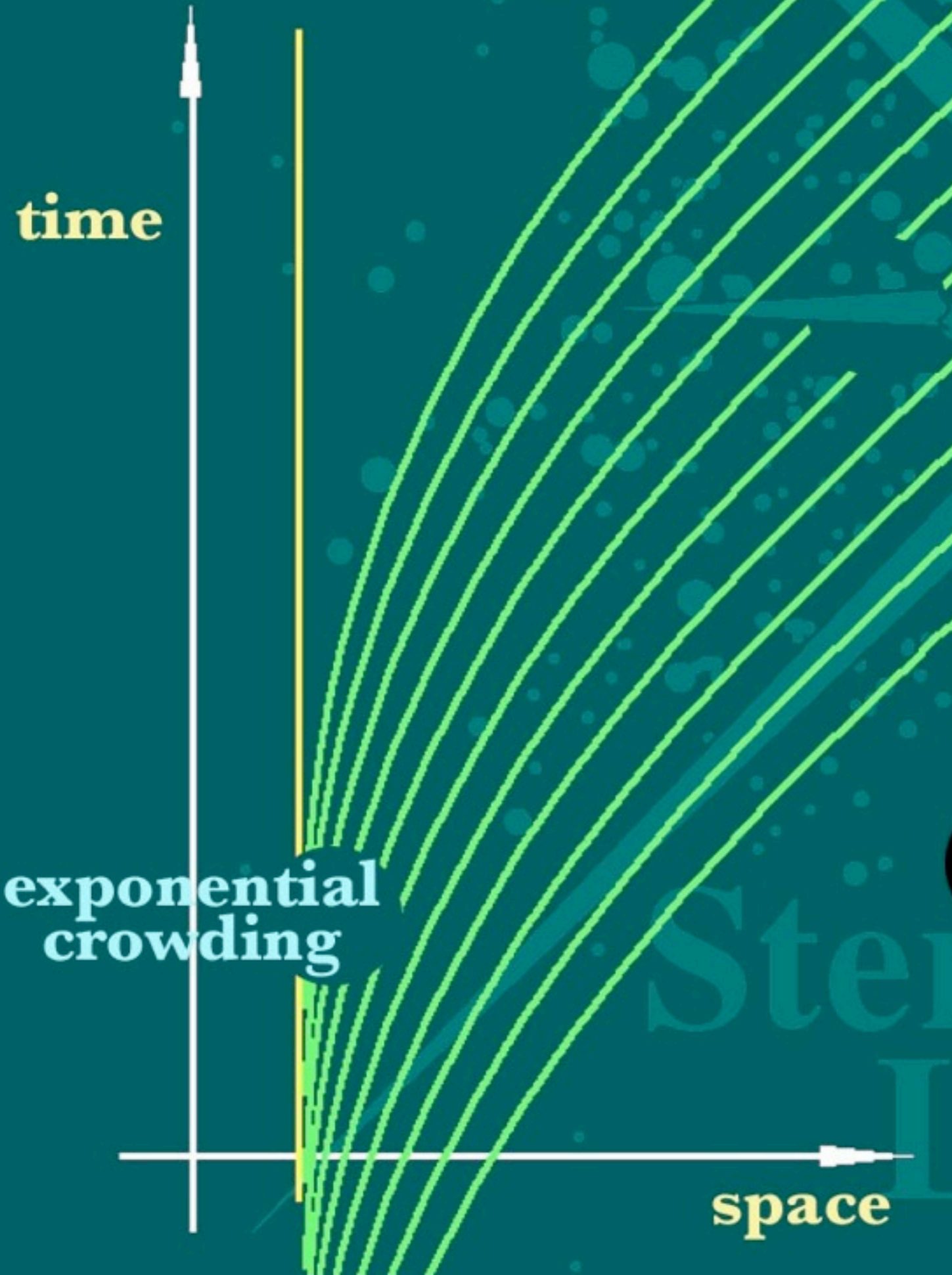
geometric
redshift



Sterrewacht
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space

Paths near the Horizon



geometric redshift



Sterrewacht
Leiden

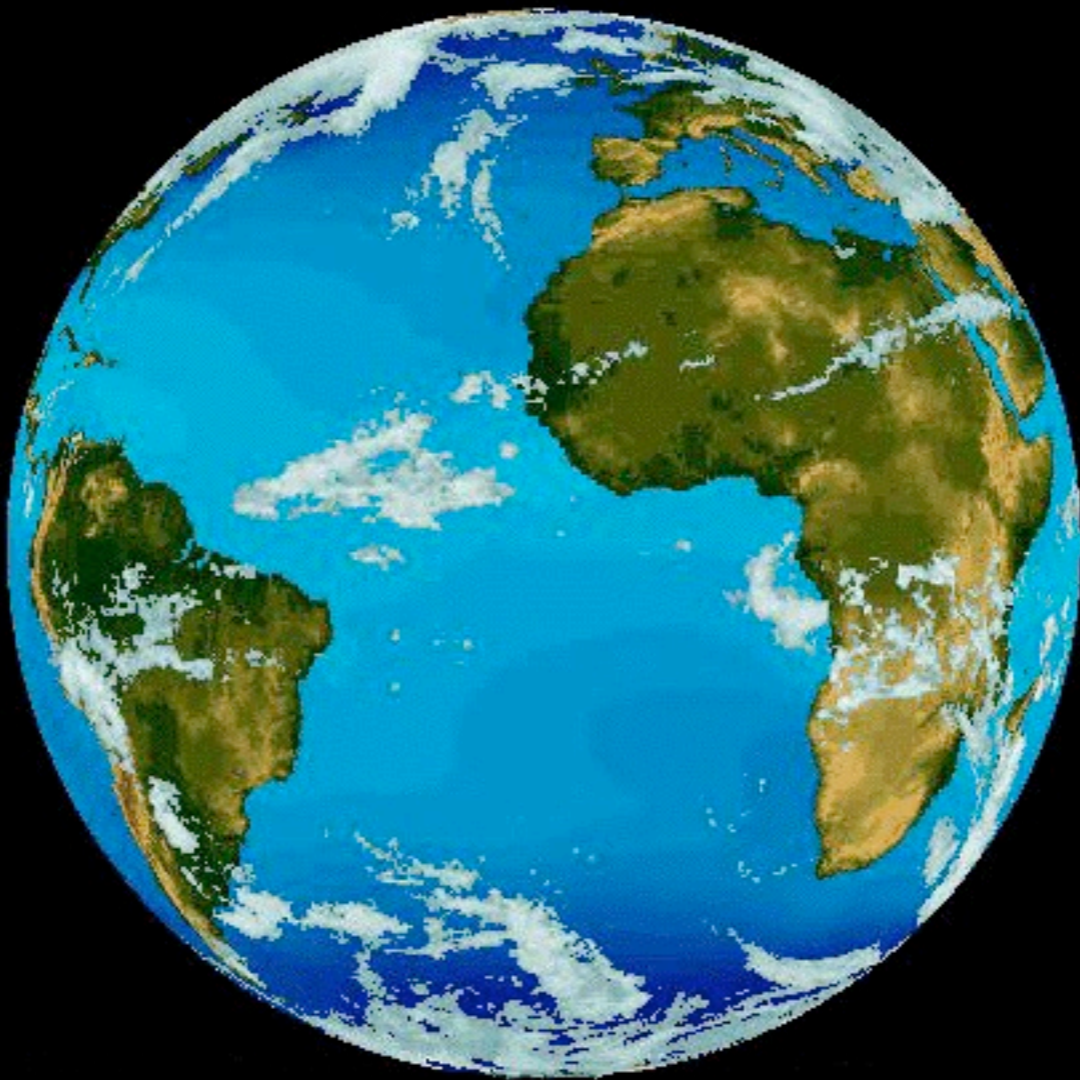
Gravitational Redshift

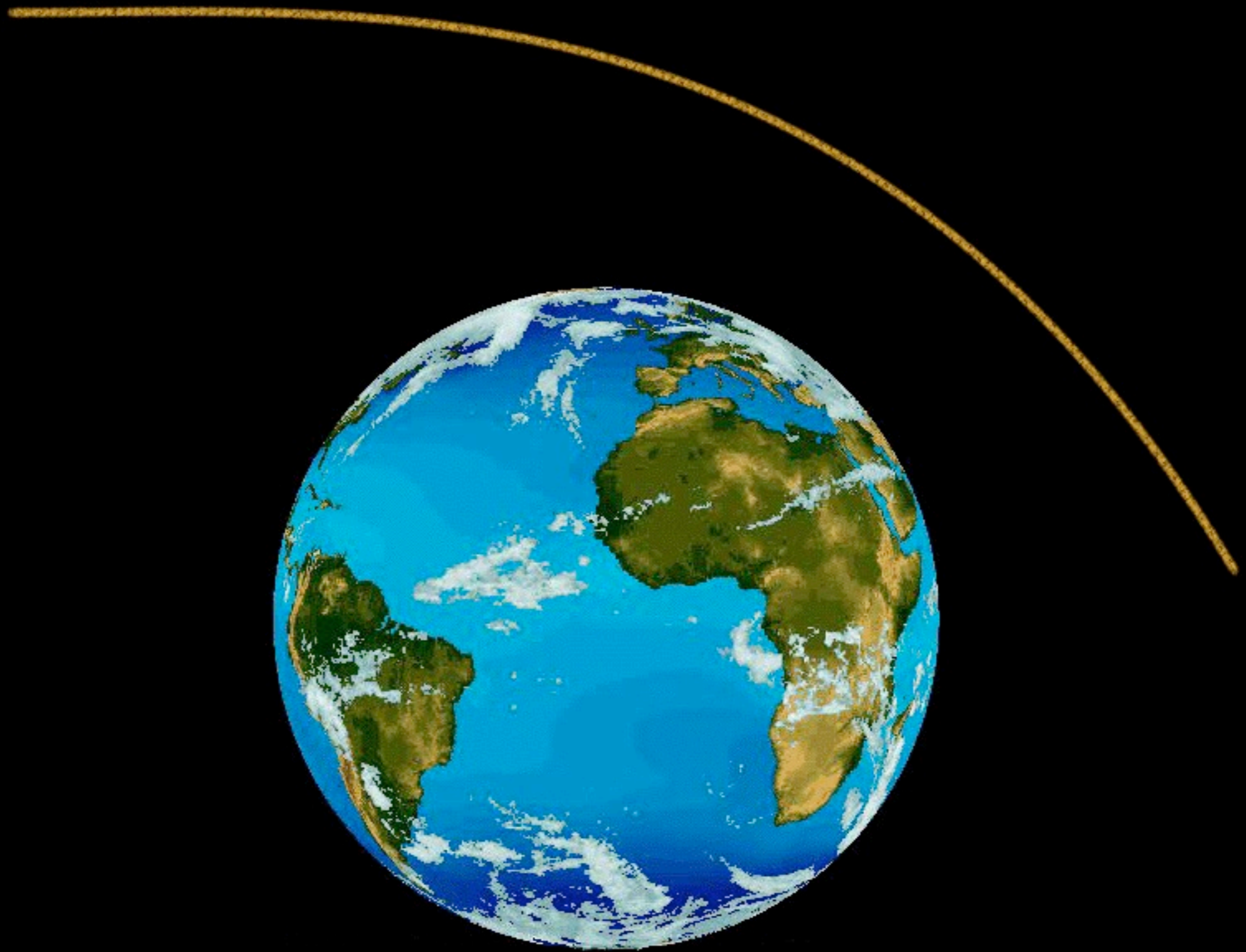
- An external observer sees time running more slowly when looking into a potential well
- Consequences for the CMBR
- Unique time only in a H&I universe

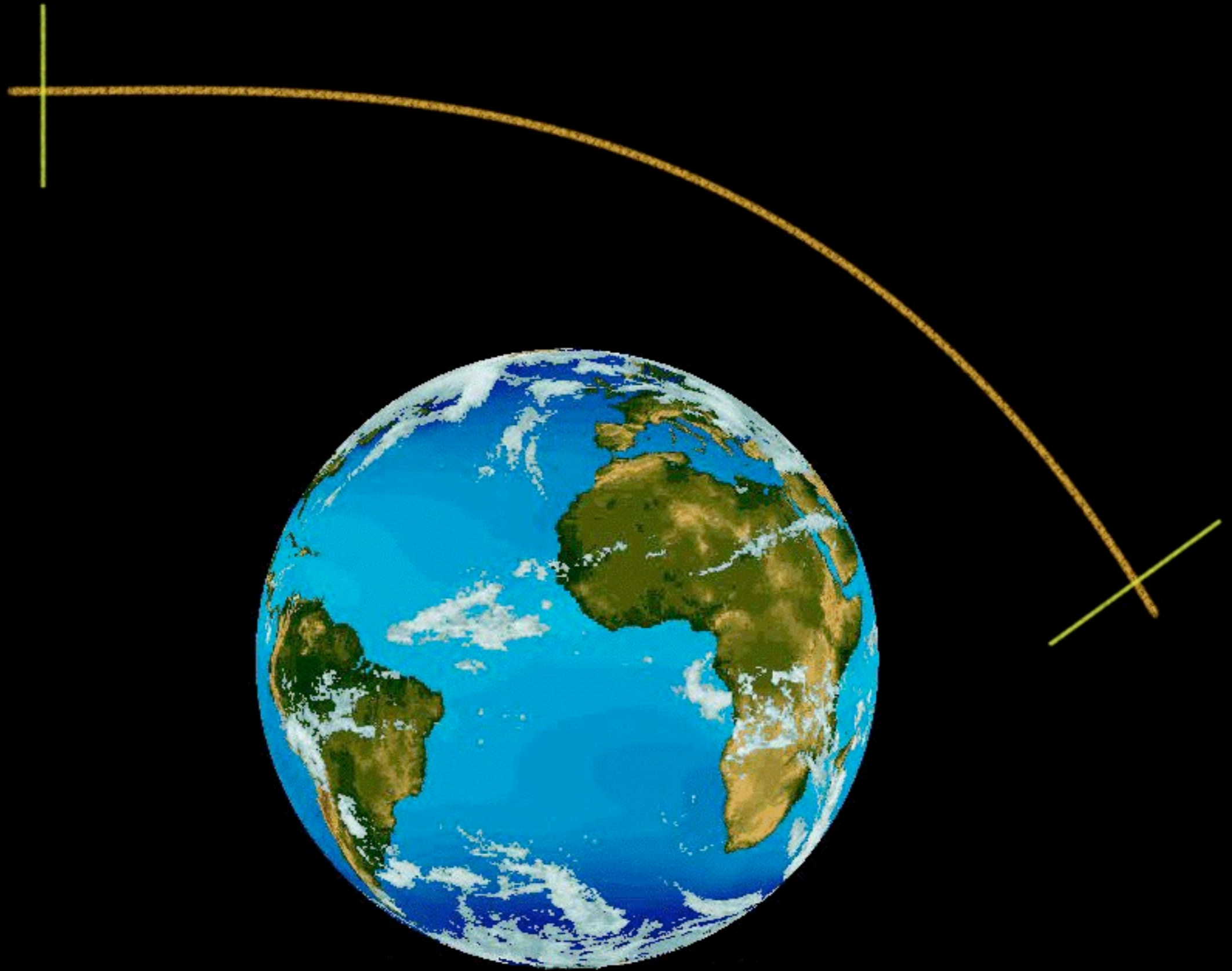


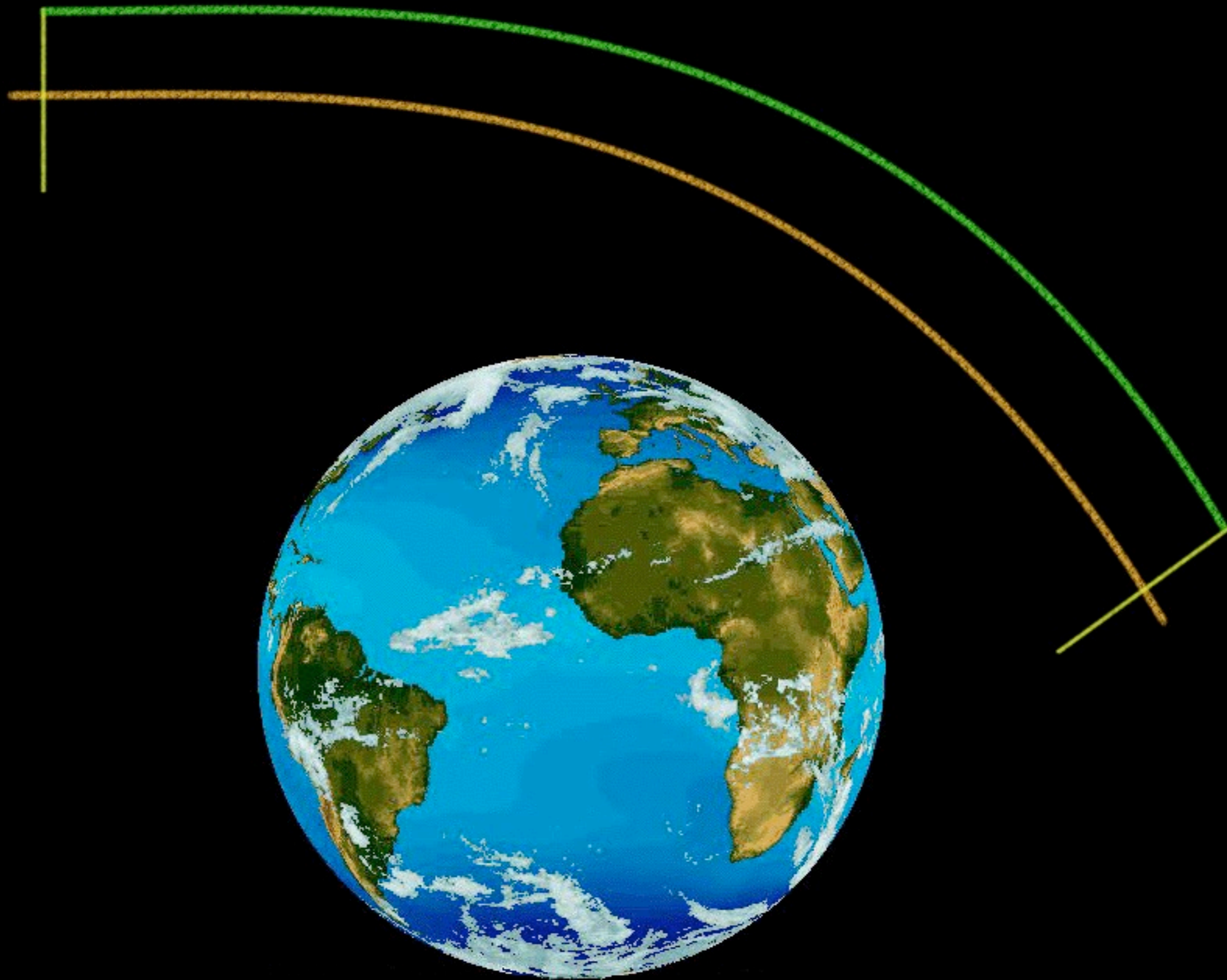


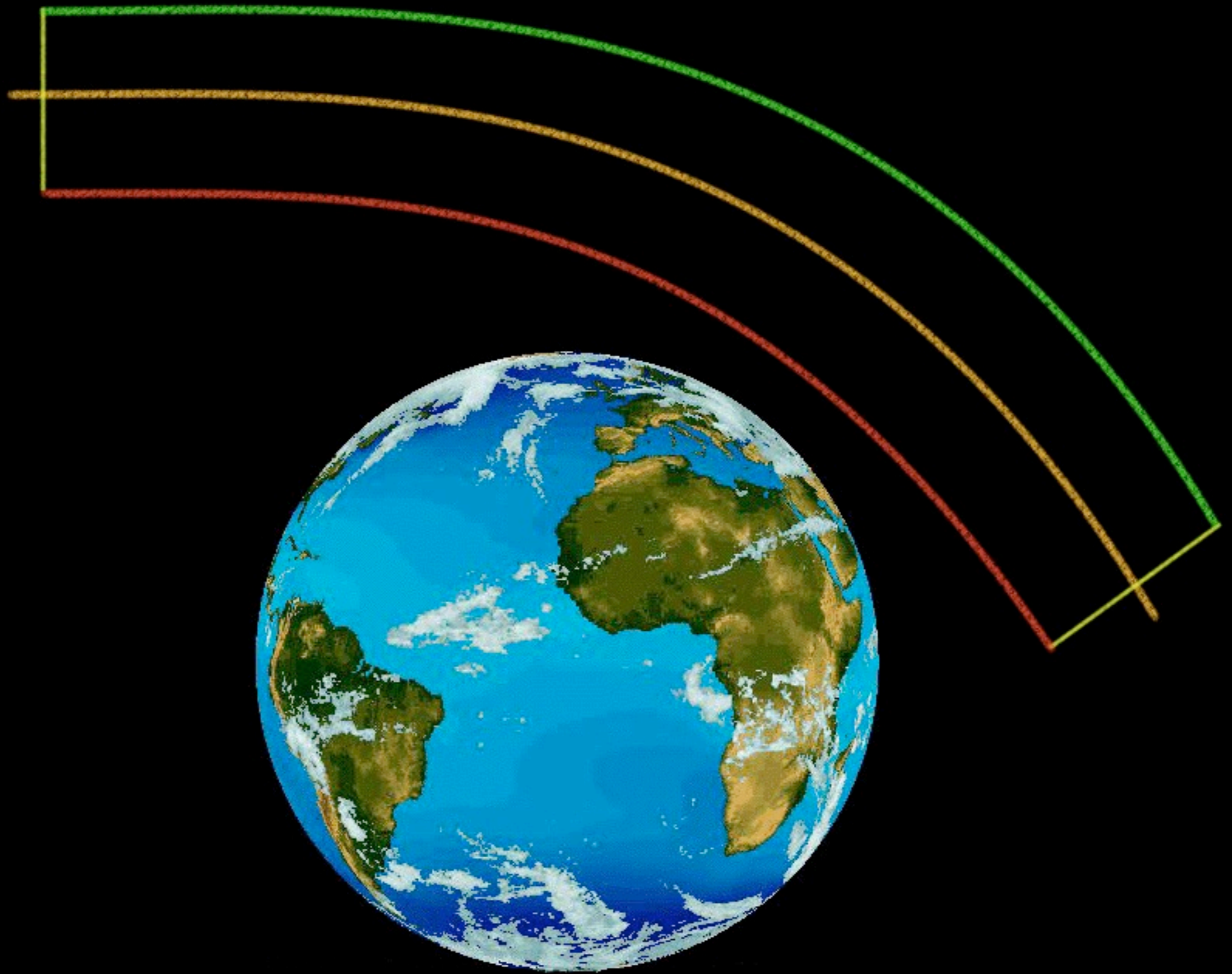


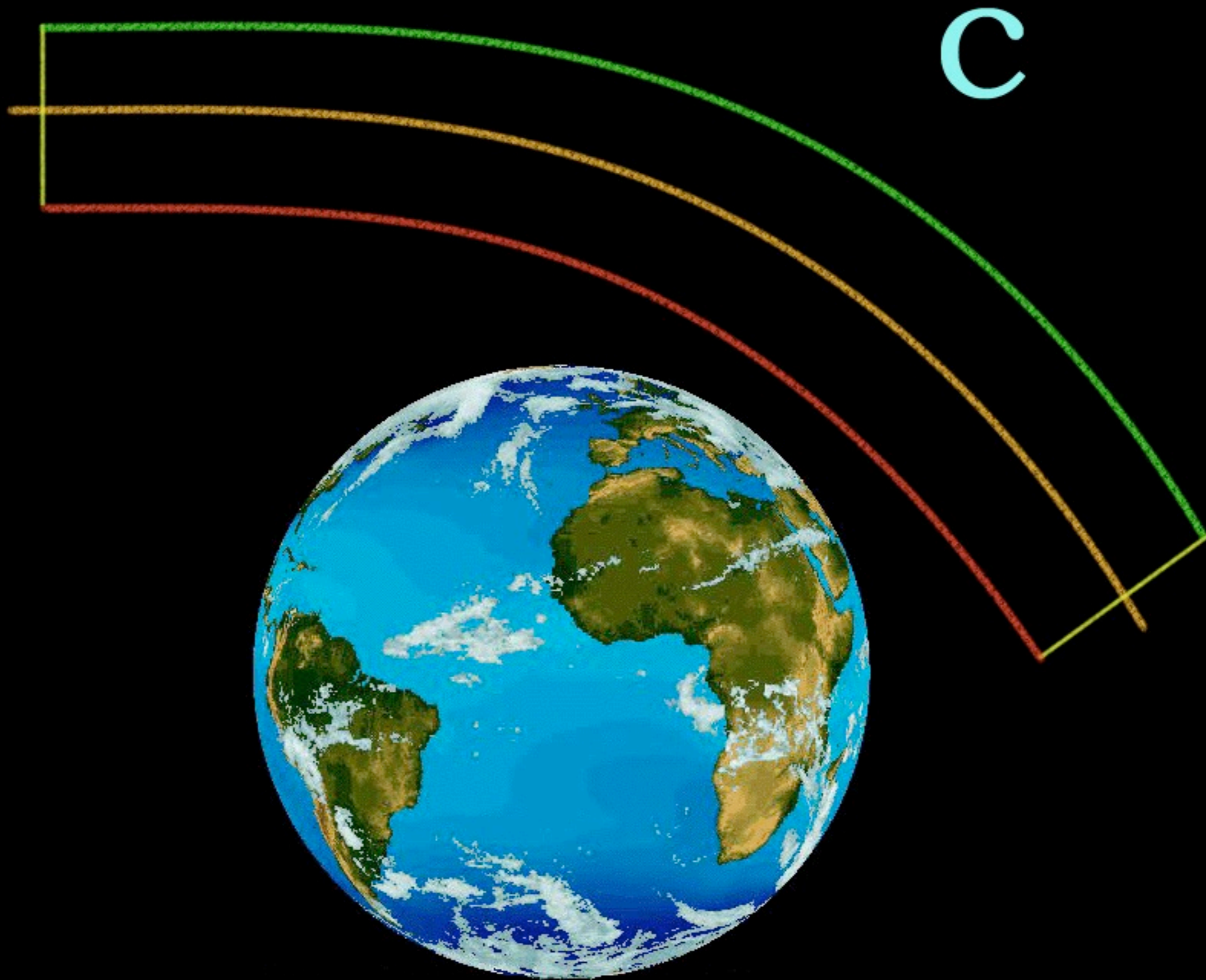












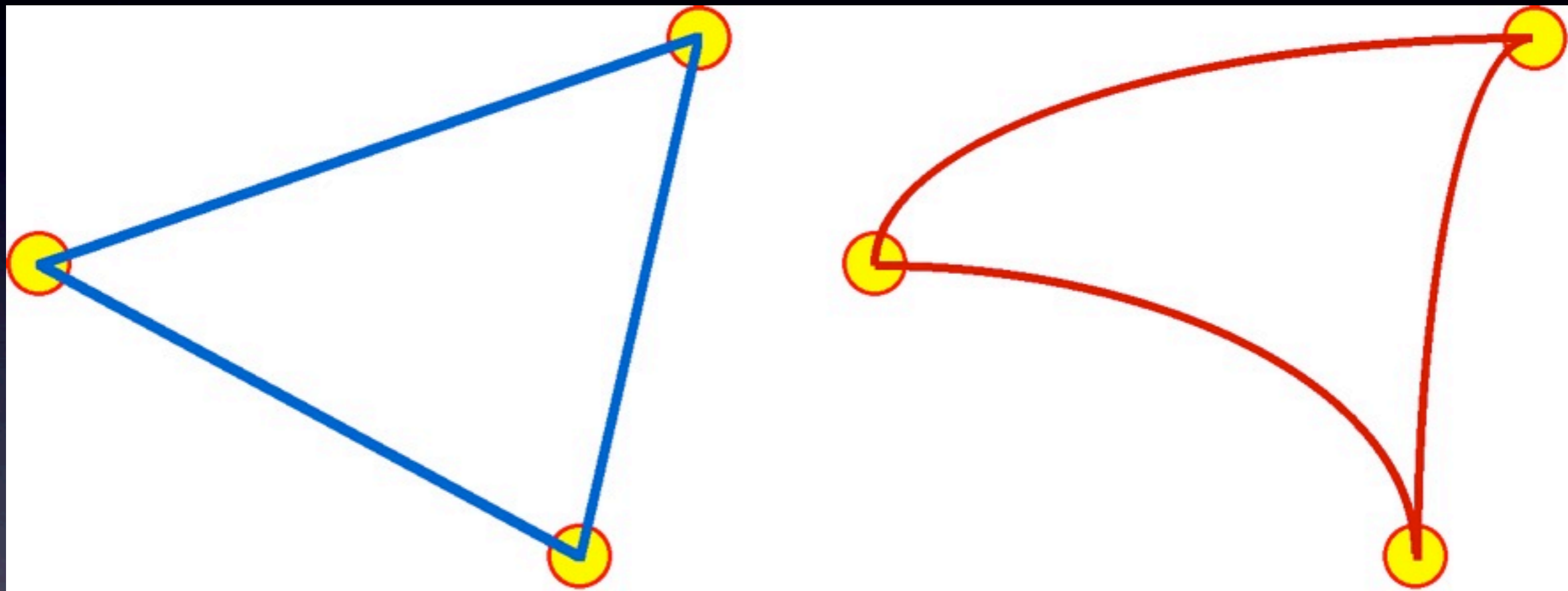
C

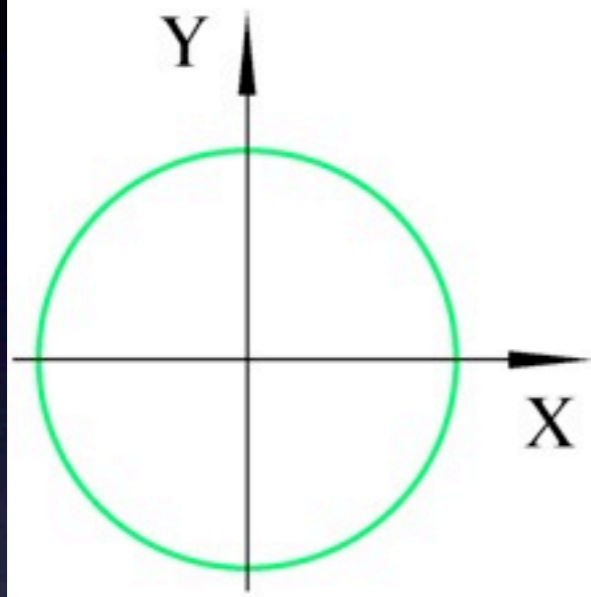
B

A

Towards the Einstein Equation

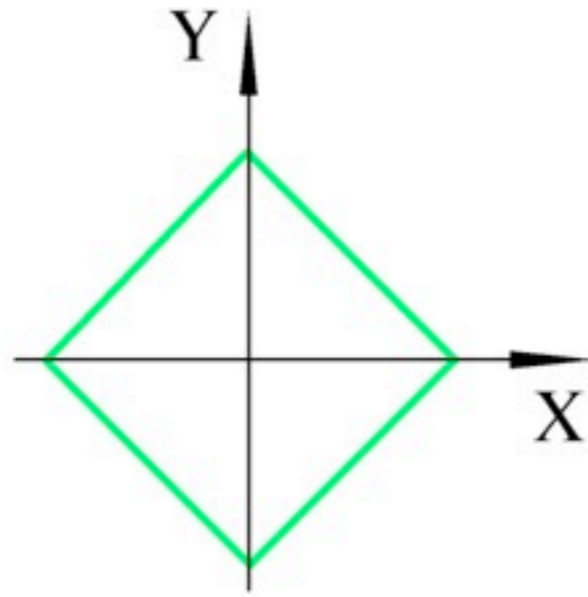
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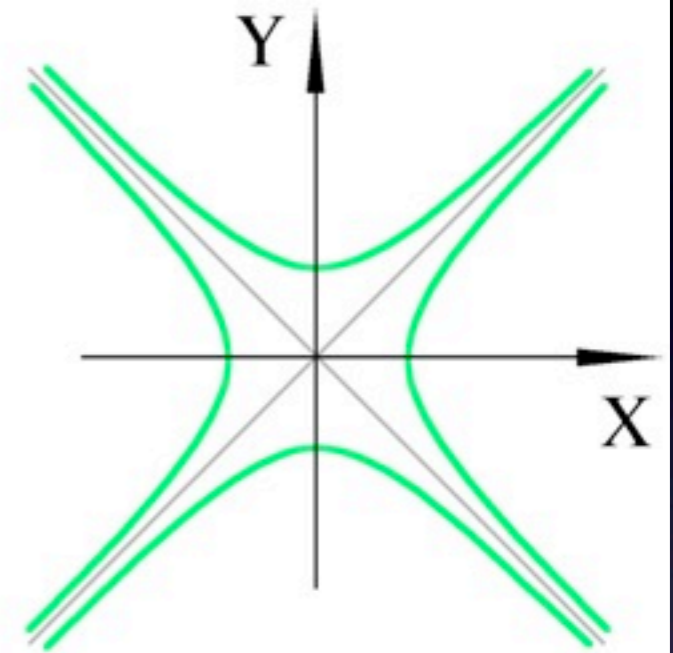
$$S^2 = X^2 + Y^2$$

Pythagoras



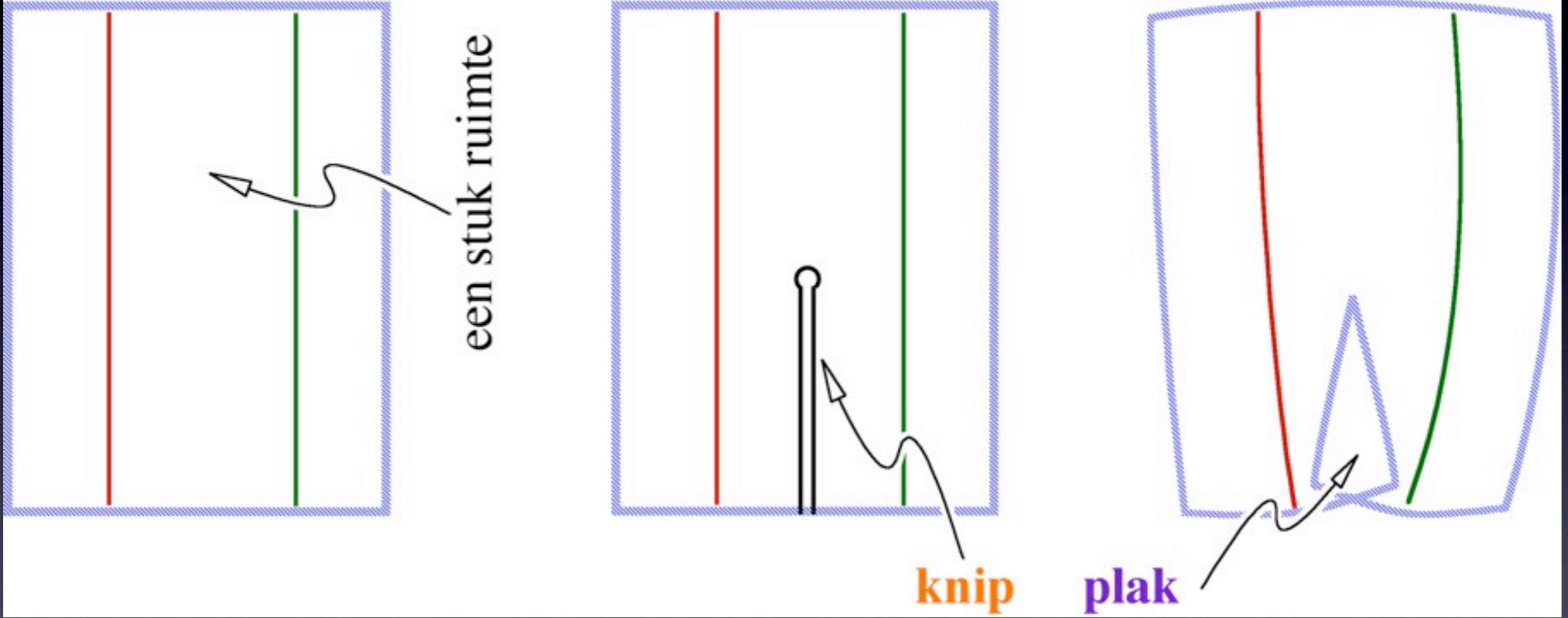
$$S = |X| + |Y|$$

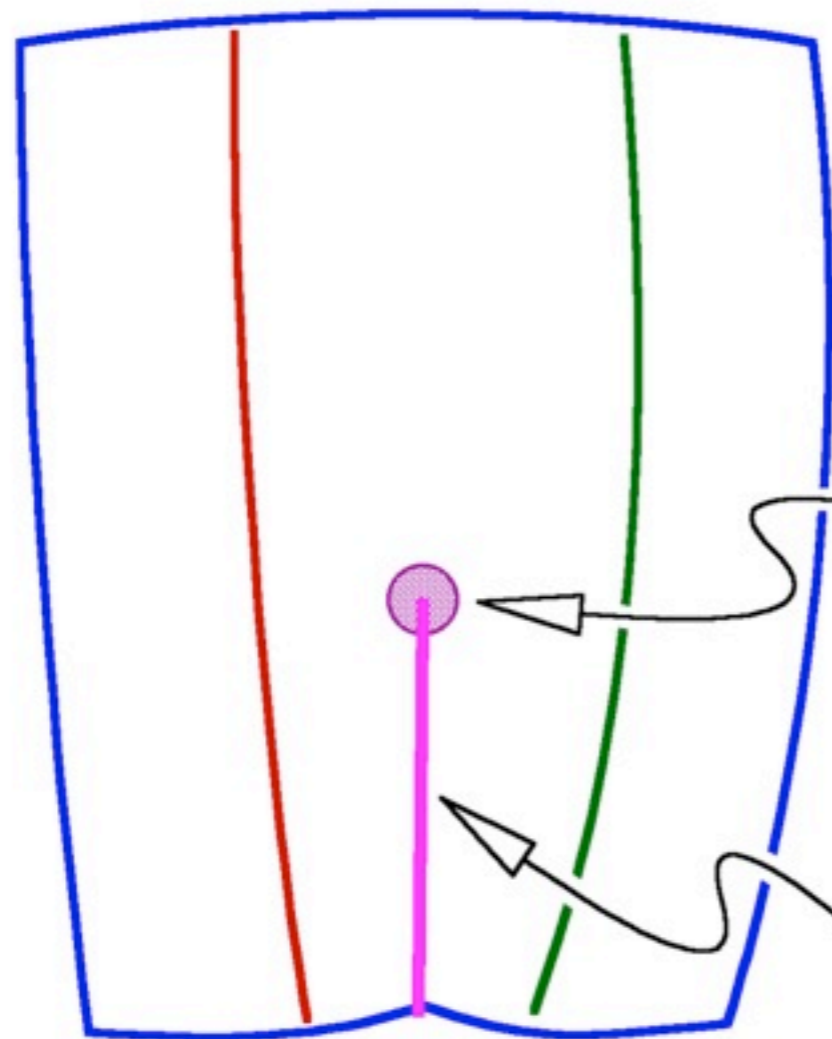
Manhattan



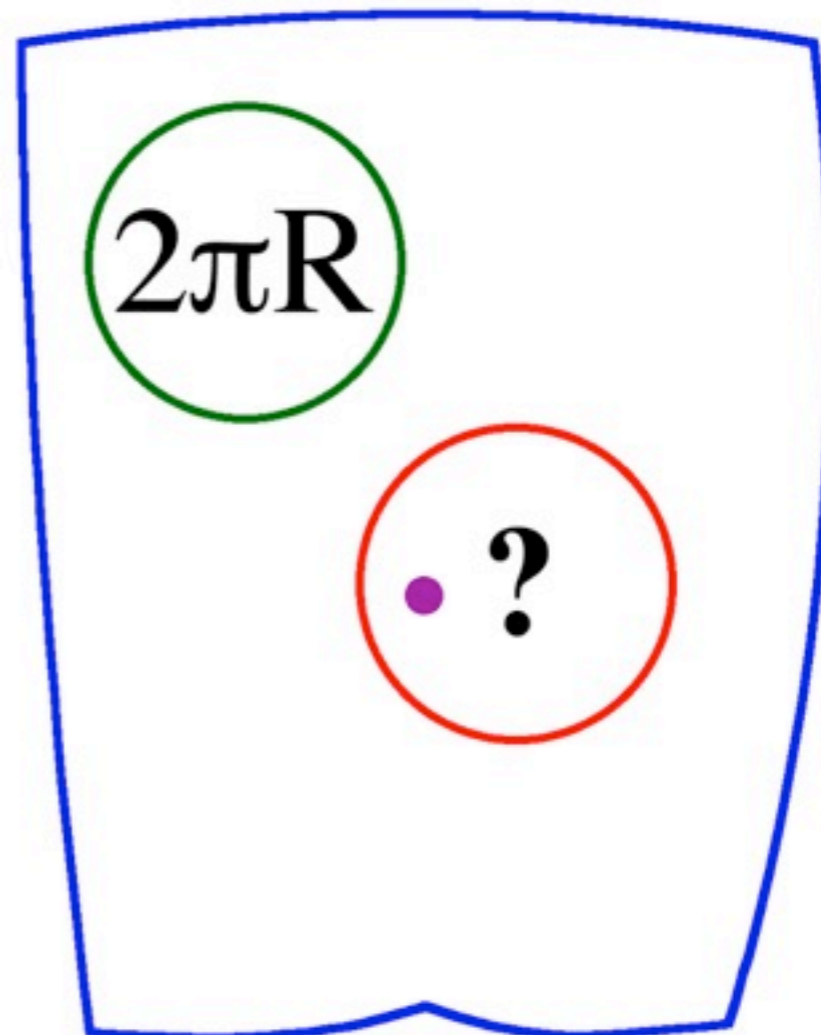
$$S^2 = X^2 - Y^2$$

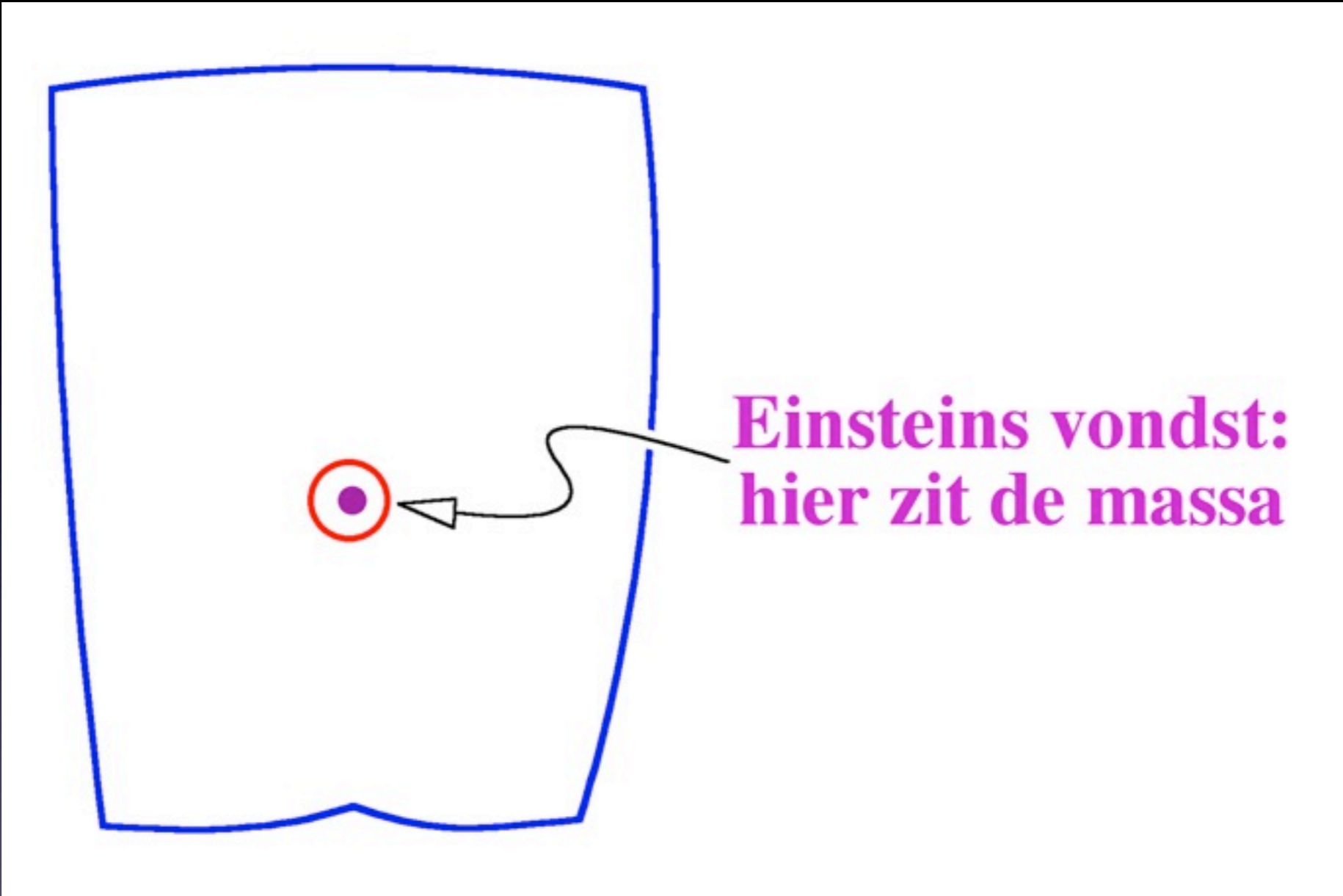
Minkowski



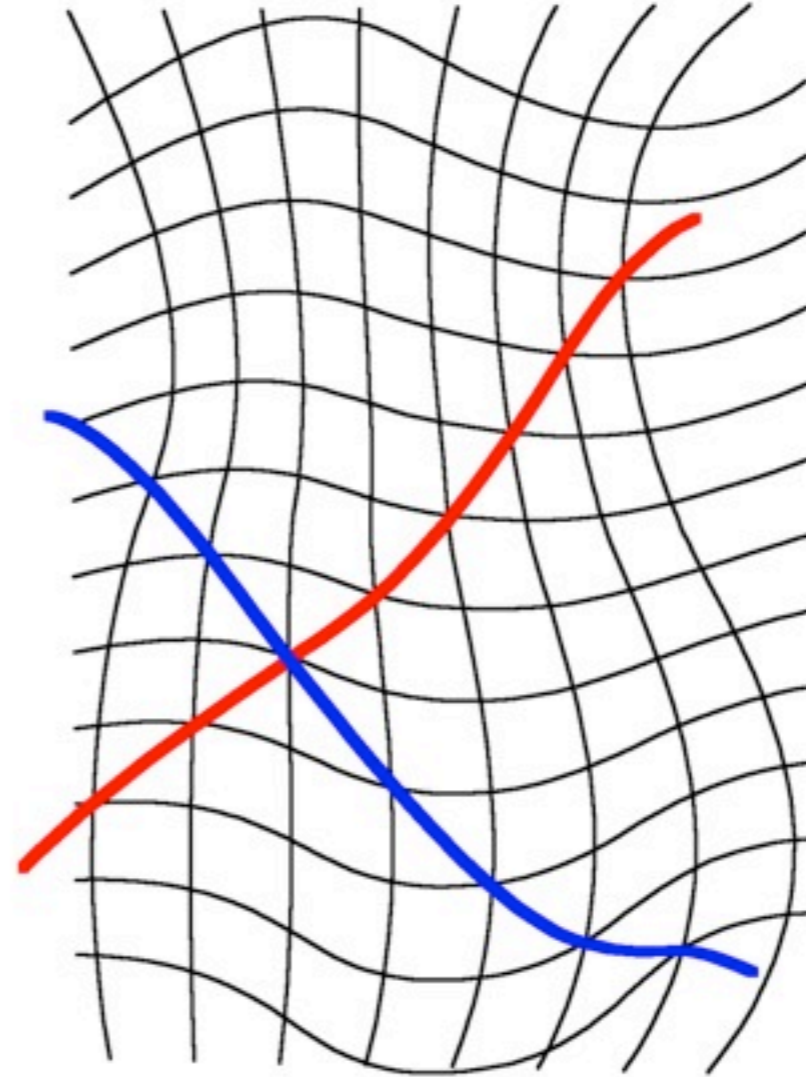
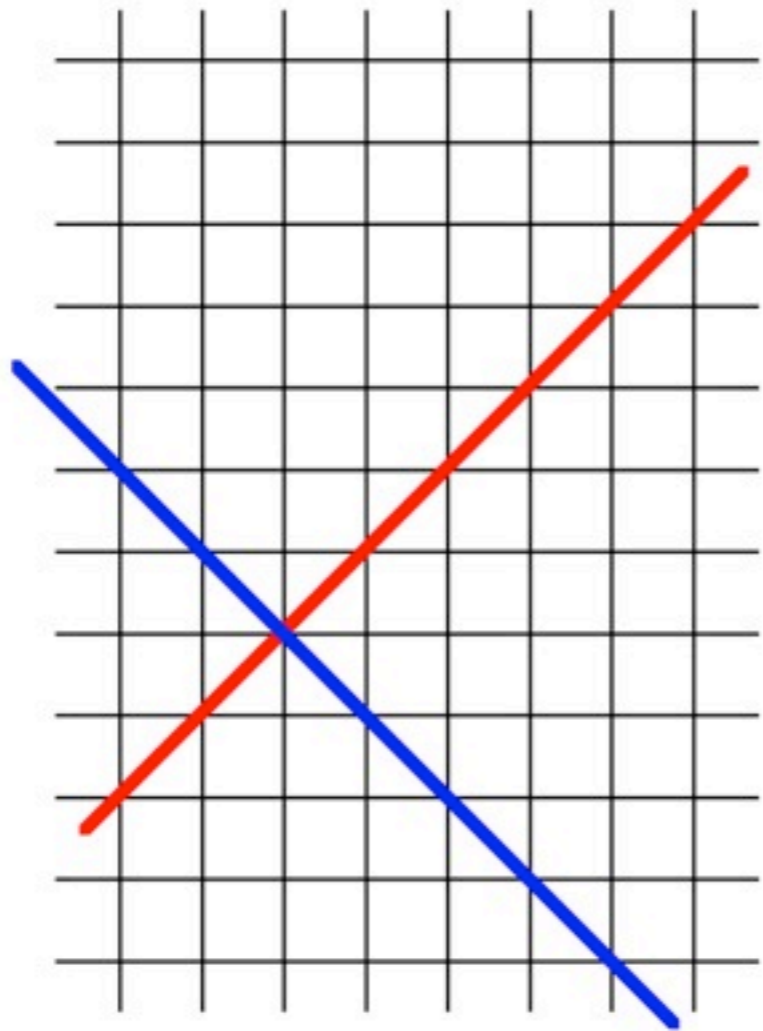


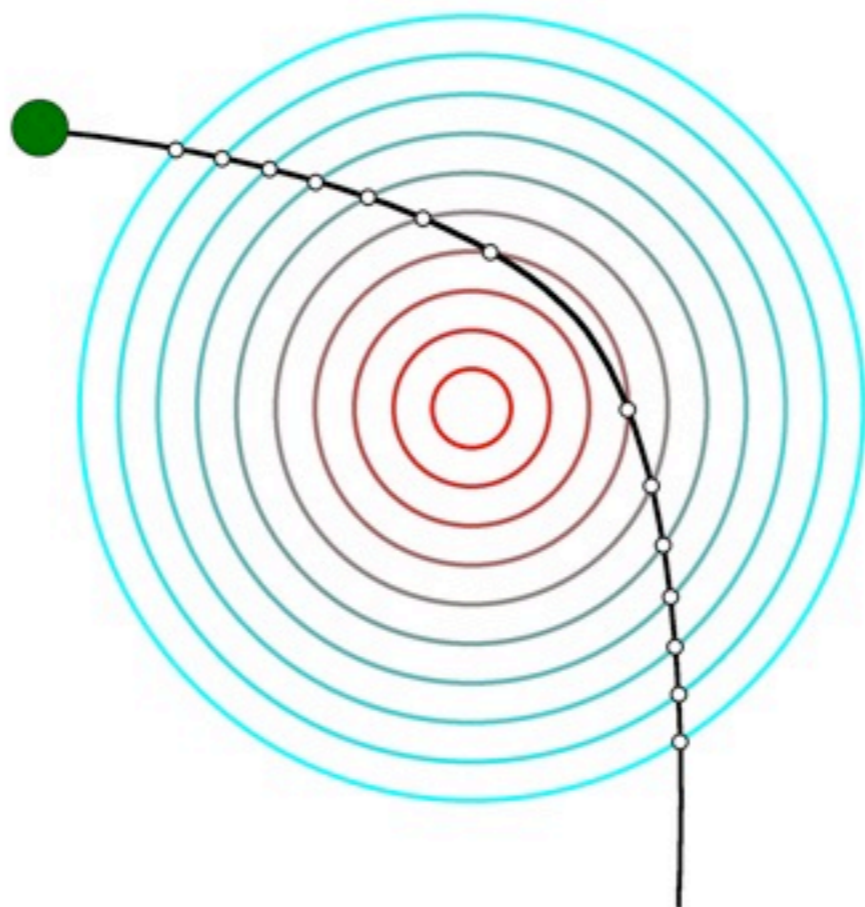
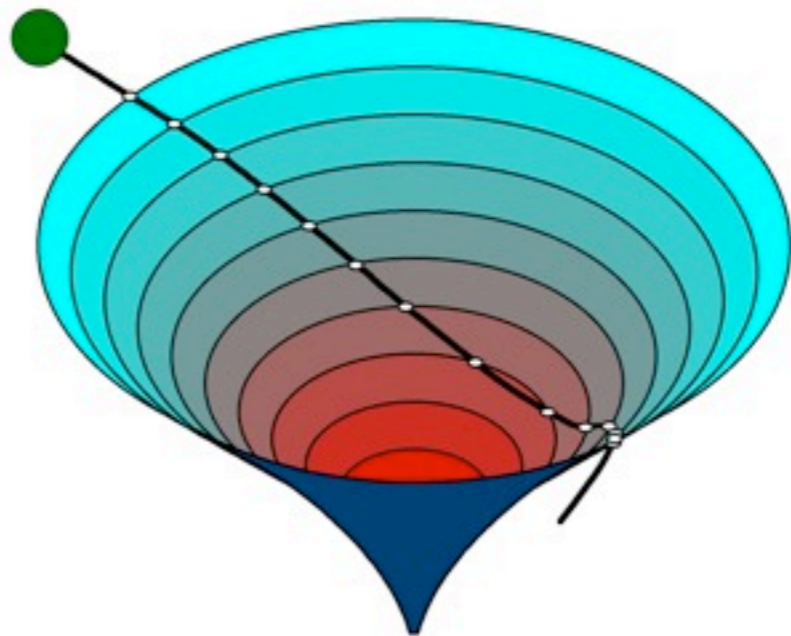
knip

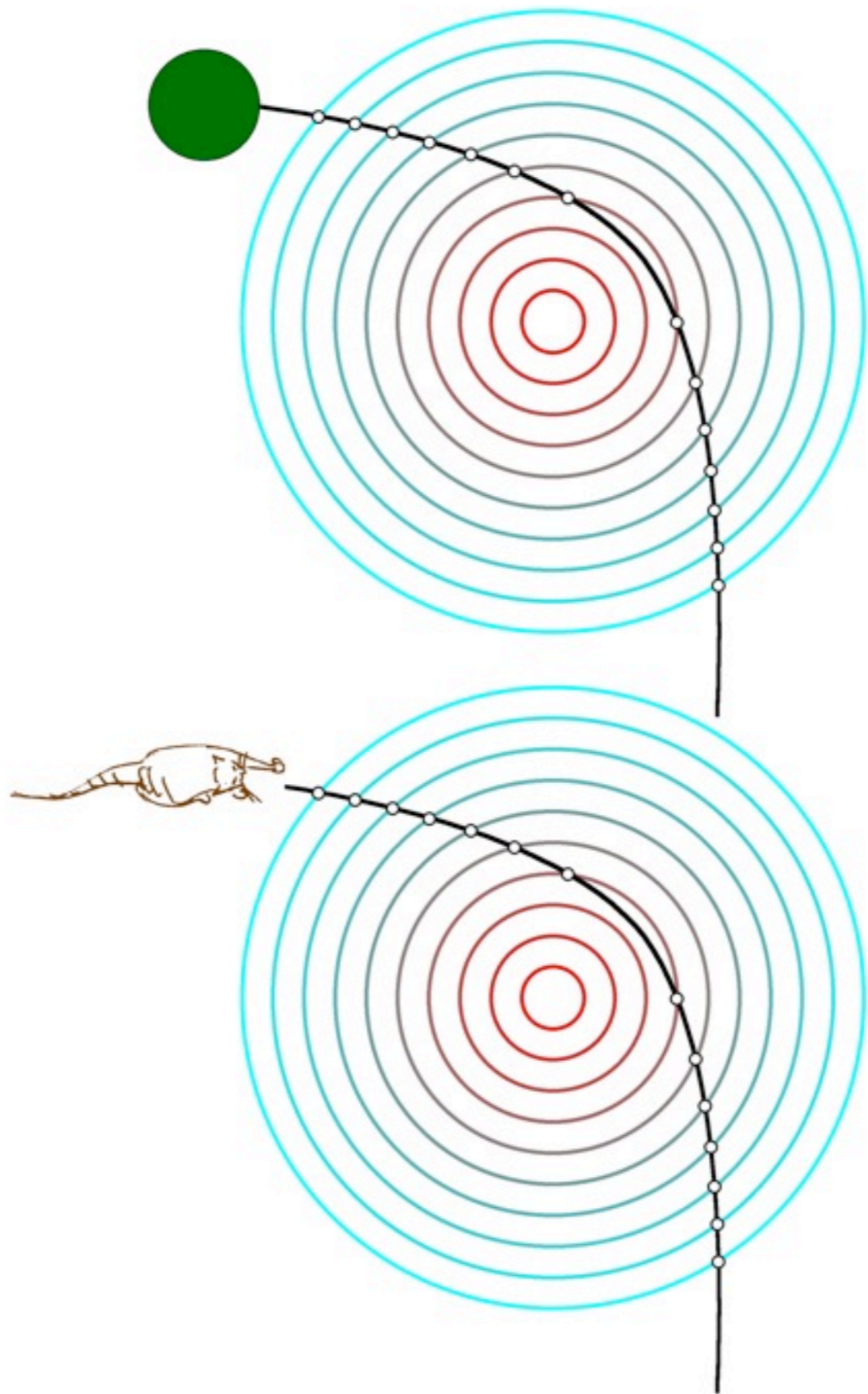


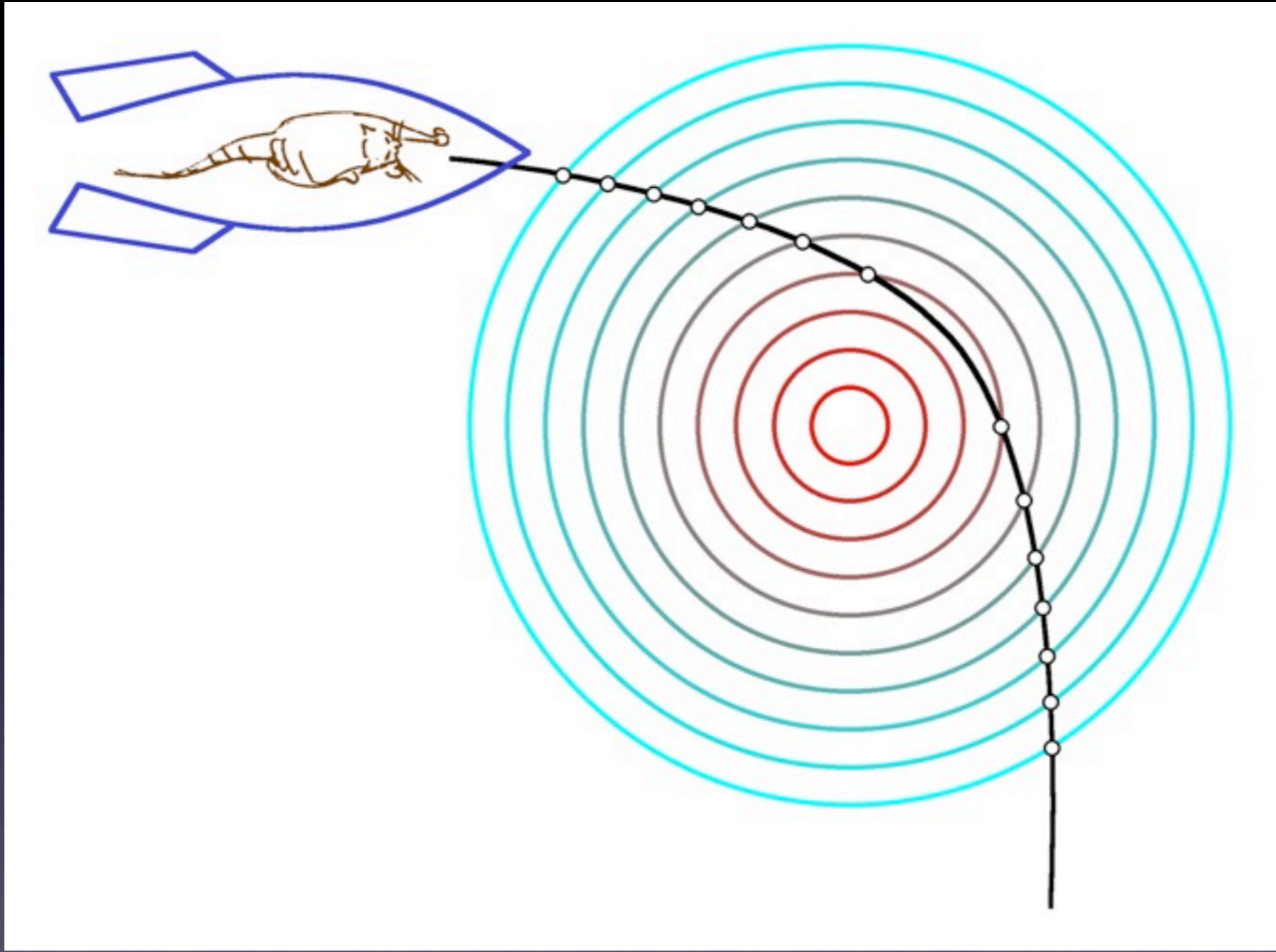


**Einsteins vondst:
hier zit de massa**









Einstein Equation

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} - \Lambda g_{\mu\nu} = 8\pi GT_{\mu\nu}$$

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Friedmann Equations

$$\left(\frac{da}{dt}\right)^2 = \frac{8\pi}{3}G\rho a^2 - kc^2 + \frac{\Lambda}{3}a^2$$

$$\frac{d}{dt}(\rho a^3) + \frac{P}{c^2} \frac{da^3}{dt} = 0$$

Preview of the solutions

- Present epoch
- Ionized plasma
- Relativistic plasma
- Quantum plasma?
- Evolution of mass scales, looking ahead to interpretation of CMBR observations