Cosmological Standard Timer from Unstable Primordial Relic

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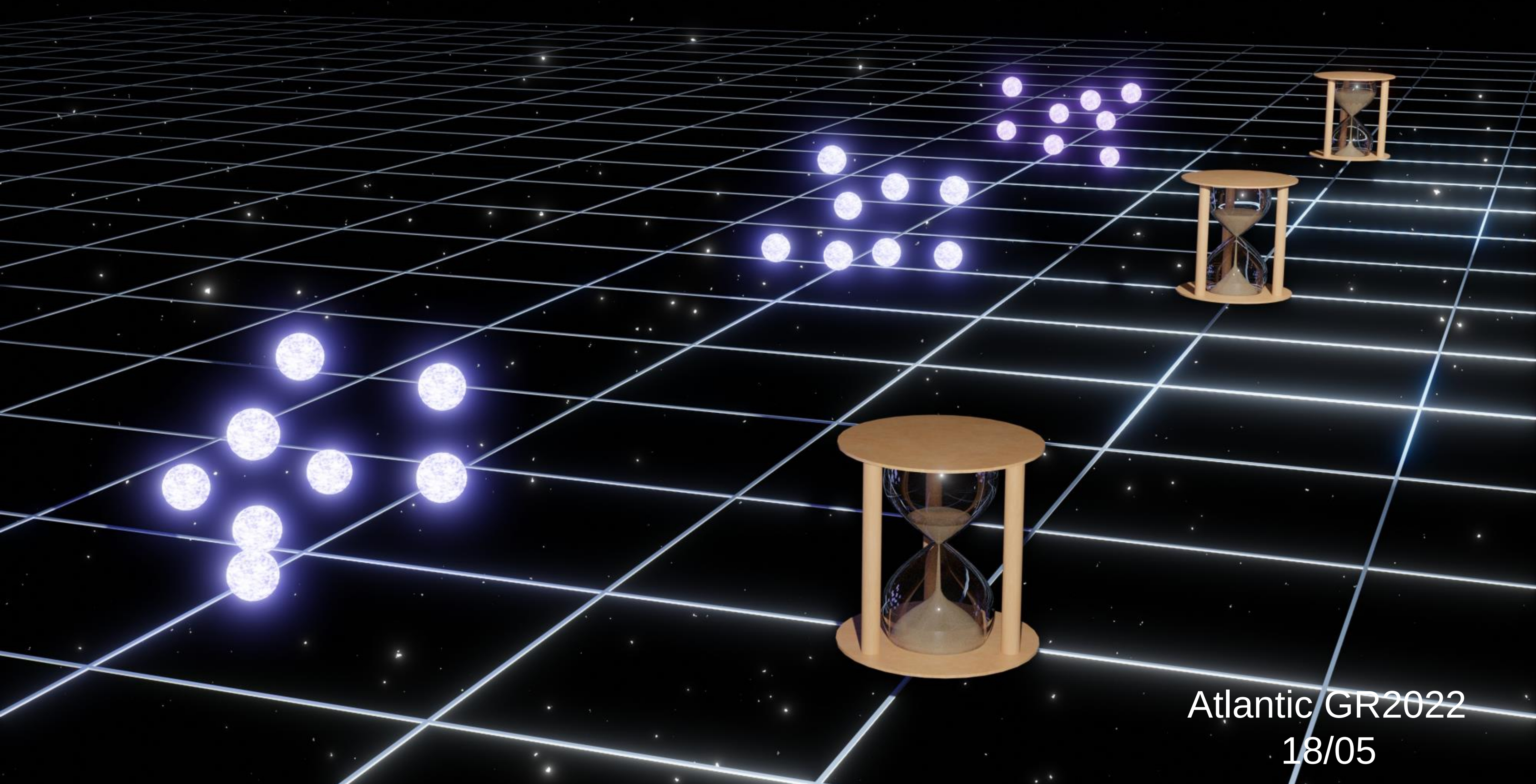

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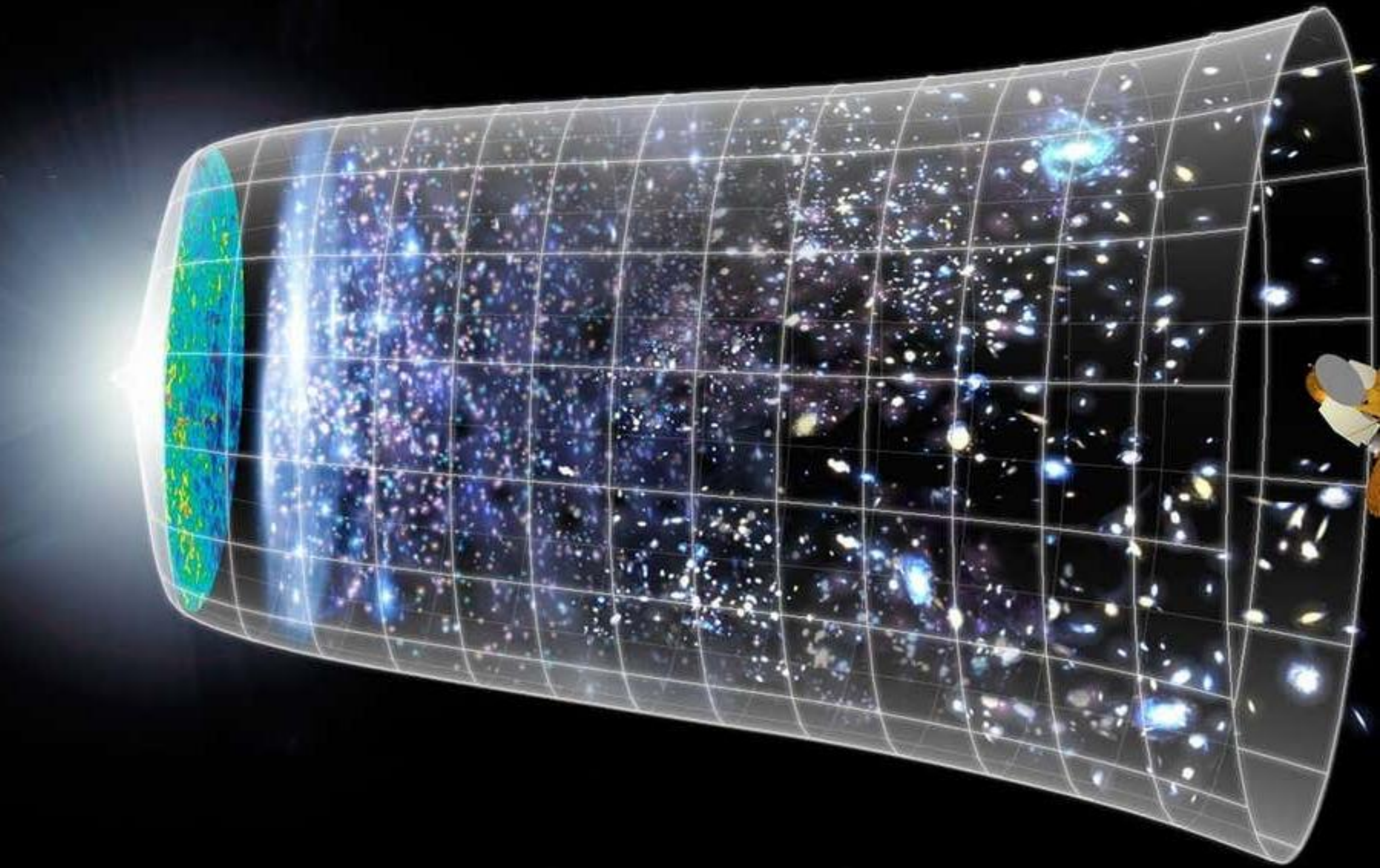


Image Credit: New Scientist

How to measure the Universe?

Image Credit: ESO

Standard Candle

$$F = \frac{L}{4\pi\, d_L^2(z)}$$

Standard Ruler

$$\theta = \frac{r_s}{D_M(z)}$$

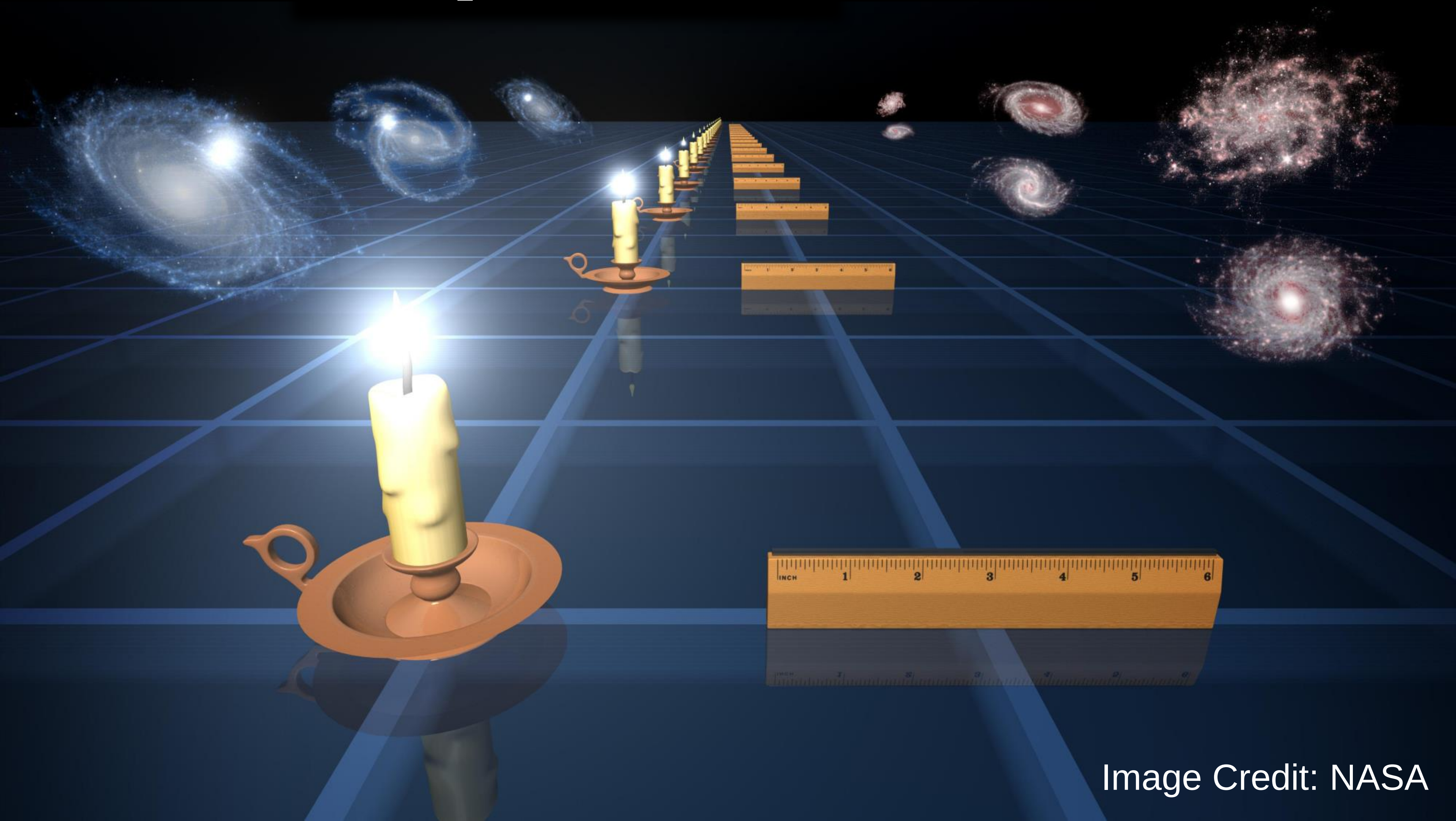
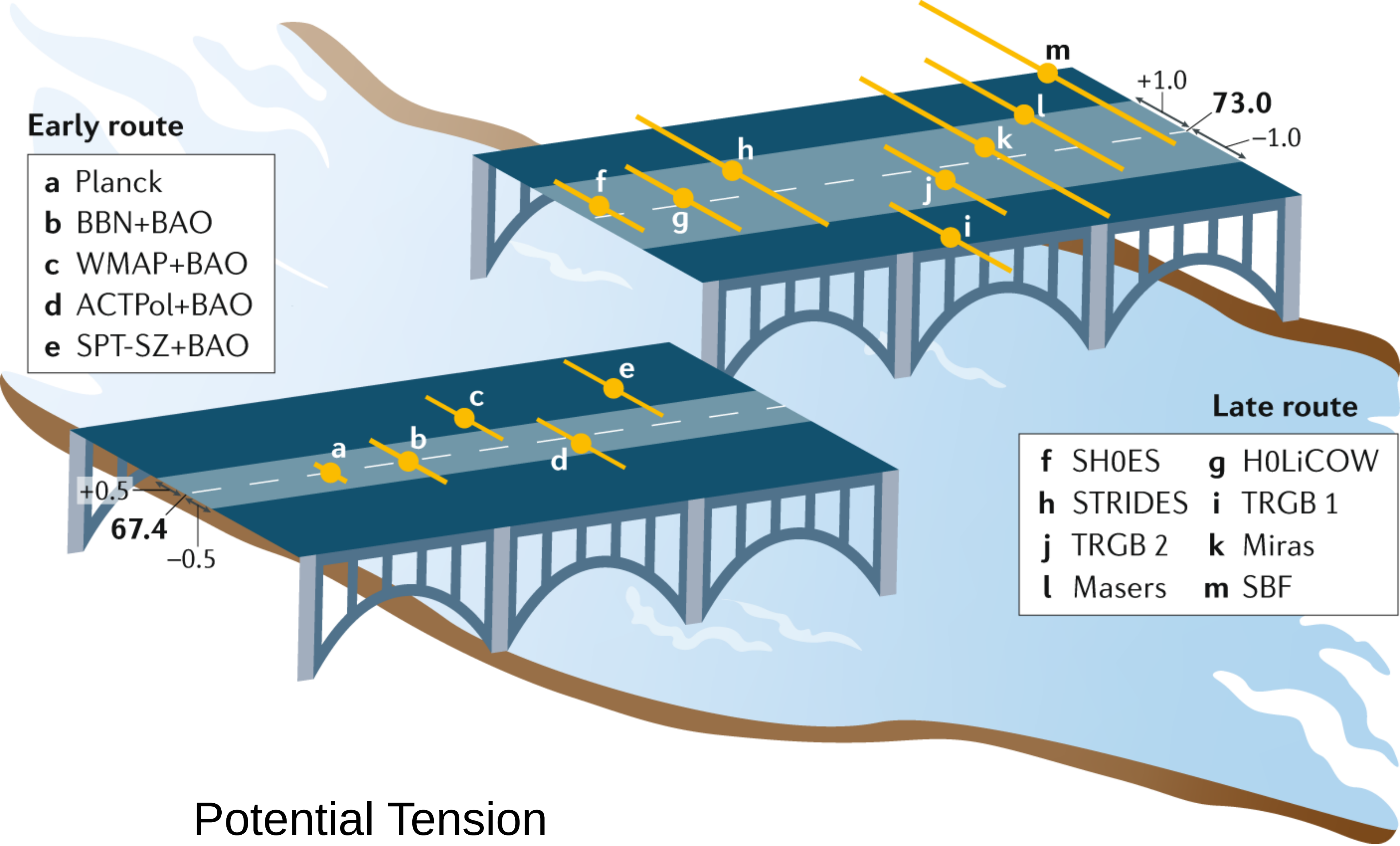


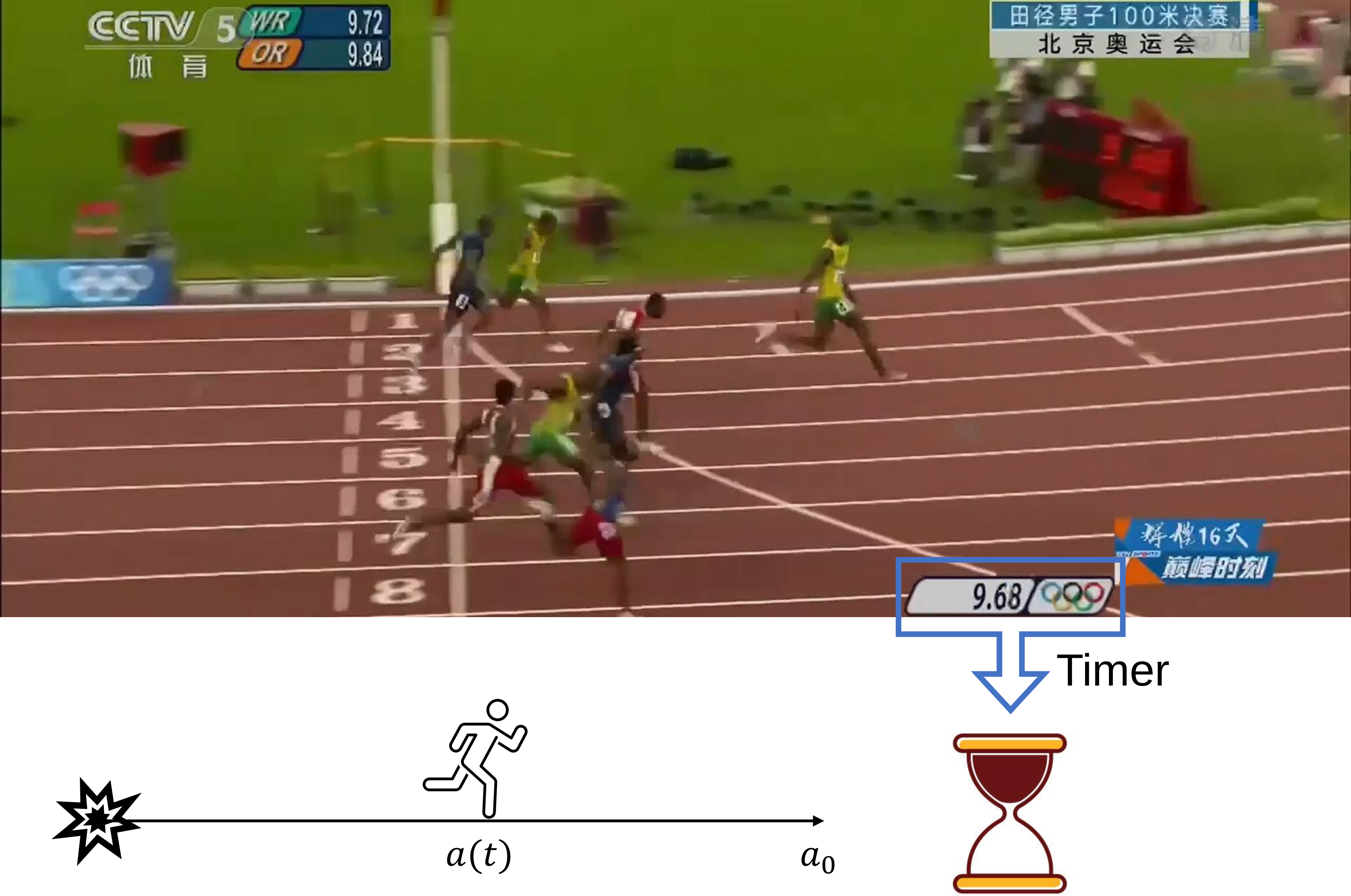
Image Credit: NASA



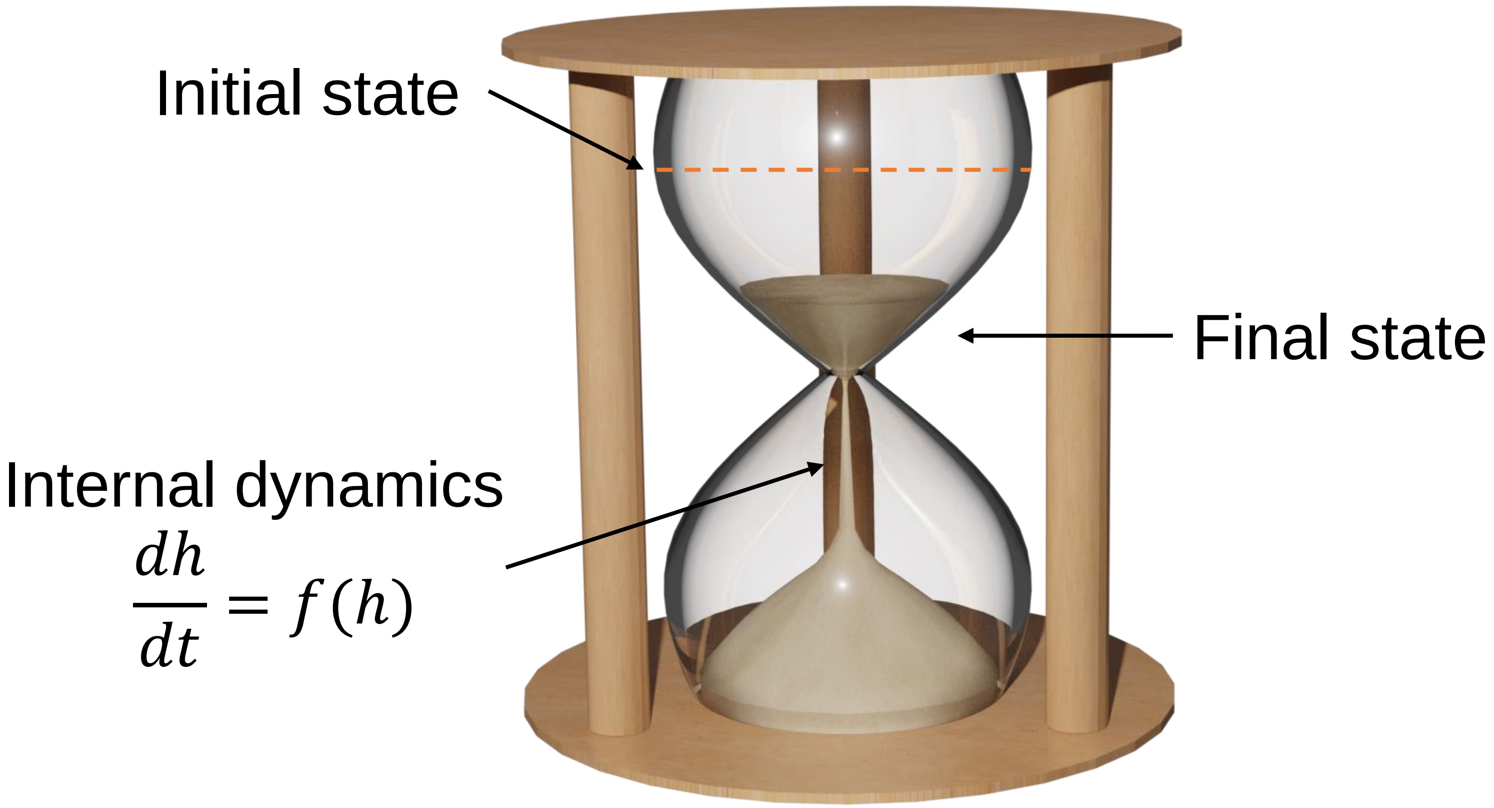
Potential Tension

Riess, Adam G. "The expansion of the universe is faster than expected." *Nature Reviews Physics* 2.1 (2020): 10-12.

Another way to measure the Universe?


CCTV 5
体育
WR 9.72
OR 9.84
田径男子100米决赛
北京奥运会
巅峰时刻
9.68
Timer
$a(t)$
a_0

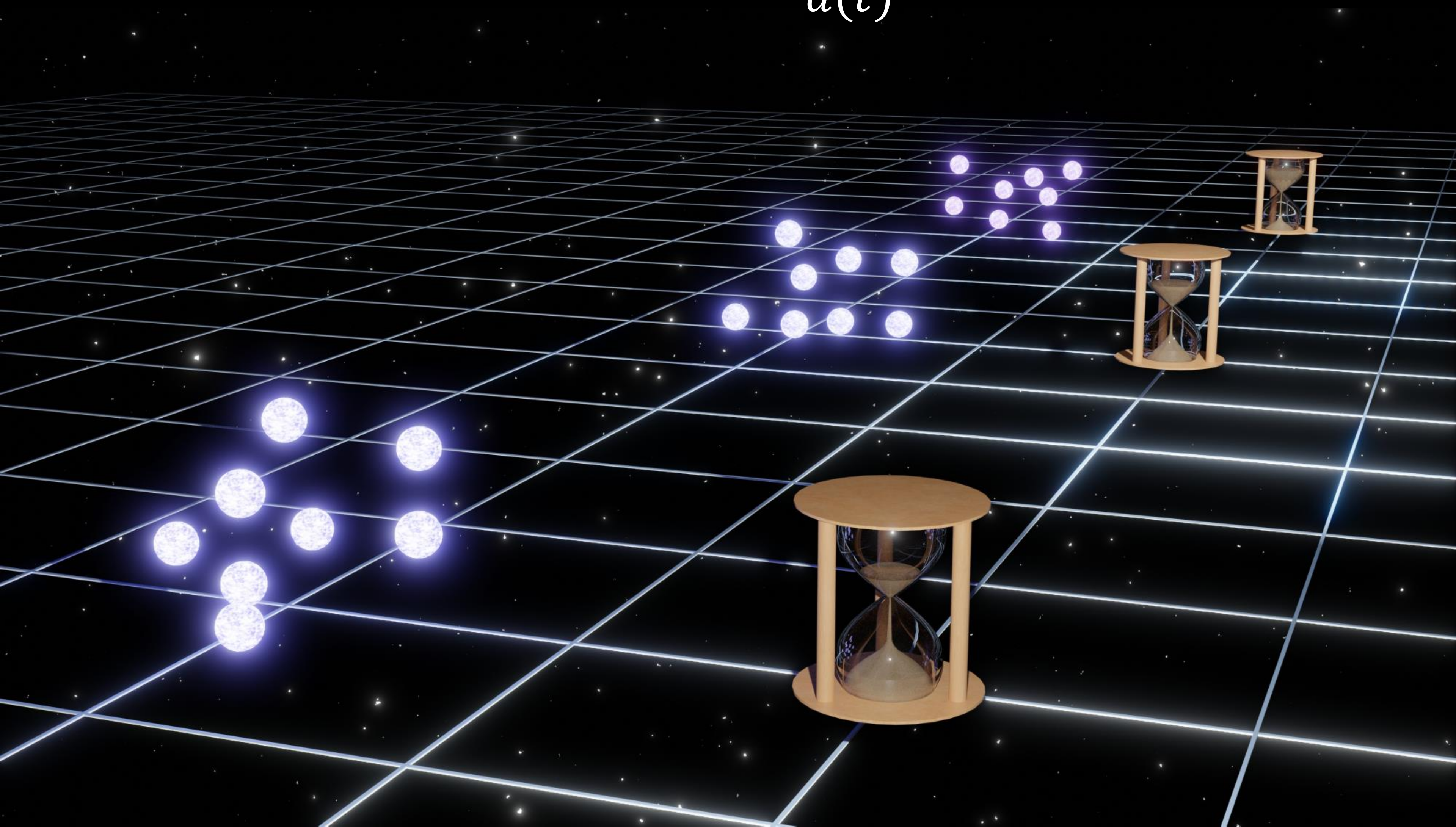
How to know the elapsed time in the timer?



Initial state
Final state
Internal dynamics
$\frac{dh}{dt} = f(h)$

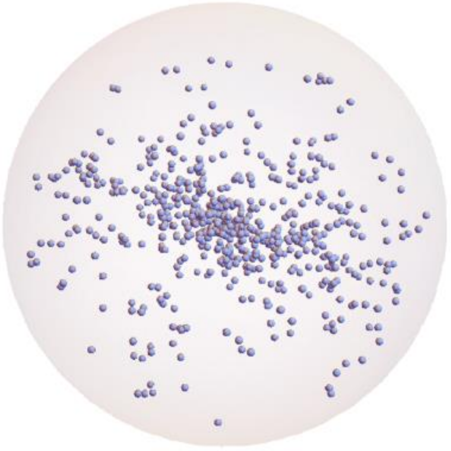
How to obtain $a(t)$?

$$1 + z(t) = \frac{a_0}{a(t)}$$



Properties for the potential timer candidates

- A standard initial state as the standard reference
- An accurate evolution mechanism
- Redshift is encoded in the observable



- Primordial mass function
- $\dot{M} = -\hbar c^4/15360\pi G^2 M^2$
- Redshift in Hawking radiation

Hawking radiation from PBH clustering

How to extract the physical evolution time?

The primordial mass function of PBHs in inflationary scenario

$$n(M) = \frac{f_{PBH}}{\sqrt{2\pi}\sigma M} \exp\left[-\frac{\ln^2(M/M_{pk})}{2\sigma^2}\right]$$

The evolution of the PBH mass function

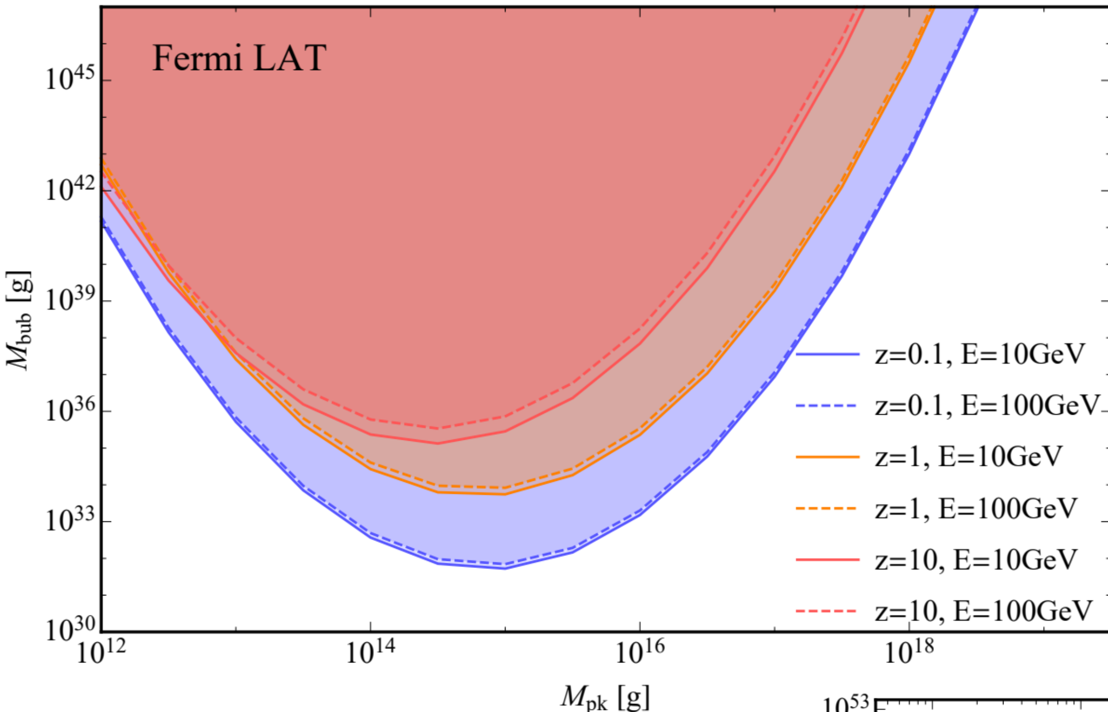
$$n(M;t) = \frac{dN}{dM} = \frac{dN}{dM_i}\frac{dM_i}{dM} = n(M;t_i)\frac{dM_i}{dM}$$

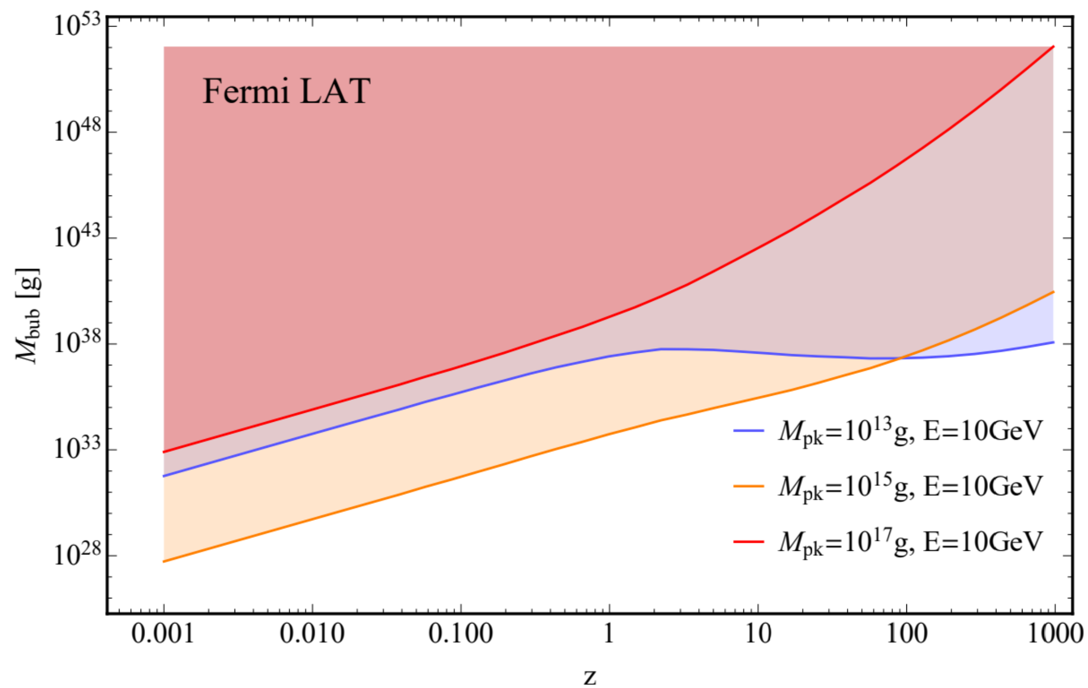
$$\frac{dM}{dt} = -\frac{\alpha}{M^2} \Longrightarrow M^3 = M_i^3 - \delta^3(\Delta t)$$

$$n(M;t) = n(M;t_i)\frac{dM_i}{dM} = n(M;t_i)\frac{M^2}{(M^3+\delta^3(\Delta t))^{2/3}}$$

$$n(M;t) \simeq \frac{n(\delta(\Delta t);t_i)}{\delta^2(\Delta t)} M^2, \qquad M \ll \delta(\Delta t)$$

Can we see them?





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How to extract the redshift from the observable?

Primary Hawking radiation from the PBH clustering

$$P(E) = \int_0^\infty H_p(E,M) n(M) dM \,,$$

$$H_p(E,M) = \frac{1}{2\pi} \frac{\Gamma_1(E,M)}{e^{8\pi GME} - 1} \qquad \Gamma_1(E,M) \propto \begin{cases} G^4 M^4 E^4, E < (8\pi GM)^{-1} \\ G^2 M^2 E^2, E > (8\pi GM)^{-1} \end{cases}$$

Redshift in the observed photon flux

$$F(E;z) = \frac{L(E(1+z);z)}{4\pi d_L^2(z)} \simeq \frac{(1+z)^2 E^2 V}{4\pi d_L^2(z)} \int_0^\infty H_p(E(1+z),M) n(M;z) dM$$

$$H_p(E(1+z),M) = H_p(E, M(1+z))$$

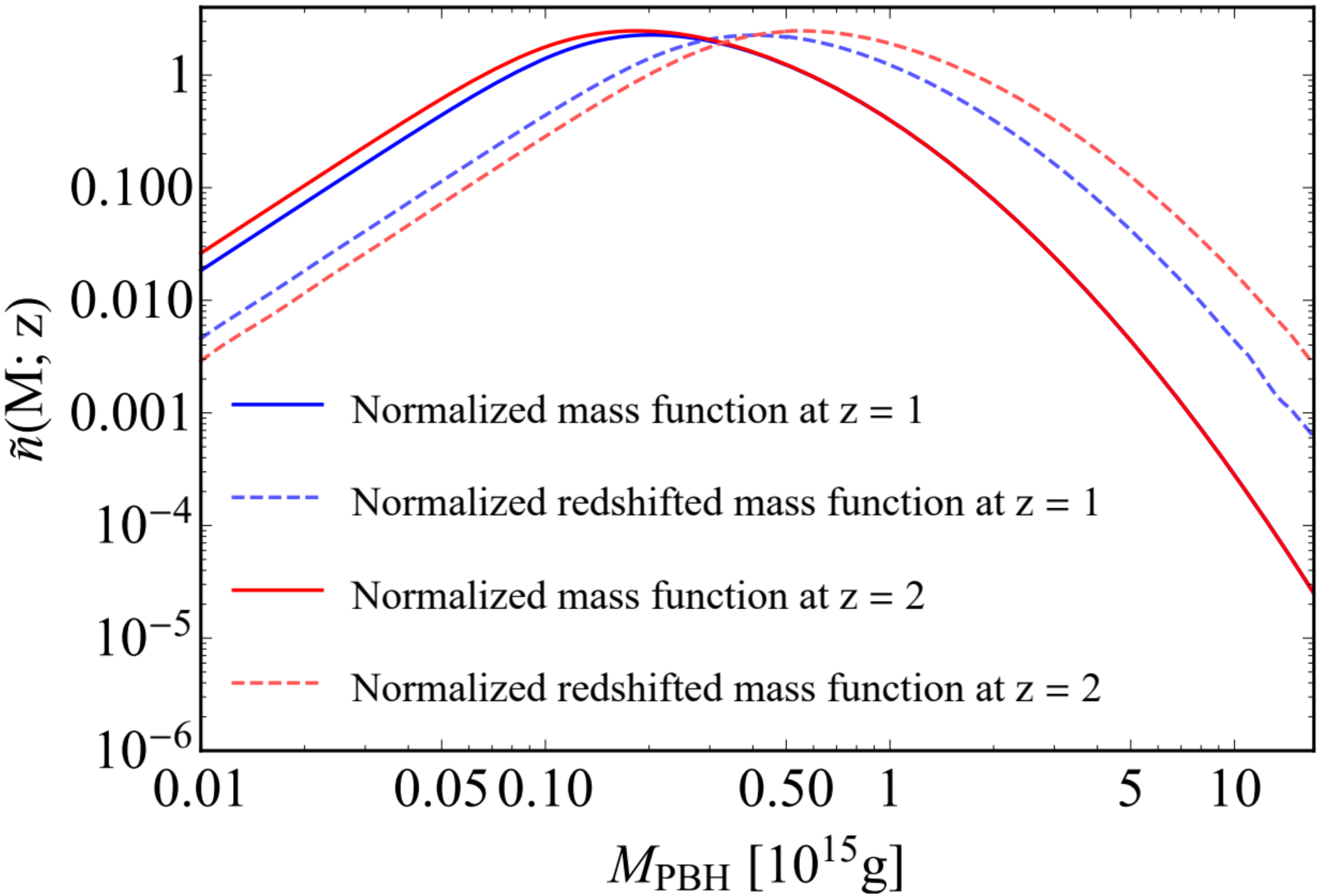
$$\frac{4\pi F(E;z)}{E^2} \simeq \int_0^\infty H_p(E,M') n\left(\frac{M'}{1+z};z\right) \frac{(1+z)V}{d_L^2(z)} dM'$$

Redshift from the inverse problem

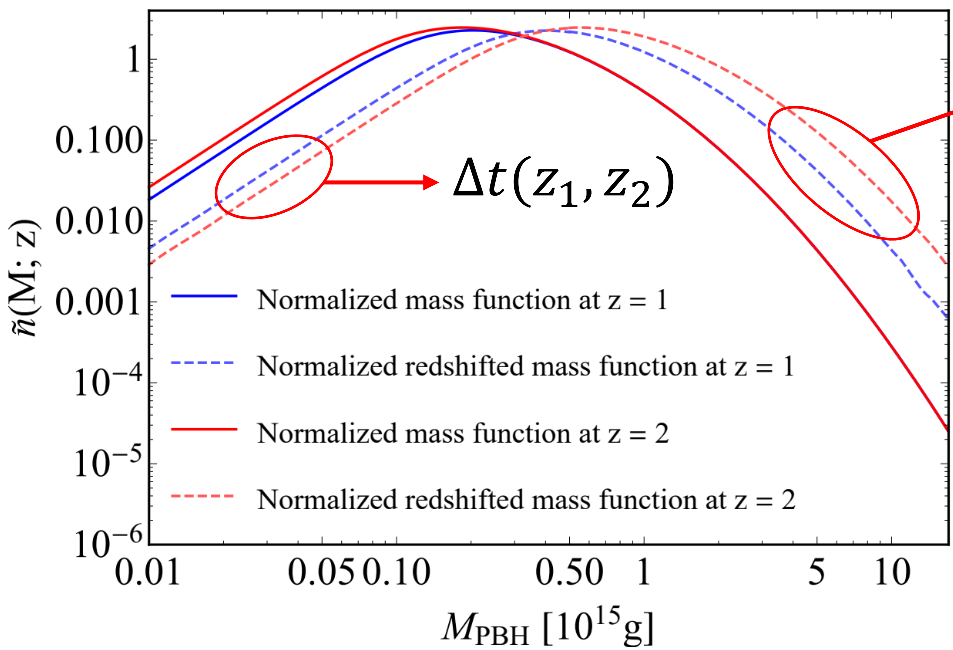
$$P(E) = \int_0^\infty K(E,M) f(M) dM \Longrightarrow f(M) = \int_0^\infty K^{-1}(E,M) P(E) dE$$

$$\frac{4\pi F(E;z)}{E^2} \simeq \int_0^\infty H_p(E,M\ ) n\left(\frac{M}{1+z};z\right)\frac{(1+z)V}{d_L^2(z)} dM$$

$$f(M) = n\left(\frac{M}{1+z};z\right)\frac{(1+z)V}{d_L^2(z)}$$



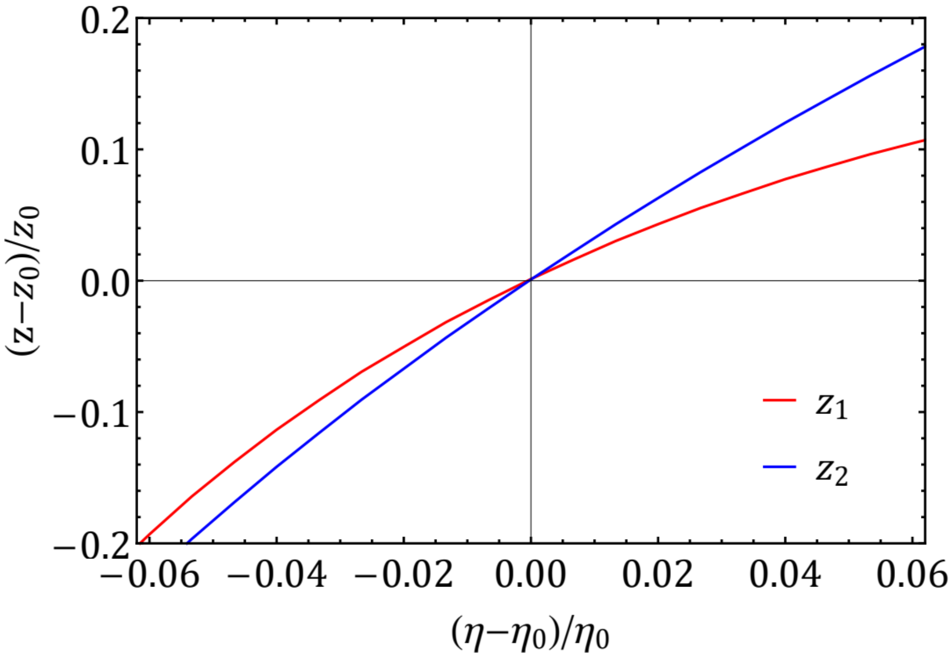
$$n(M) = \frac{f_{PBH}}{\sqrt{2\pi}\sigma M} \exp\left[-\frac{\ln^2(M/M_{pk})}{2\sigma^2}\right] \qquad \tilde{n}(M;z) = n\left(\frac{M}{1+z};z\right)$$

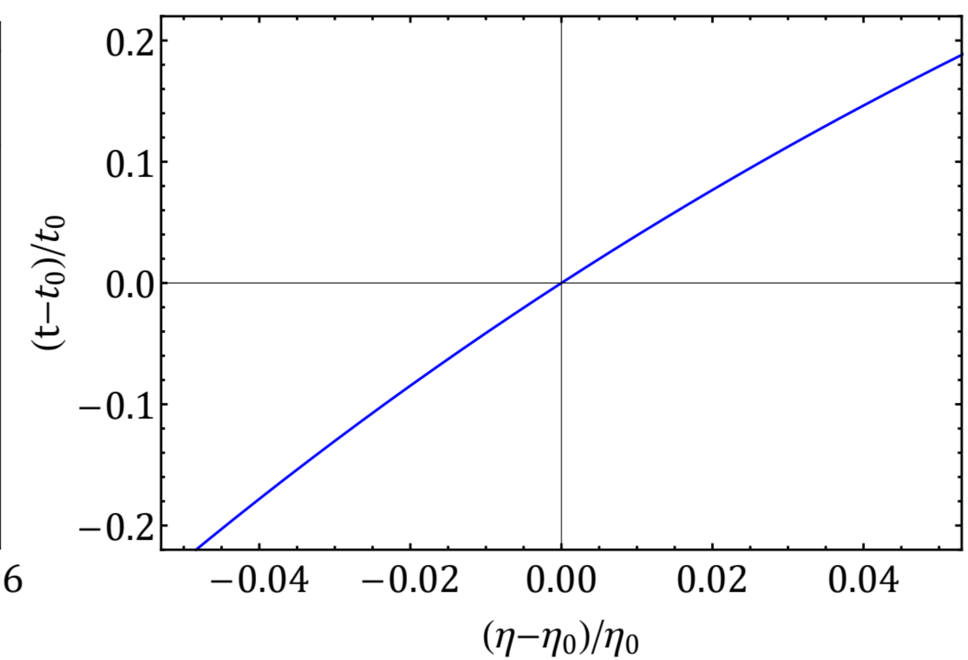


$$\eta = \frac{1+z_2}{1+z_1}$$

$$t_z = \int_{z_1}^{z_2} \frac{dz}{H(z)(1+z)}$$

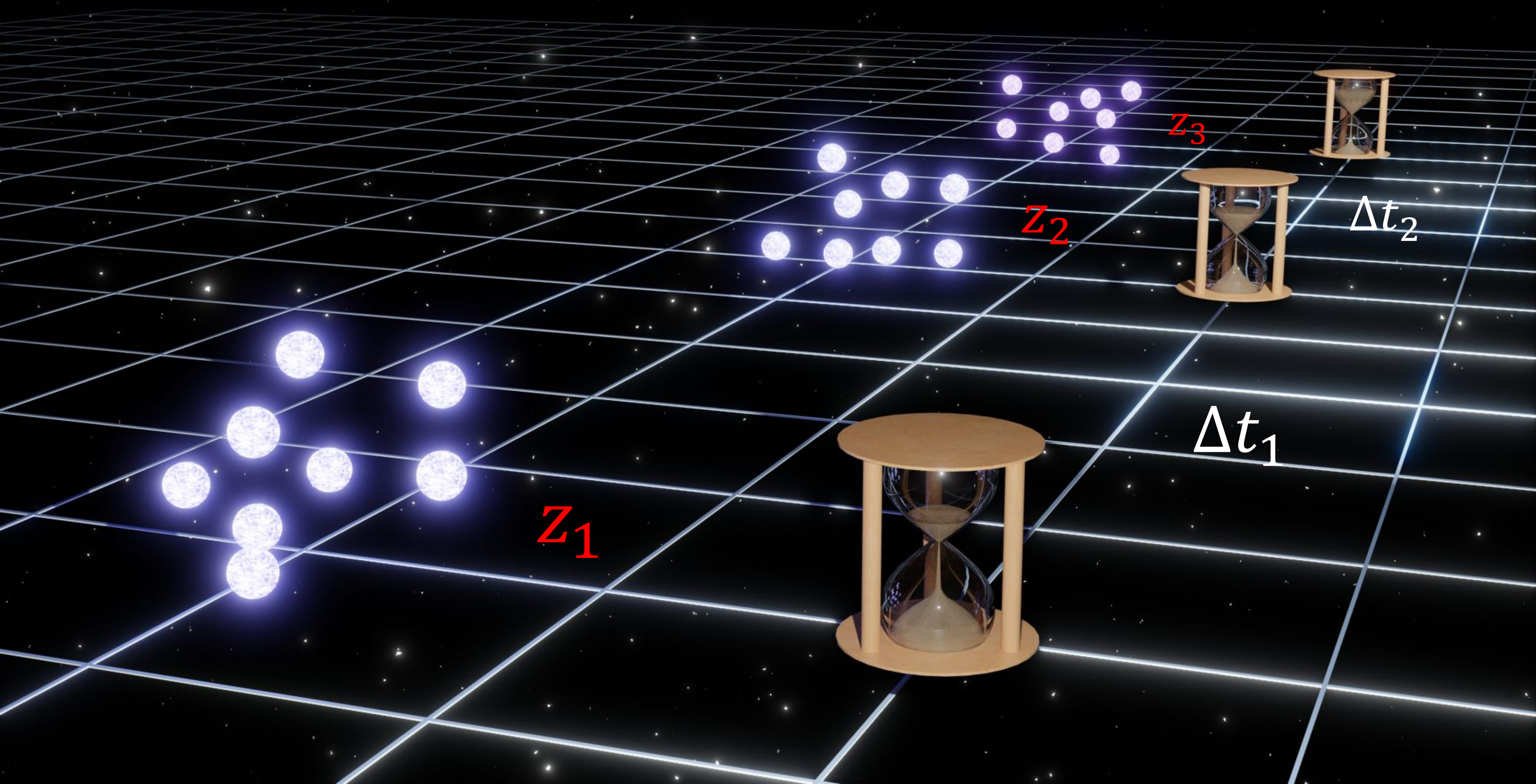
$$\Delta t(z_1, z_2) = t_z$$





$$\Delta t = \int_{z_1}^{z_2} \frac{dz}{H(z)(1+z)}$$

$$H(z) = H_0\sqrt{\Omega_\gamma(1+z)^4 + \Omega_m(1+z)^3 + \Omega_\Lambda}$$



Thank you !