

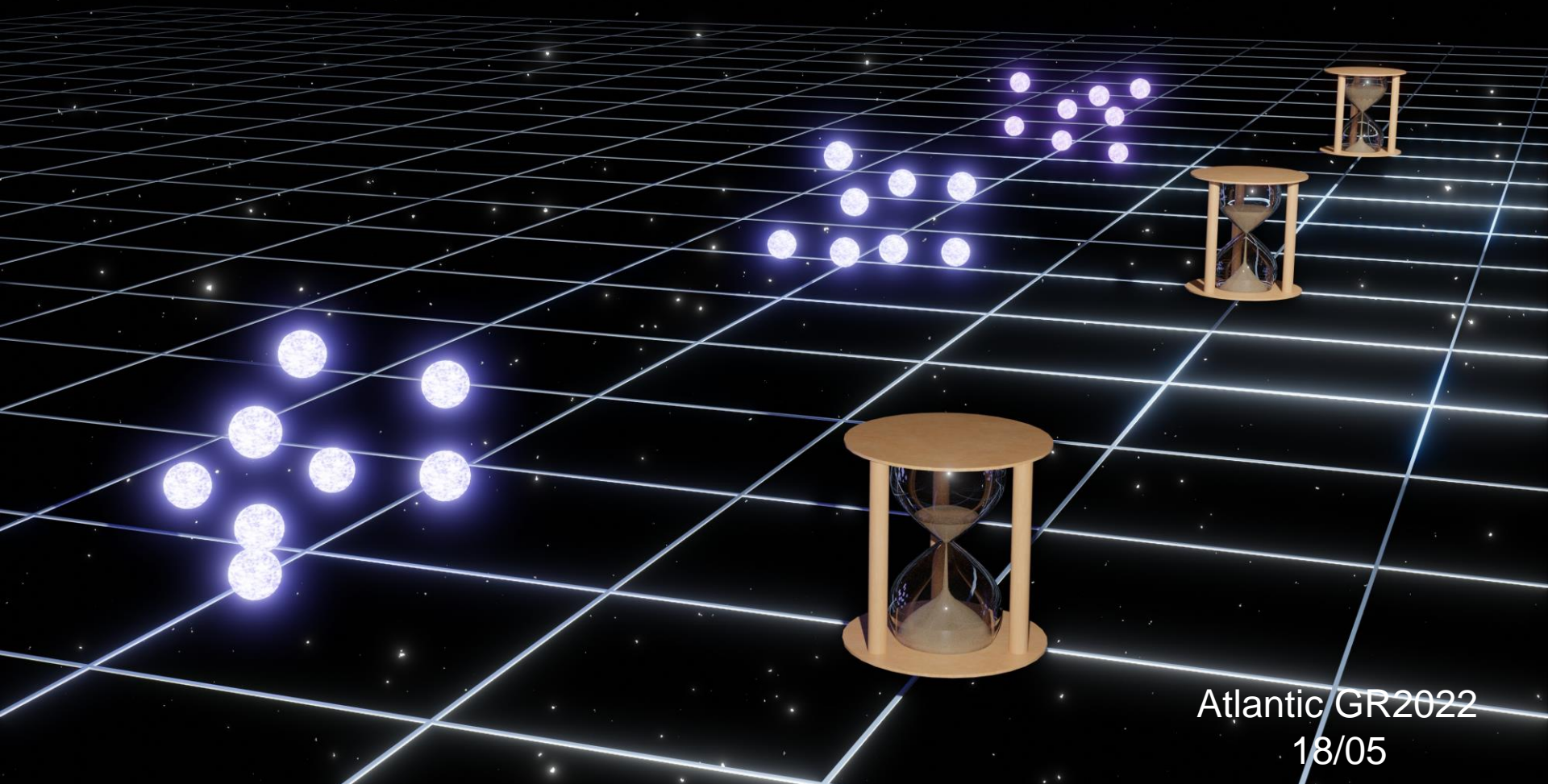
# Cosmological Standard Timer from Unstable Primordial Relic

arXiv: 2112.10422

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Atlantic/GR2022  
18/05

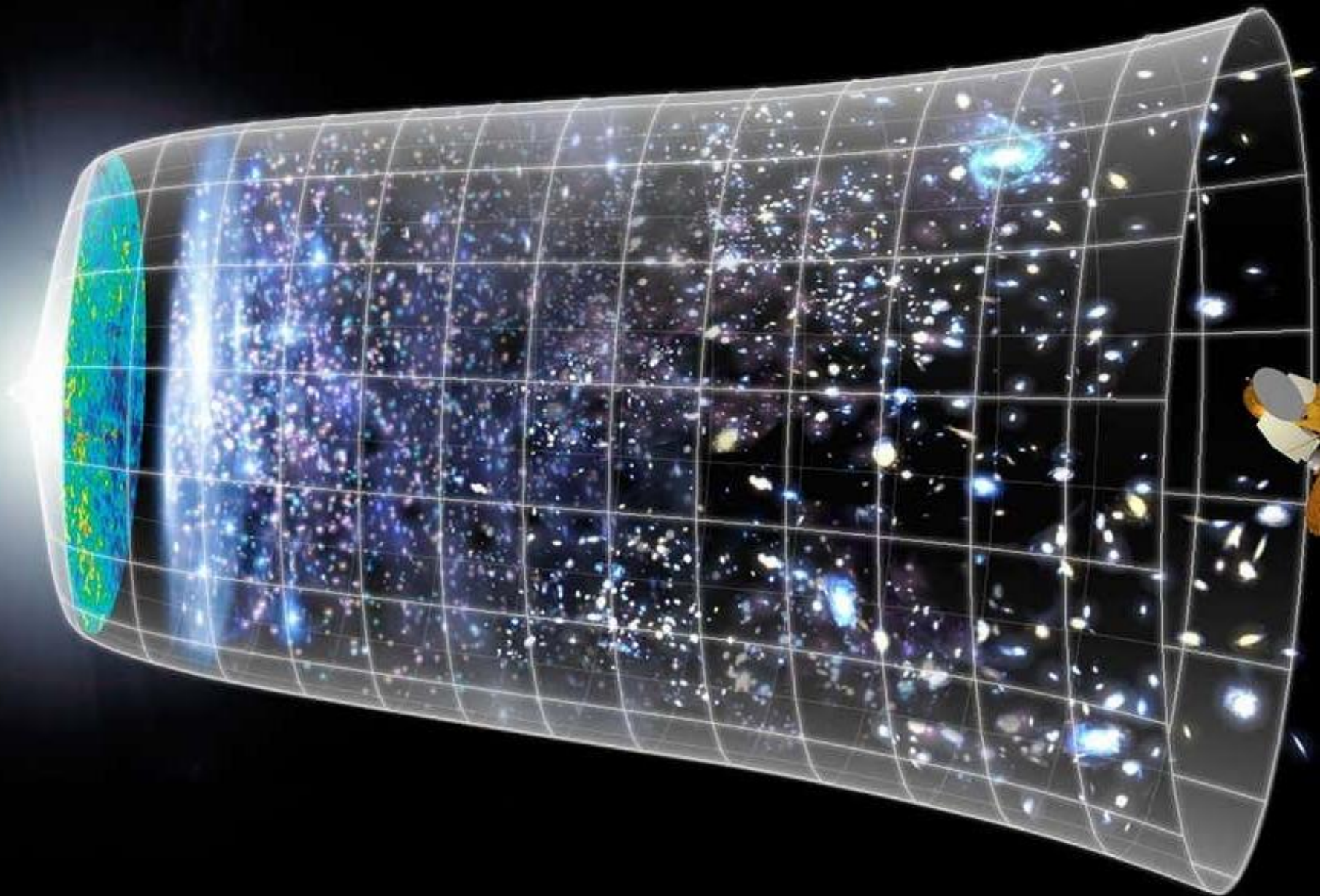


Image Credit: New Scientist



A photograph of a radio telescope array at night. Four large parabolic dish antennas are visible, mounted on concrete bases. The sky is dark blue and filled with stars. The Milky Way galaxy is visible as a bright, hazy band of light stretching across the upper left portion of the frame. A bright, circular light source, likely the Moon, is visible on the right side of the image. The foreground is dark and flat, suggesting a desert or high-altitude environment.

How to measure the Universe?

Image Credit: ESO



## Standard Candle

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

## Standard Ruler

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

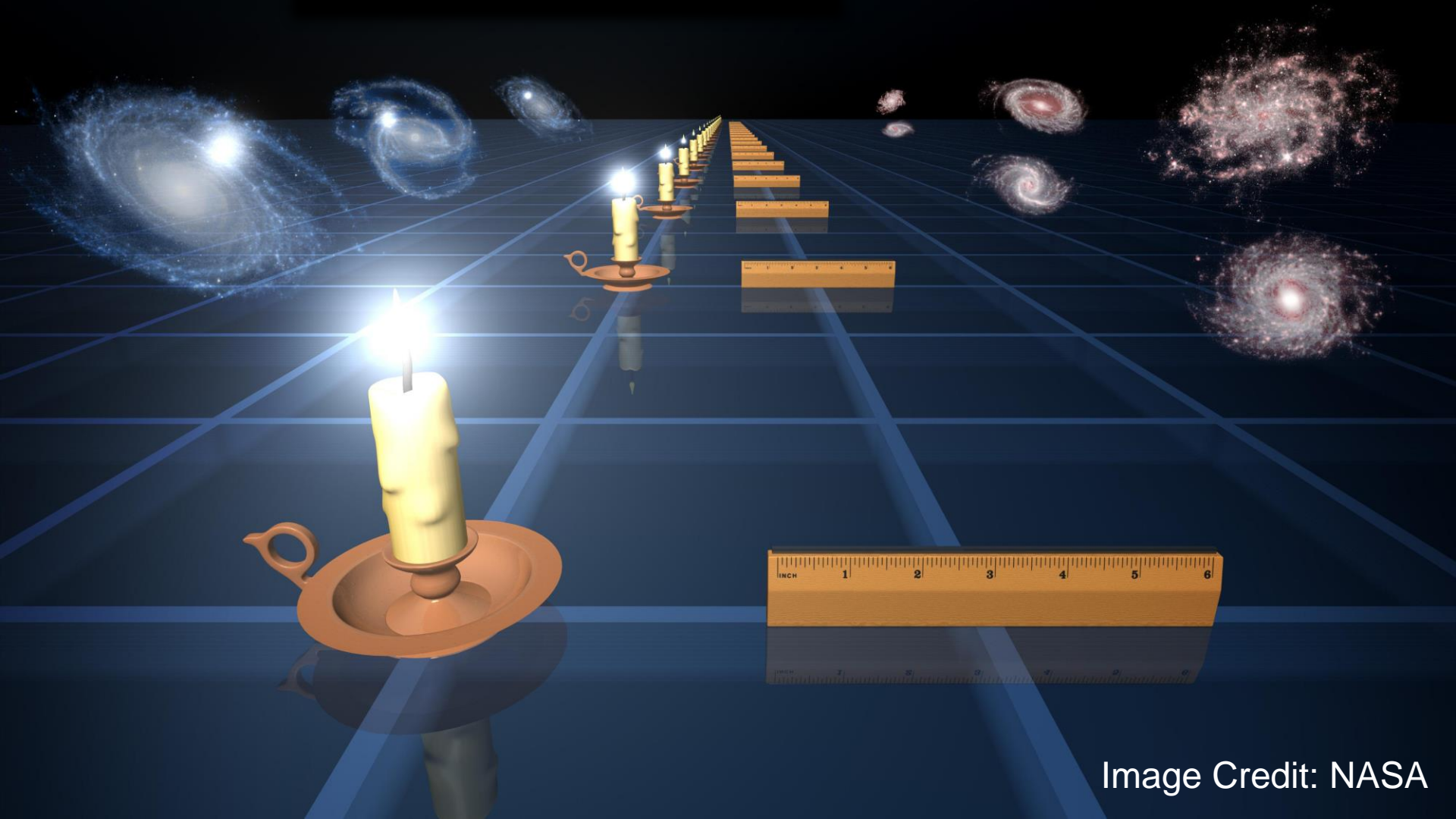
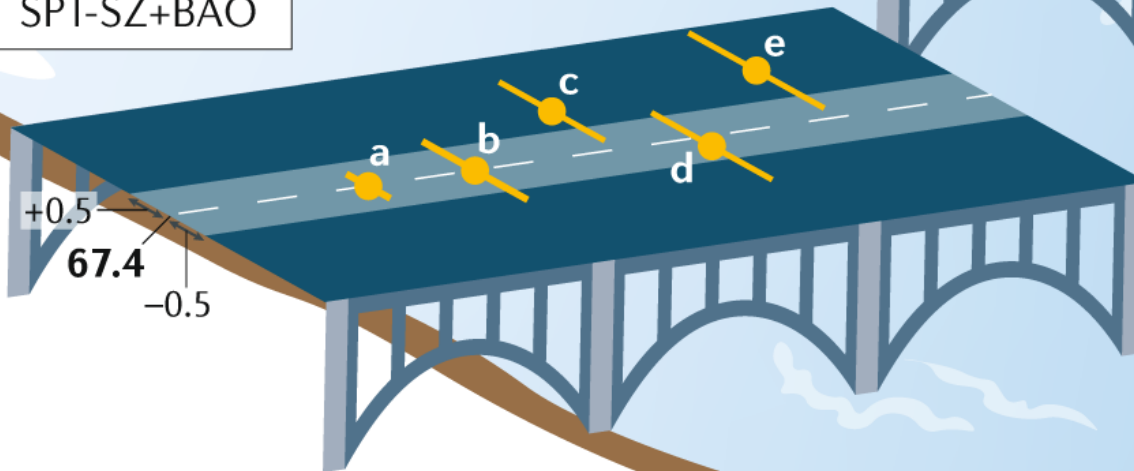


Image Credit: NASA

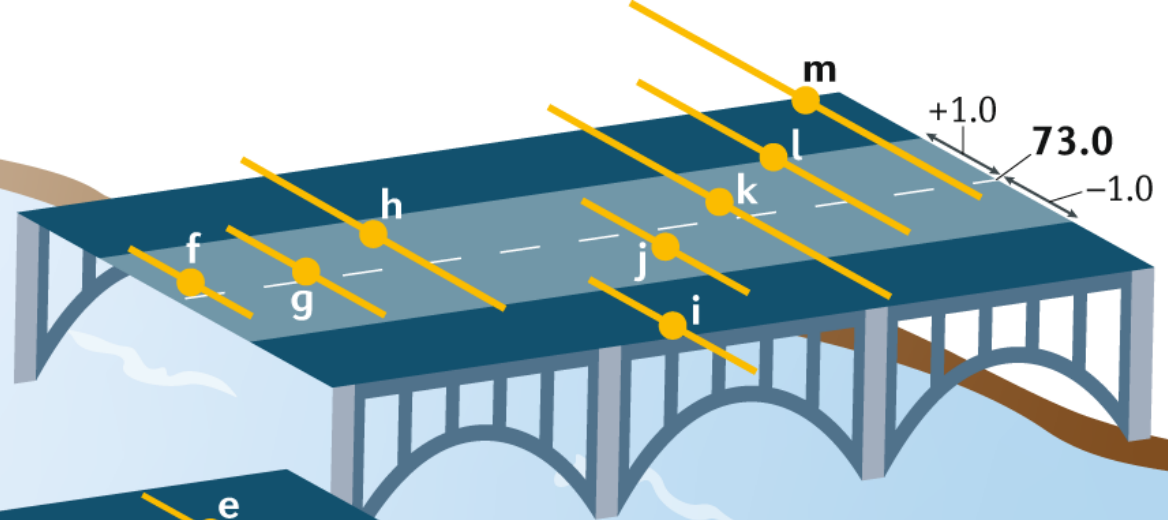
## Early route

- a** Planck
- b** BBN+BAO
- c** WMAP+BAO
- d** ACTPol+BAO
- e** SPT-SZ+BAO



## Late route

- |                  |                  |
|------------------|------------------|
| <b>f</b> SH0ES   | <b>g</b> H0LiCOW |
| <b>h</b> STRIDES | <b>i</b> TRGB 1  |
| <b>j</b> TRGB 2  | <b>k</b> Miras   |
| <b>l</b> Masers  | <b>m</b> SBF     |



Potential Tension

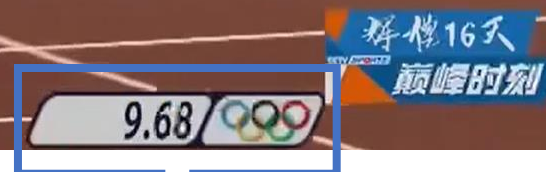
Riess, Adam G. "The expansion of the universe is faster than expected." *Nature Reviews Physics* 2.1 (2020): 10-12.



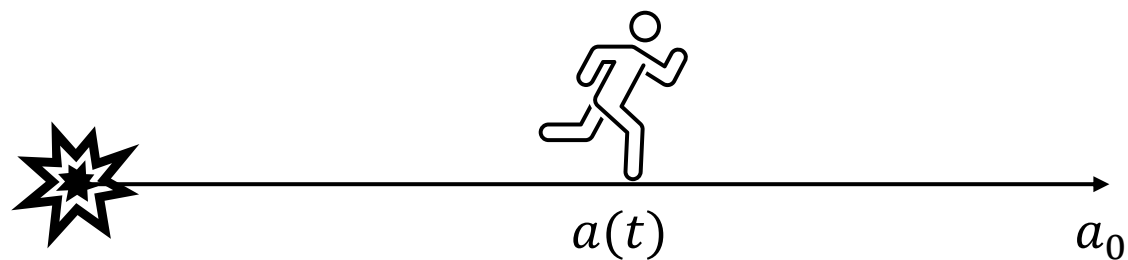
Another way to measure the Universe?







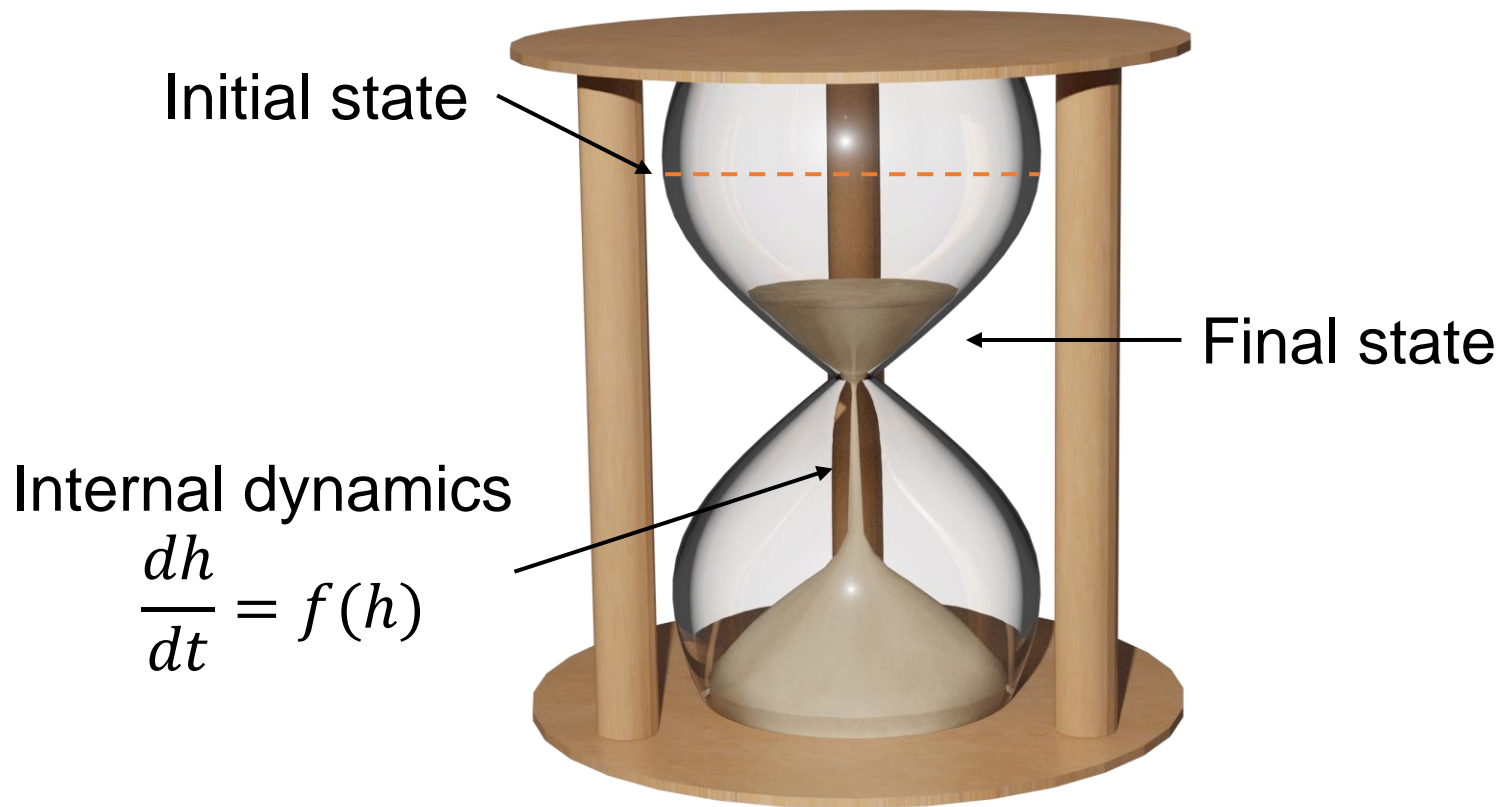
Timer



How to know the elapsed time in the timer?

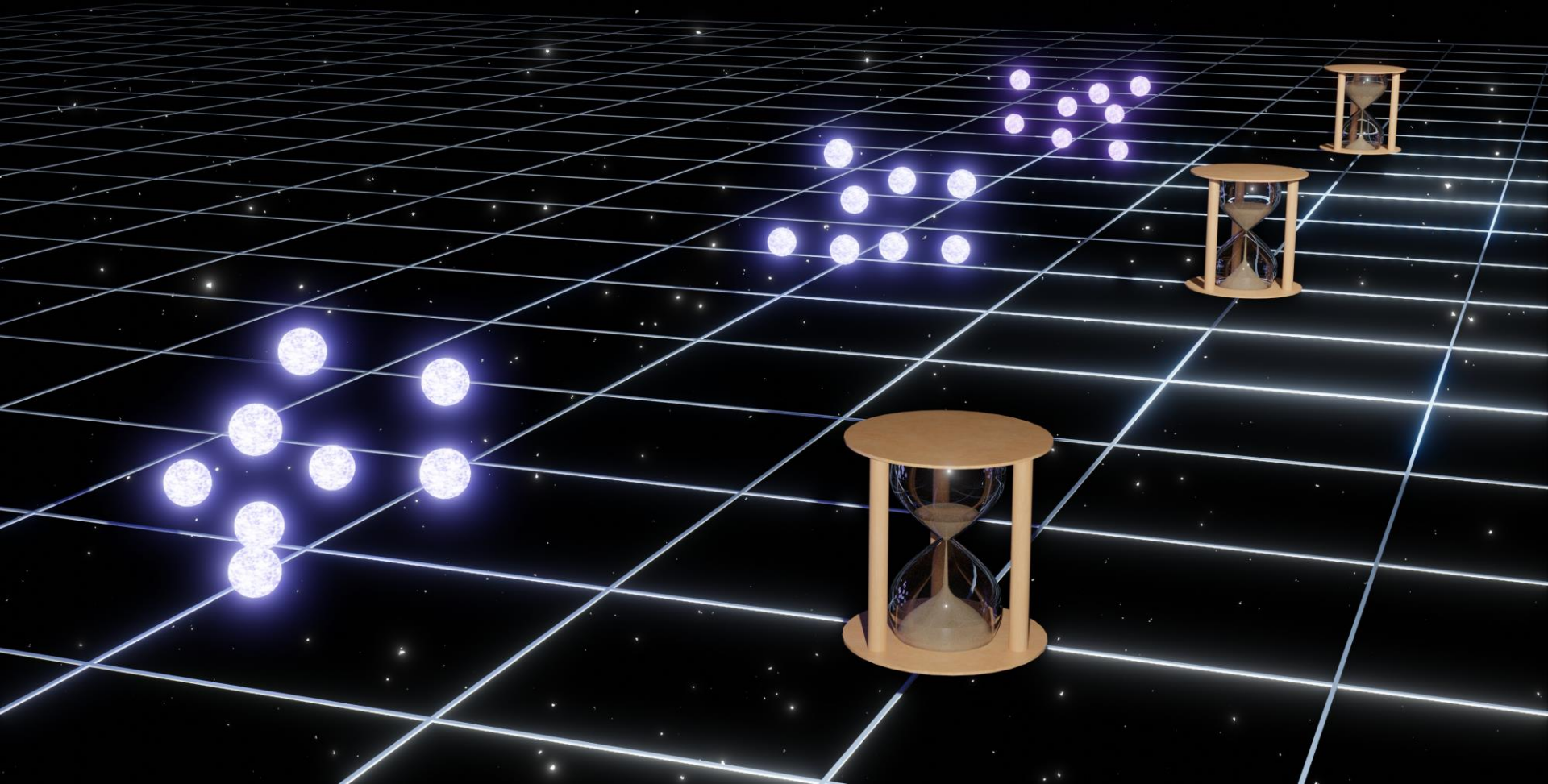






How to obtain  $a(t)$  ?

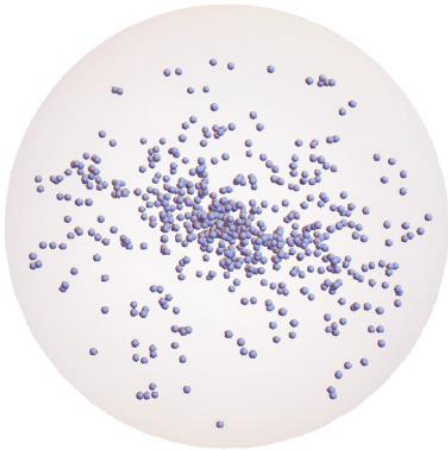
$$1 + z(t) = \frac{a_0}{a(t)}$$





# 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

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

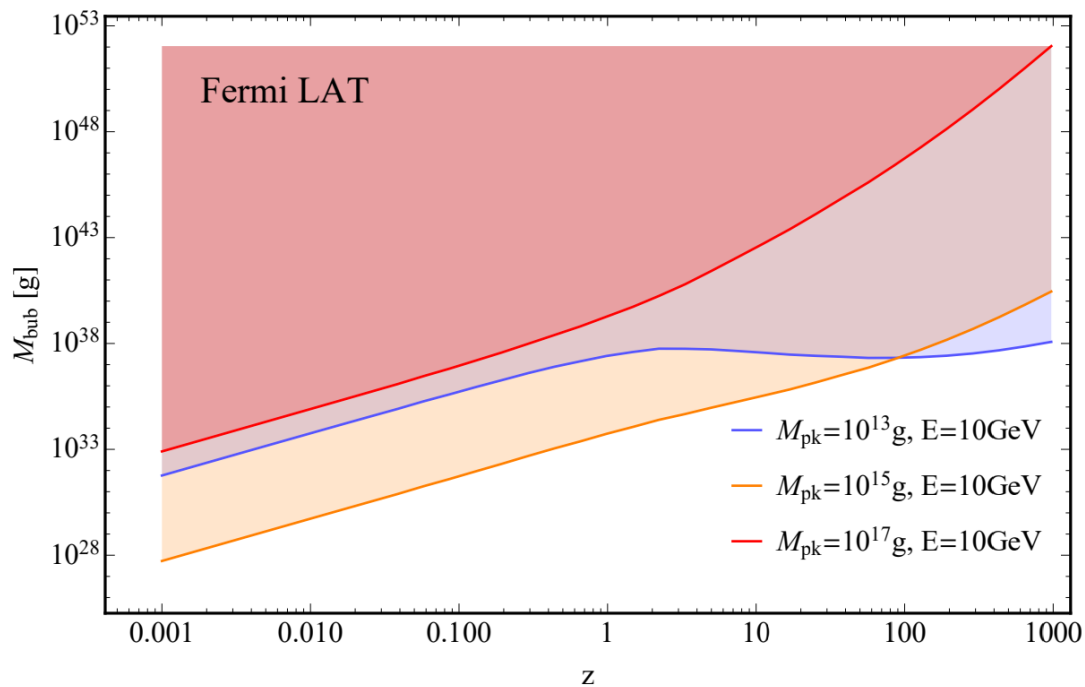
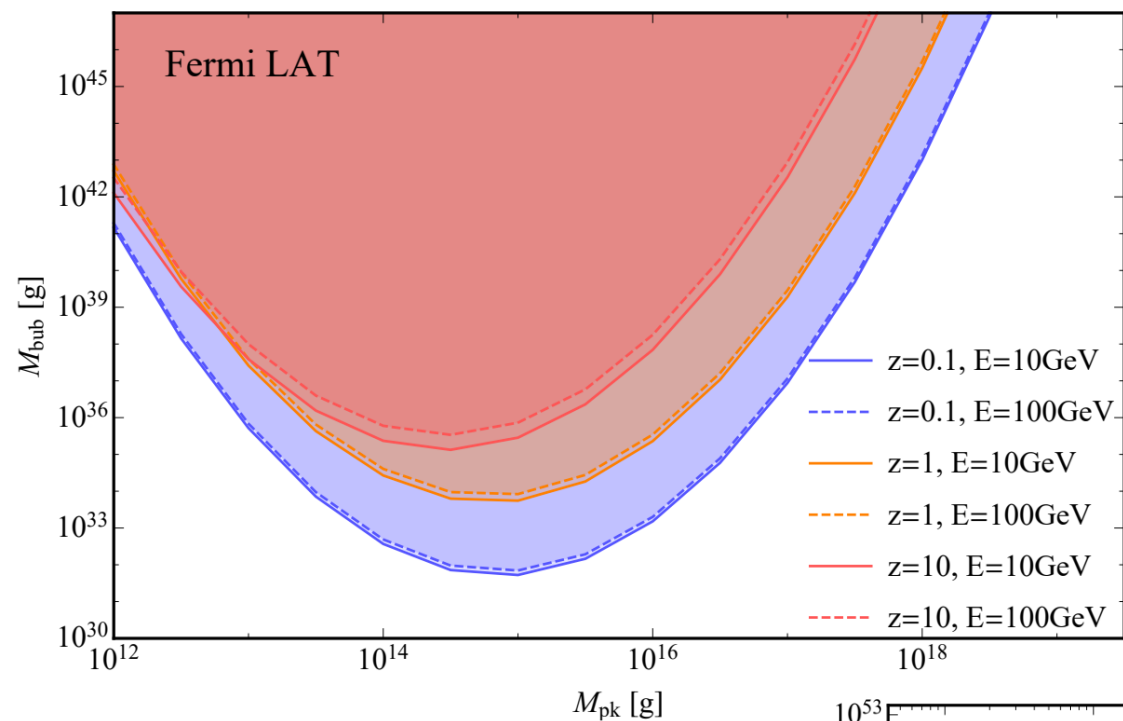
$$\frac{dM}{dt} = -\frac{\alpha}{M^2} \Rightarrow M^3 = M_i^3 - \delta^3(\Delta t)$$

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

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

Can we see them?





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2105.11481

How to extract the redshift from the observable?

## Primary Hawking radiation from the PBH clustering

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

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

## Redshift in the observed photon flux

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

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

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

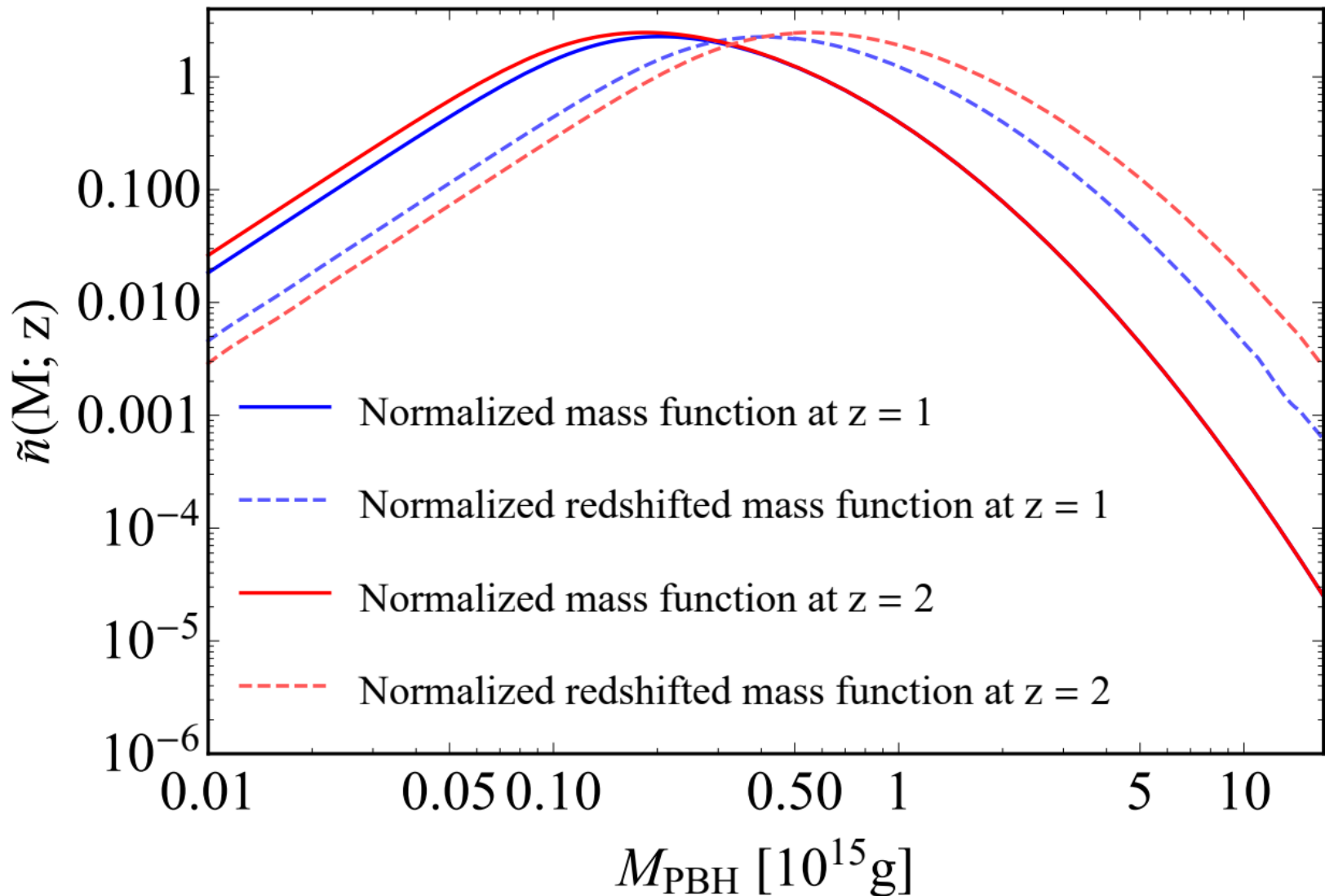
## Redshift from the inverse problem

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

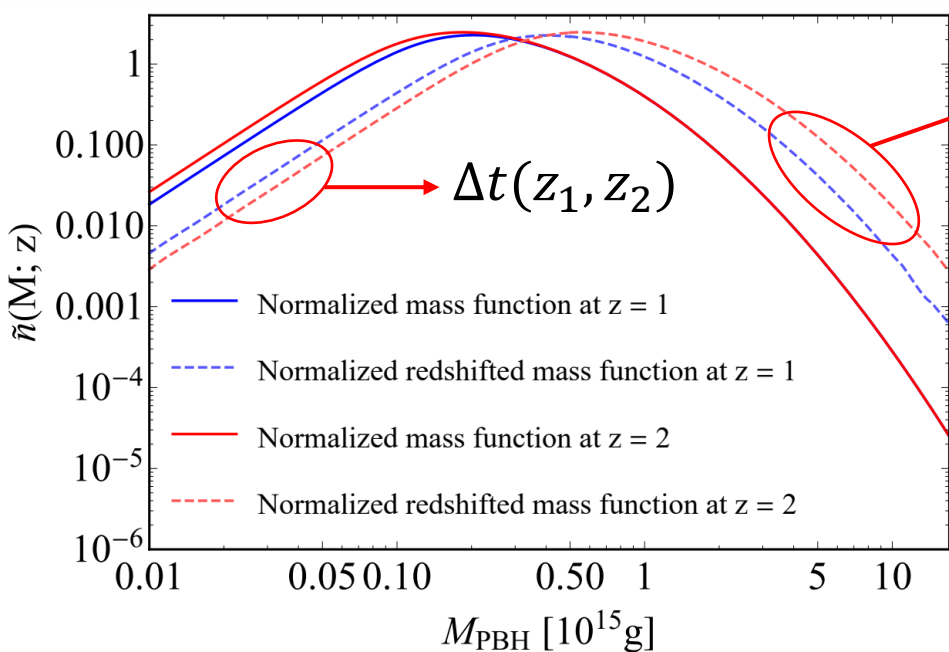
$$\frac{4\pi F(E; z)}{E^2} \simeq \int_0^\infty H_p(E, M) n\left(\frac{M}{1+z}; z\right) \frac{(1+z)V}{d_L^2(z)} dM$$

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





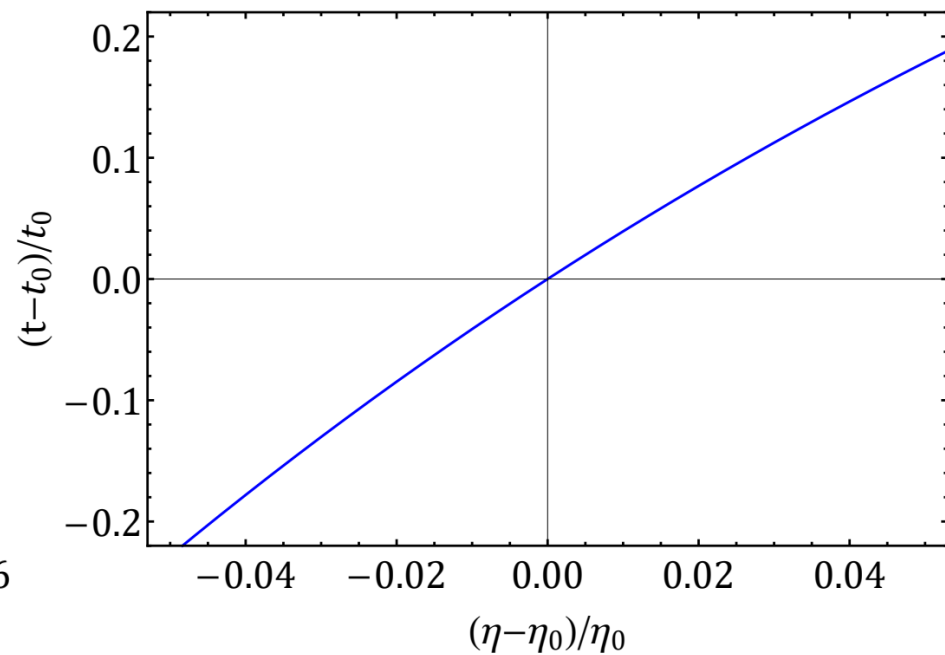
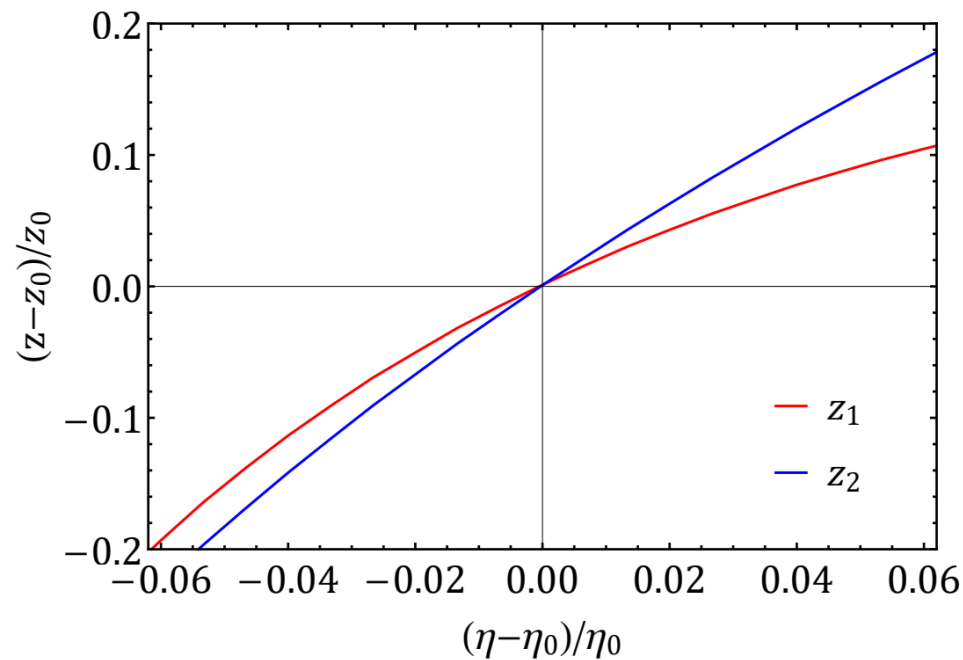
$$n(M) = \frac{f_{\text{PBH}}}{\sqrt{2\pi}\sigma M} \exp\left[-\frac{\ln^2(M/M_{pk})}{2\sigma^2}\right] \quad \tilde{n}(M; z) = n\left(\frac{M}{1+z}; z\right)$$



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

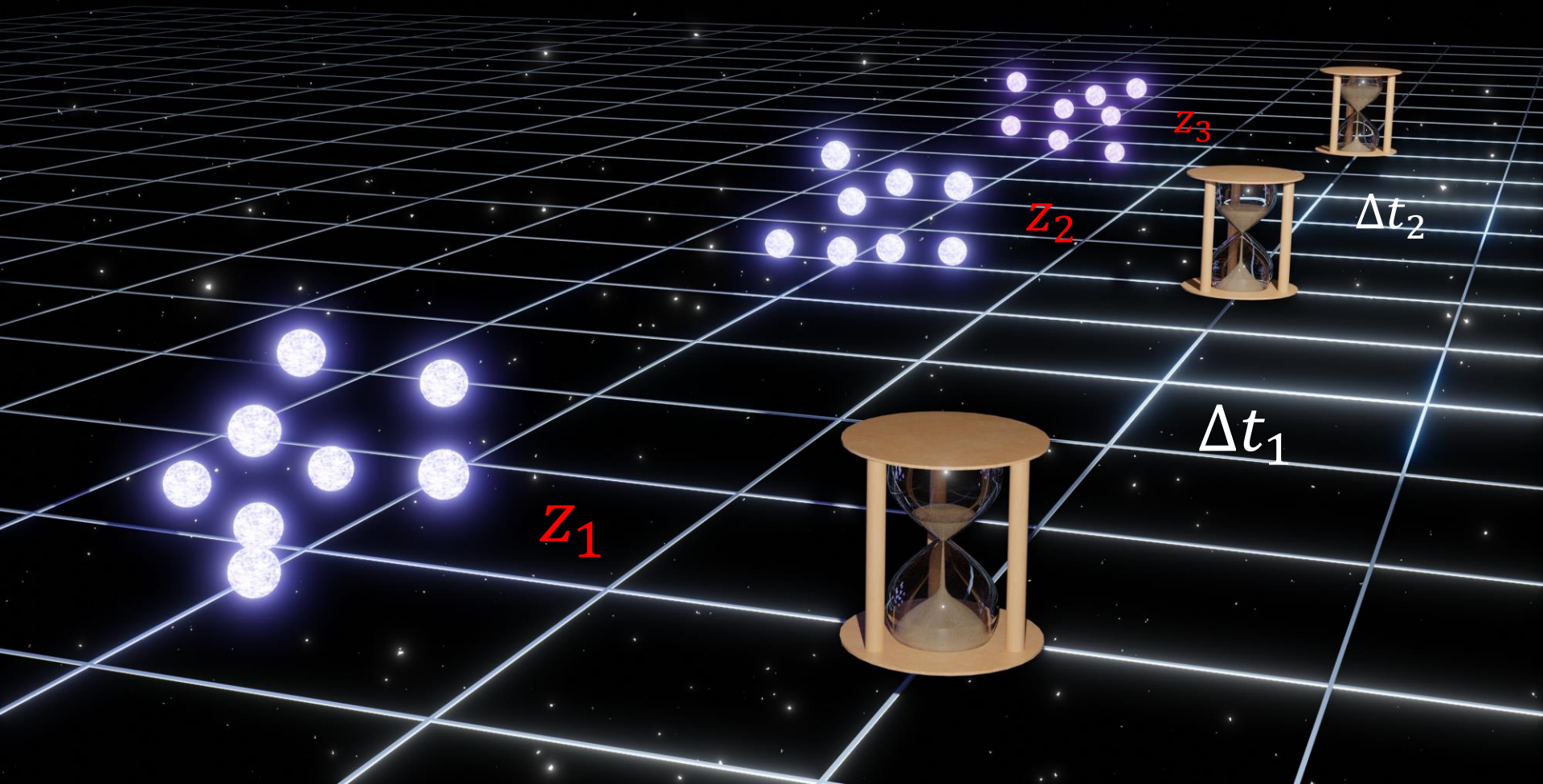
$$t_z = \int_{z_1}^{z_2} \frac{dz}{H(z)(1+z)}$$

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



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

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



# Thank you !

