COSMOVIA Lectures
Virtual Institute of Astroparticle physics
Paris, October 18, 2019

White holes

Igor Nikitin

Fraunhofer Institute for Algorithms and Scientific Computing
Sankt Augustin, Germany

Content

- White hole, the definition
- White holes and cosmological models
- Stability of white holes
- White holes and FRBs

arXiv:1811.03368

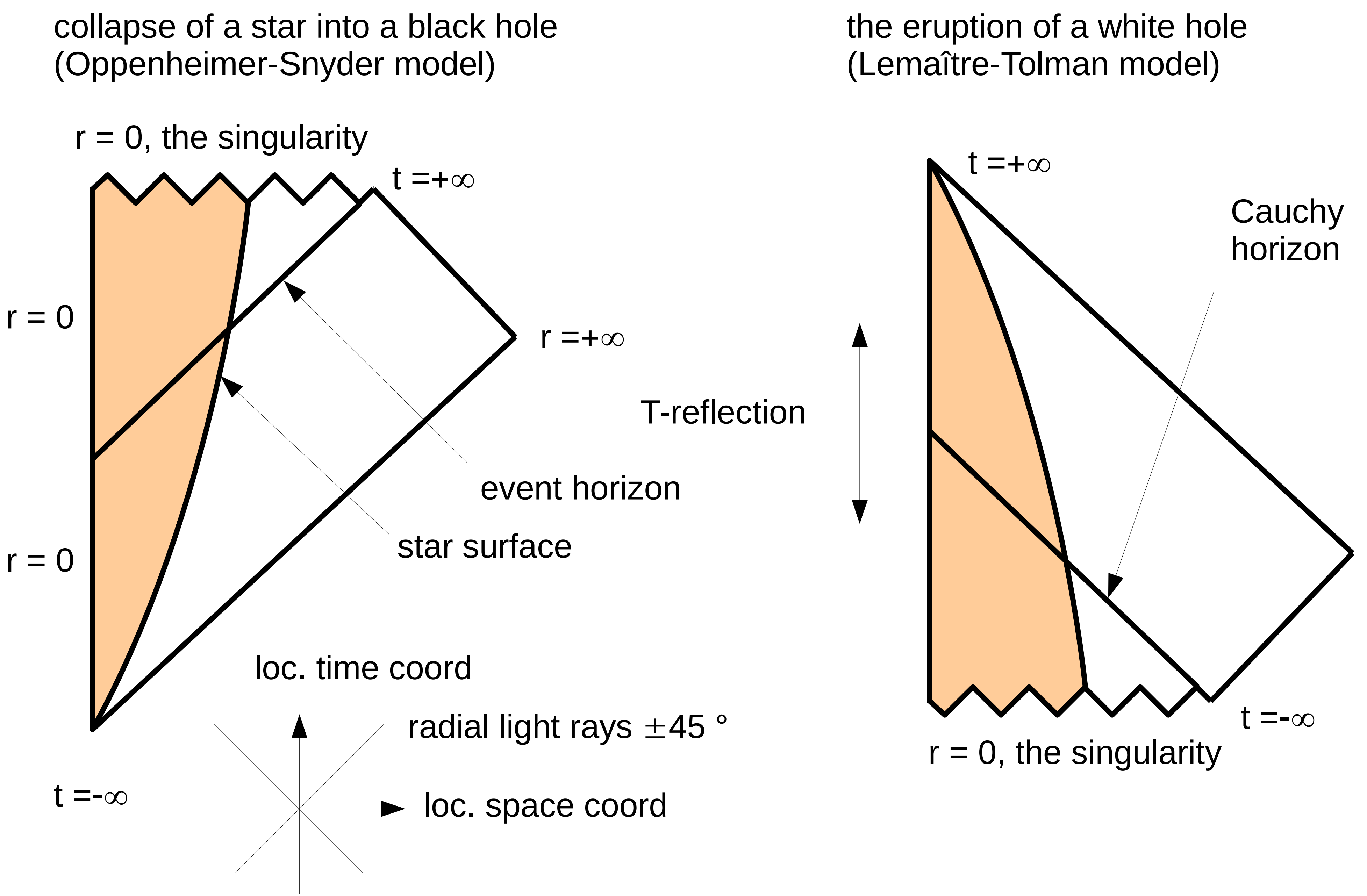
White hole

- T-reflection of a black hole
- „is not always white“: like the black hole having active and passive phases, main collapse event and episodic matter injections, its T-reflection should not be always active, can eject the matter episodically
- looks similar to the **repeating FRBs** (the question we will consider further in detail)
- „is not like a movie of a black hole reverted in time“: the evolution is reverted, but the light rays defining the *observed* evolution, are not... they still come from the past to the present at observer's location
- how does the white hole look from inside? for the black hole under event horizon all future directed light rays end in the central singularity => for the white hole under (Cauchy) horizon all past directed light rays come from the central singularity => the observer sees the central singularity in all directions

White hole

- similar to the Big Bang / CMB visible in all directions in **cosmological models**
- moreover, there is (a piecewise) isomorphism between the white holes and the cosmological models (the other question we will consider further in detail)
- there are also **instability effects**, looking as if a thermodynamical time arrow of the surrounding universe tries to take over the oppositely directed time arrow of the white hole (one more question for our discussion today)

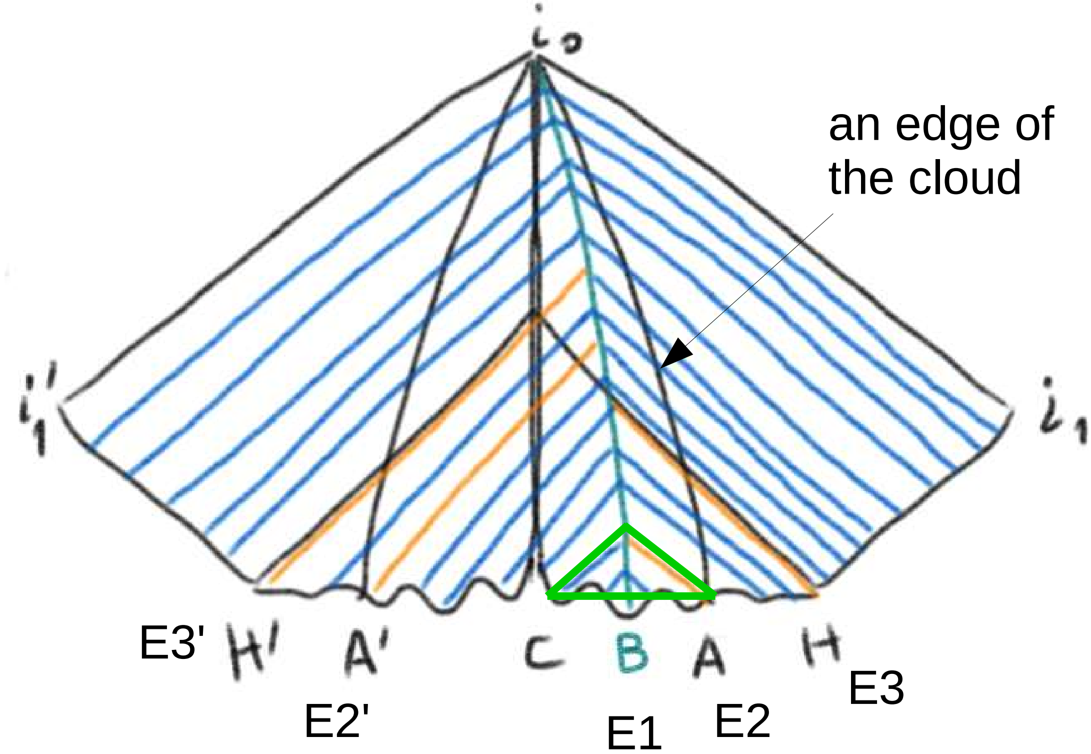
White hole on Penrose diagram

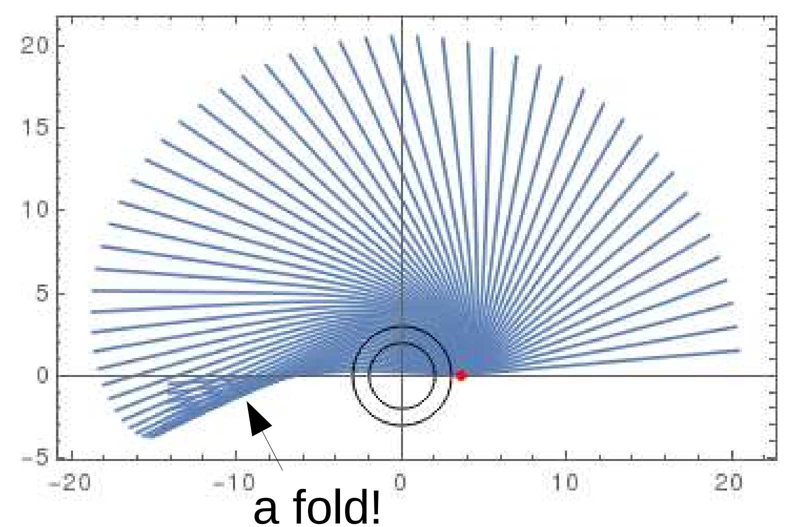


White hole on Penrose diagram (cont'd)

- Lemaître-Tolman model (1933)
- extended Penrose diagram (a reflected copy added for better visualization of radial light rays)
- eruption of dust cloud from white hole
- can be considered as cosmological model
- B – an observer (a galaxy)
- 3-epoch evolution

- **Epoch 1:** uniform expansion of galaxies with relict radiation in the background, equivalent to the Big Bang theory, the Friedman universe (1922)
- **Epoch 2:** the edge A of the dust cloud (the universe) becomes visible
- **Epoch 3:** the universe goes beyond Cauchy horizon H
- E2-3 processes are repeated in the opposite spatial direction: E2'-3'
- Ray tracing visualization in *Mathematica*
- includes all, not only radial light rays





White hole, computation of null geodesics

$$g^{ext}_{\mu\nu}(\tau,r,\theta)\ @\ r>R(\tau)=$$

$$=\begin{pmatrix} -1+2m/r & \sqrt{2m/r} & 0 & 0 \\ \sqrt{2m/r} & 1 & 0 & 0 \\ 0 & 0 & r^2 & 0 \\ 0 & 0 & 0 & r^2\sin\theta^2 \end{pmatrix},$$

continuous connection of external Schwarzschild and internal Friedman metrics (in Painlevé-Gullstrand coordinates, for details see M.Blau Lecture Notes on General Relativity)

$$g^{int}_{\mu\nu}(\tau,r,\theta)\ @\ r\leqslant R(\tau)=$$

$$=\begin{pmatrix} -1+4r^2/(9\tau^2) & -2r/(3\tau) & 0 & 0 \\ -2r/(3\tau) & 1 & 0 & 0 \\ 0 & 0 & r^2 & 0 \\ 0 & 0 & 0 & r^2\sin\theta^2 \end{pmatrix},$$

$$\ddot{x}^\mu+\Gamma^\mu{}_{\nu\lambda}\dot{x}^\nu\dot{x}^\lambda=0$$

geodesic equation

$$R(\tau)=\begin{cases} (9m/2)^{1/3}(-\tau)^{2/3}, & \tau<0 \\ 0, & \tau\geqslant 0 \end{cases}$$

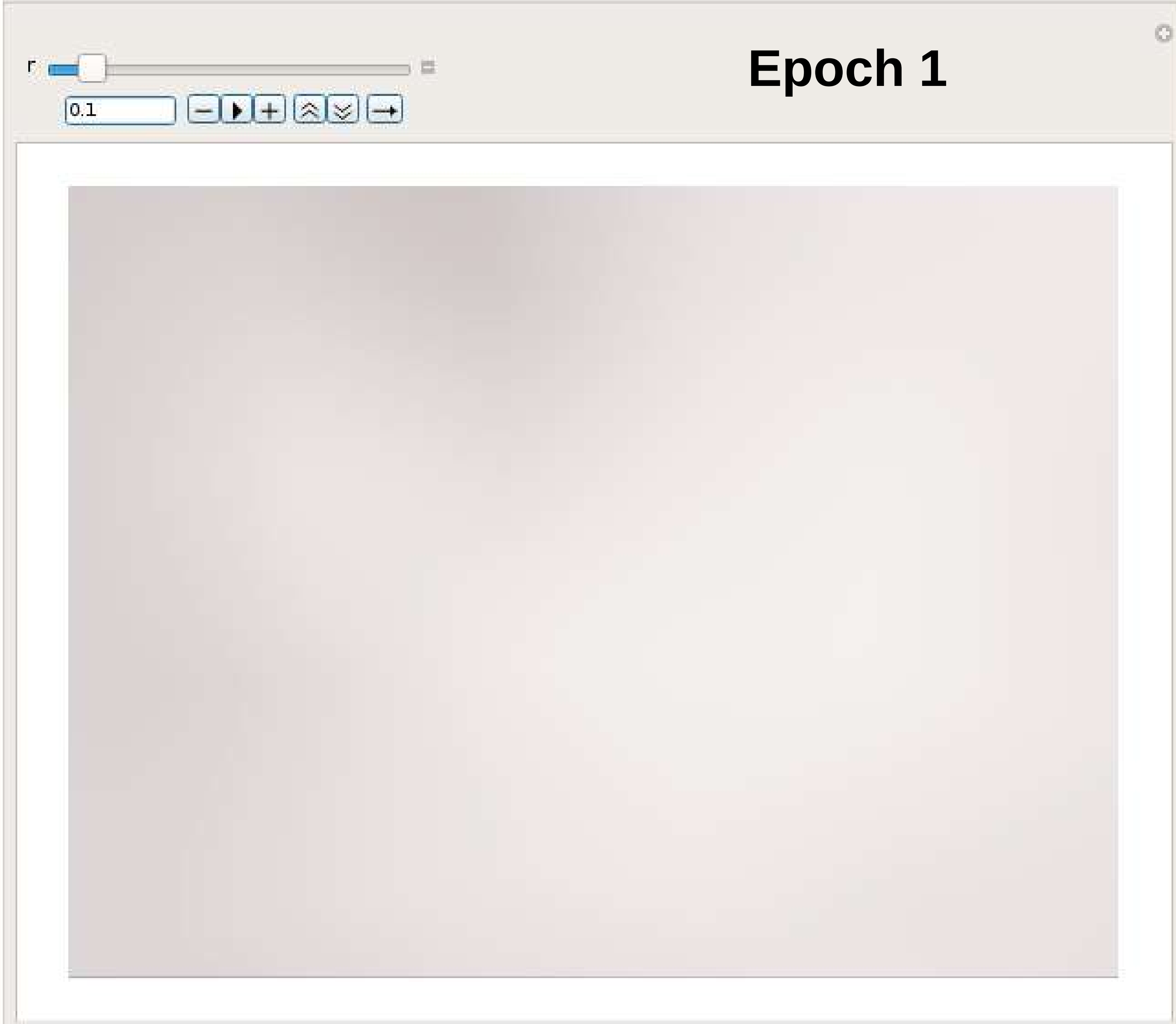
surface of the cloud

$$\Gamma^\lambda{}_{\mu\nu}=\tfrac{1}{2}g^{\lambda\sigma}(\partial_\mu g_{\sigma\nu}+\partial_\nu g_{\sigma\mu}-\partial_\sigma g_{\mu\nu})$$

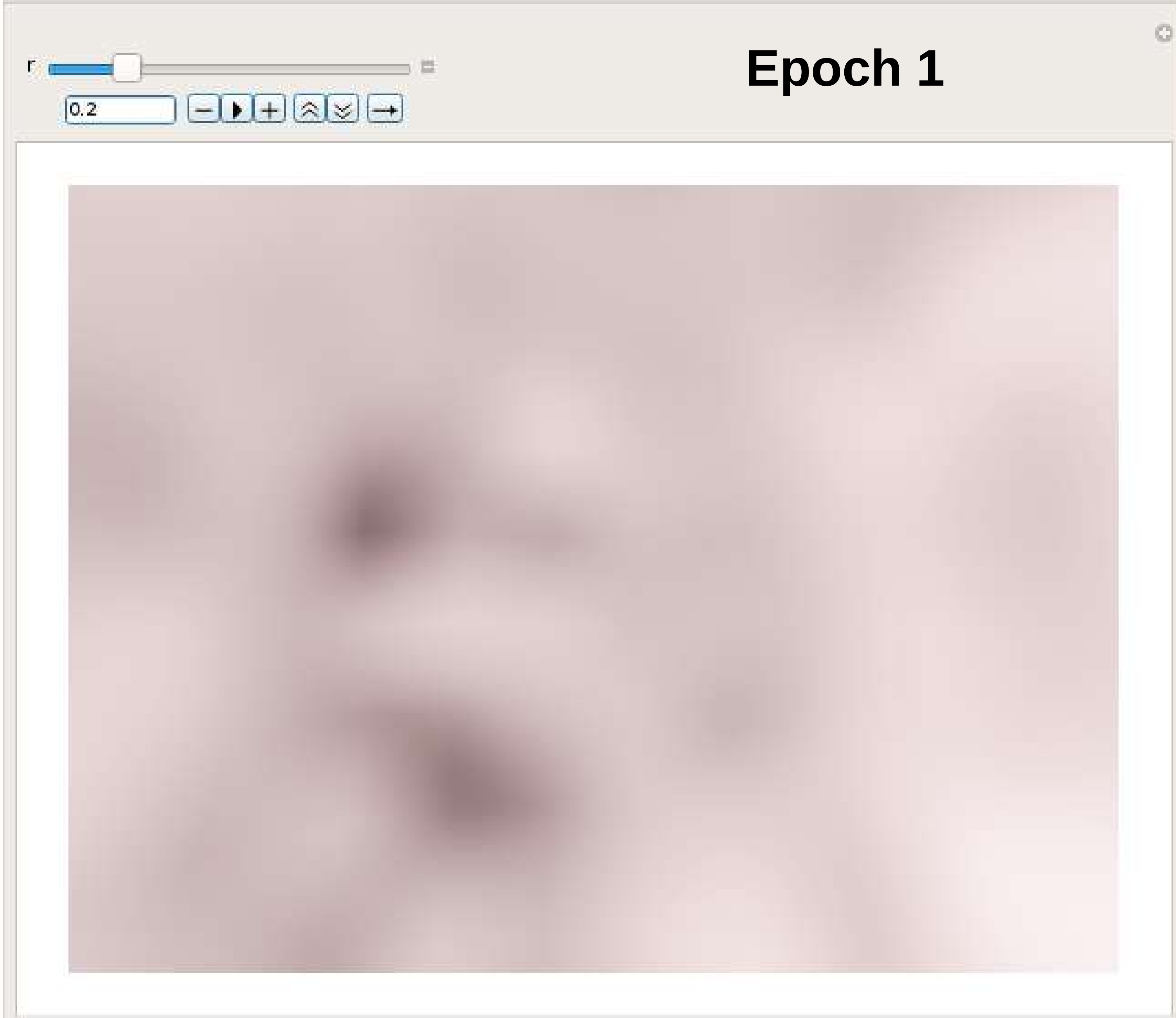
Christoffel symbols

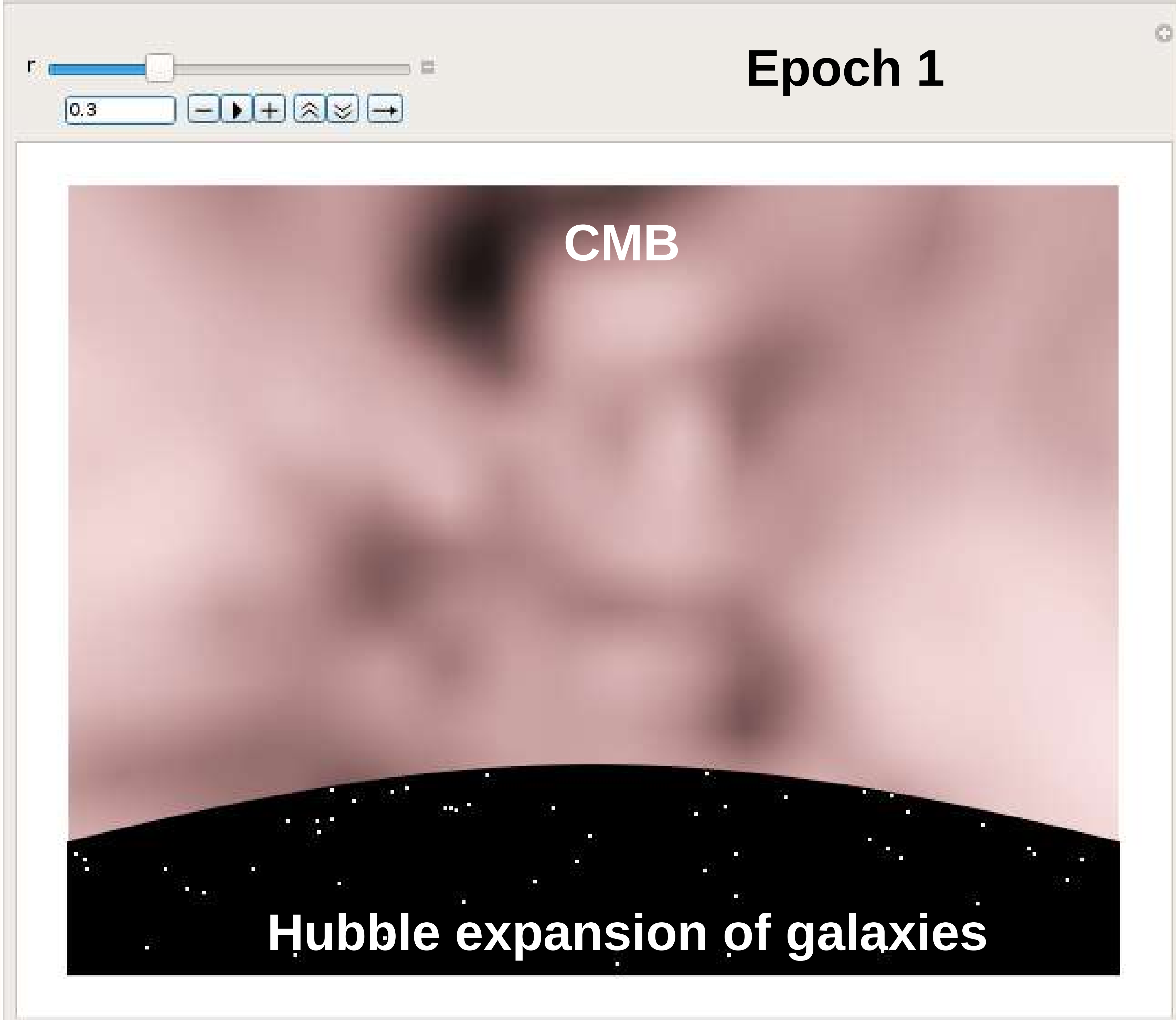

r
0.05
Epoch 1
Big Bang!

Epoch 1

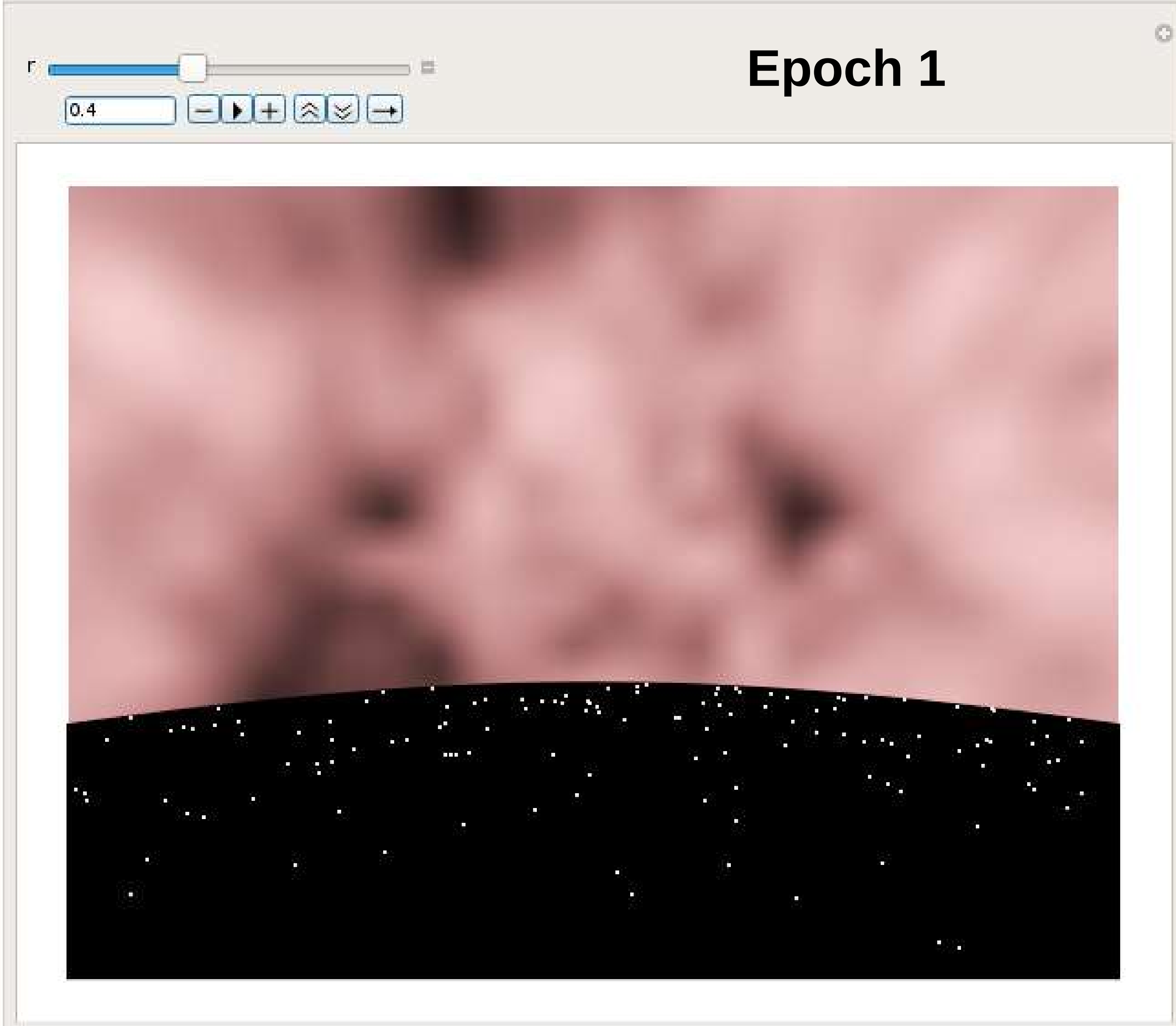


Epoch 1

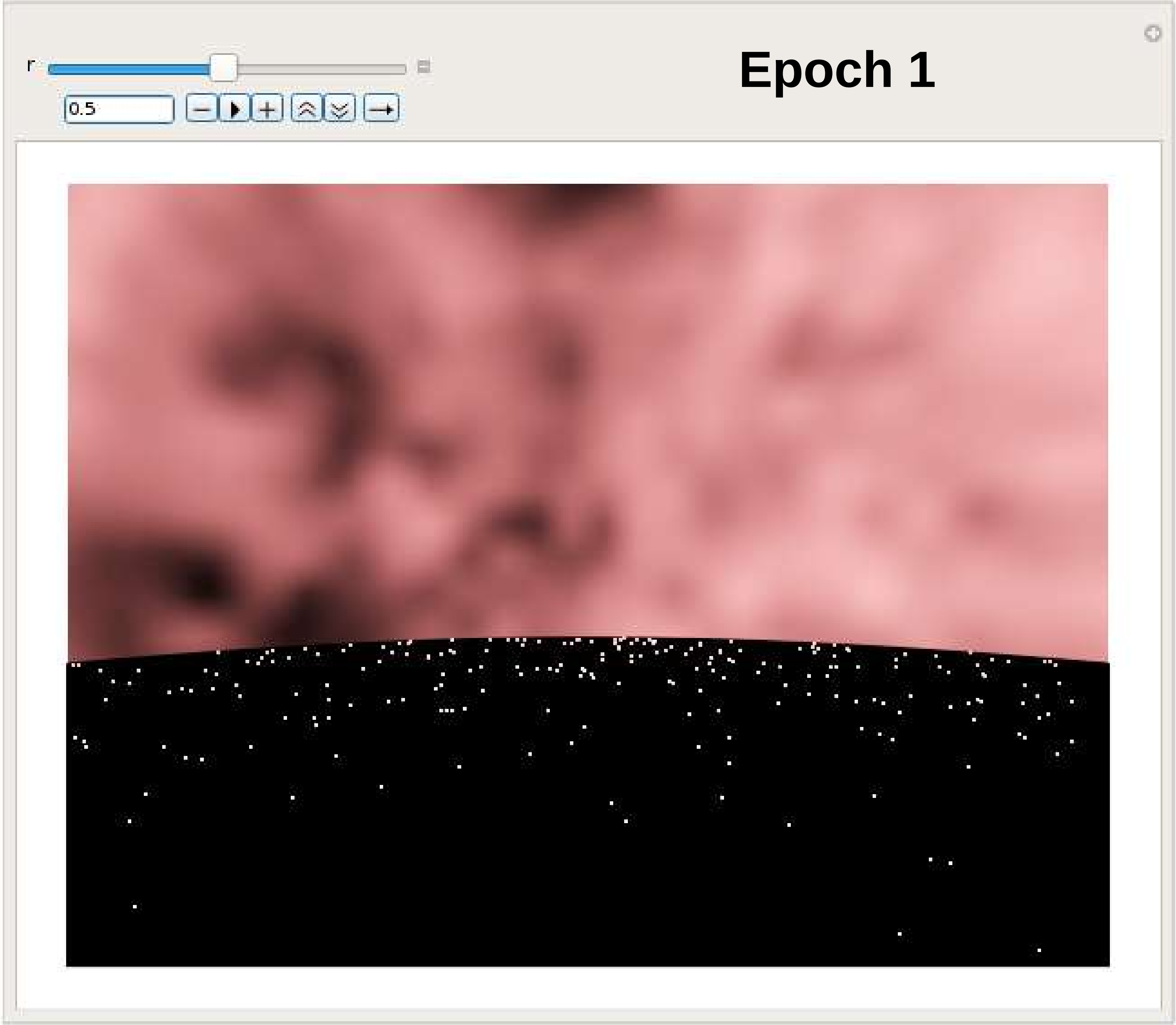



0.3
Epoch 1
CMB
Hubble expansion of galaxies

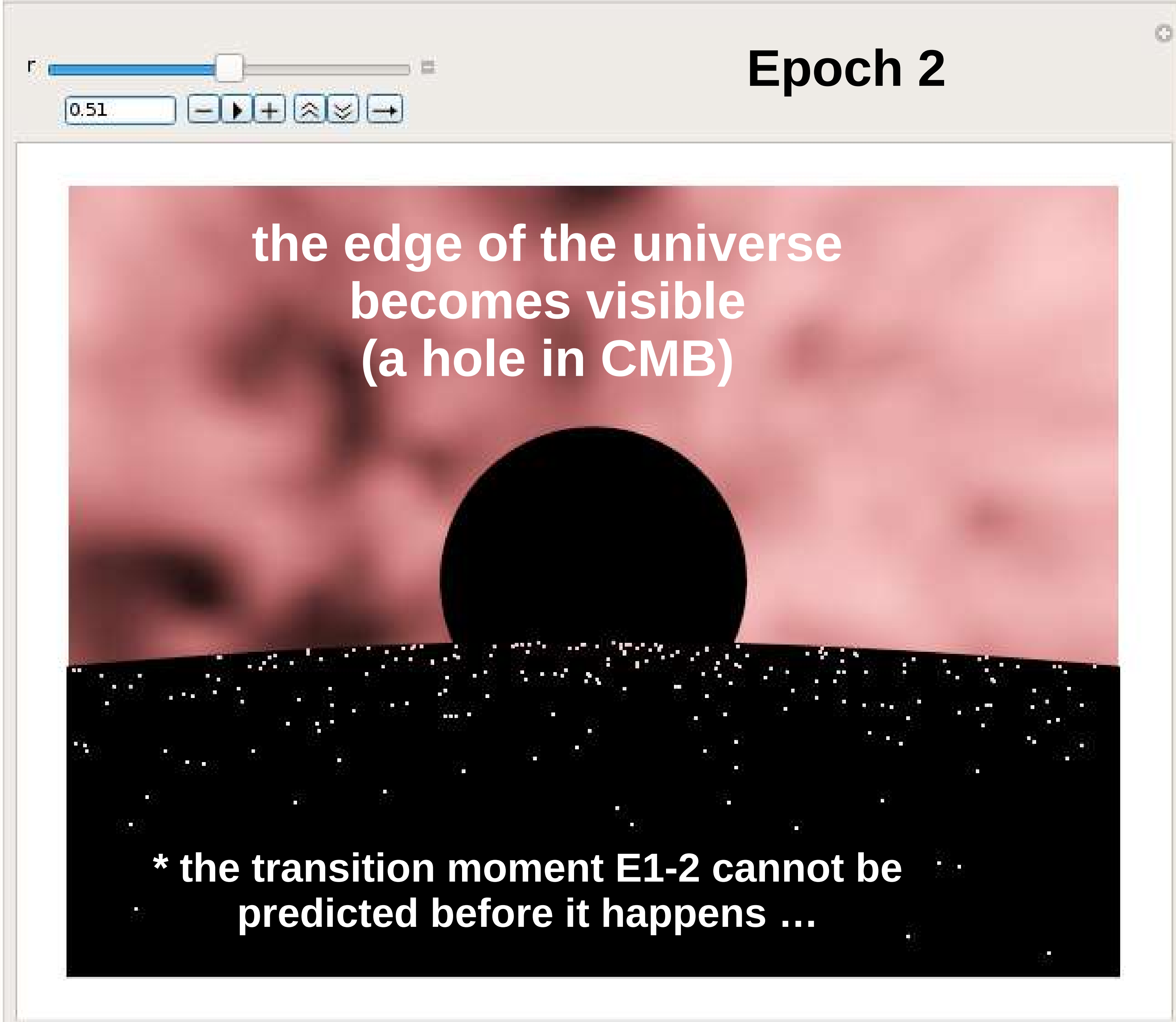
Epoch 1



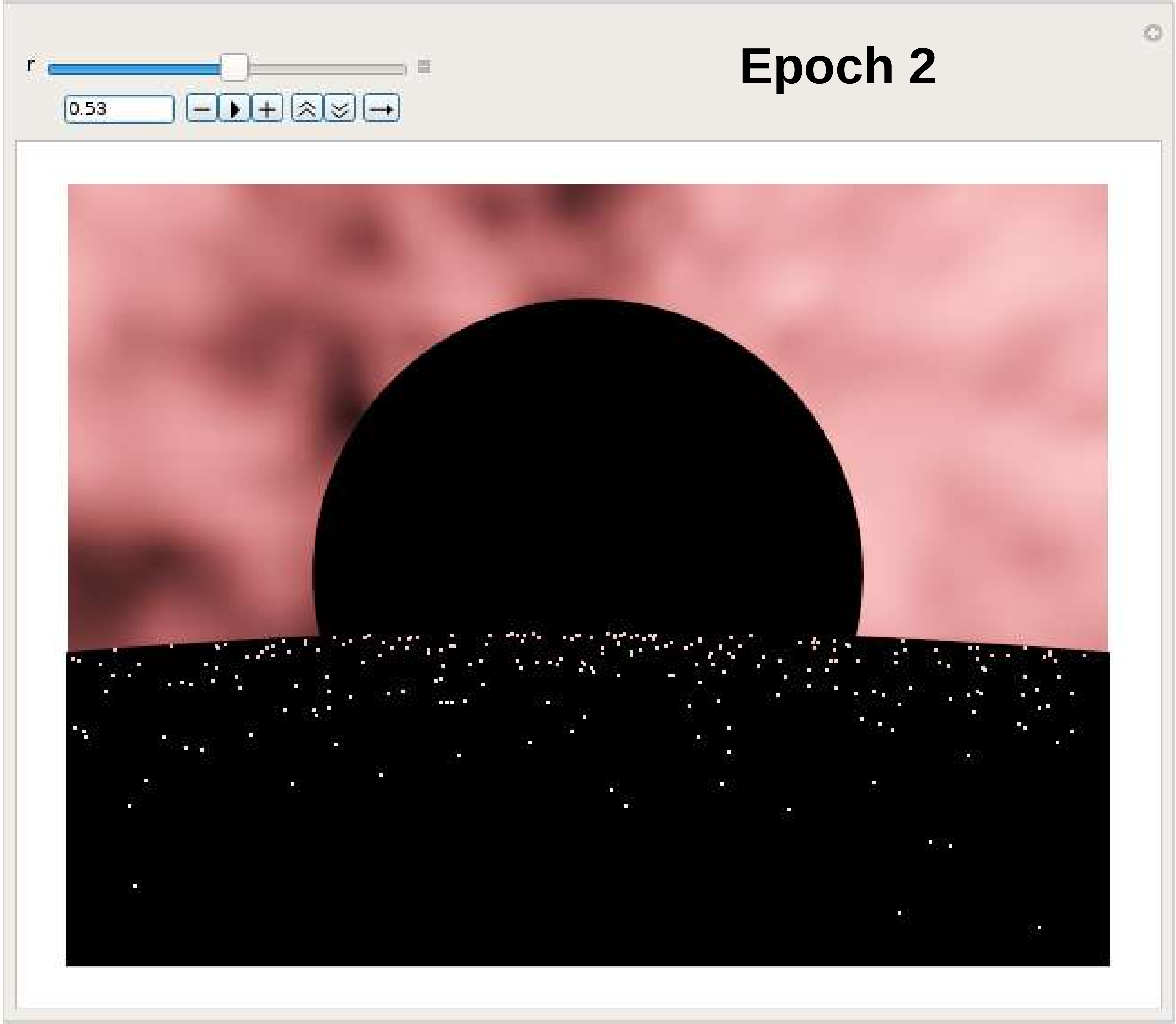
Epoch 1



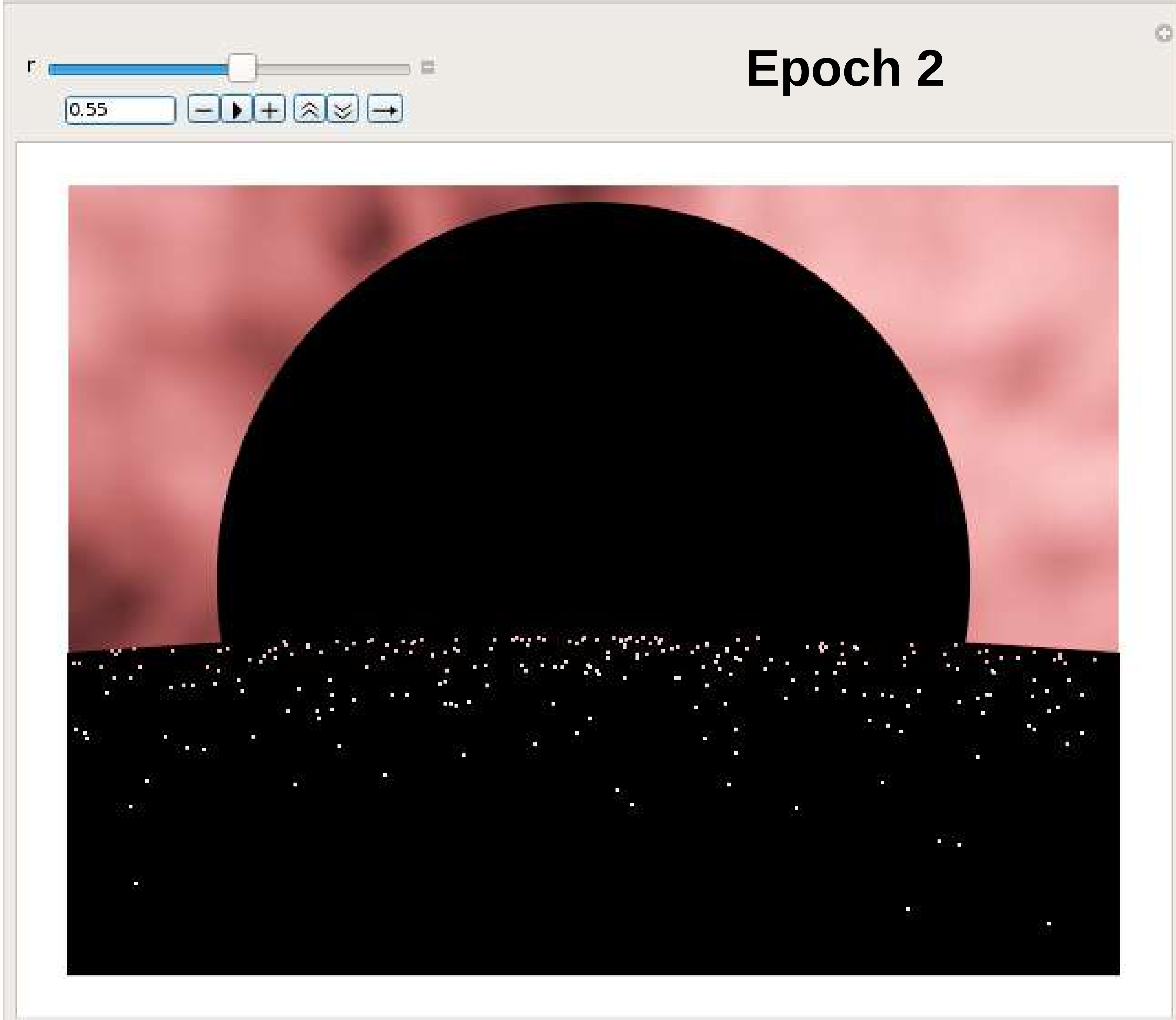
Epoch 2


0.51
the edge of the universe
becomes visible
(a hole in CMB)
* the transition moment E1-2 cannot be
predicted before it happens …

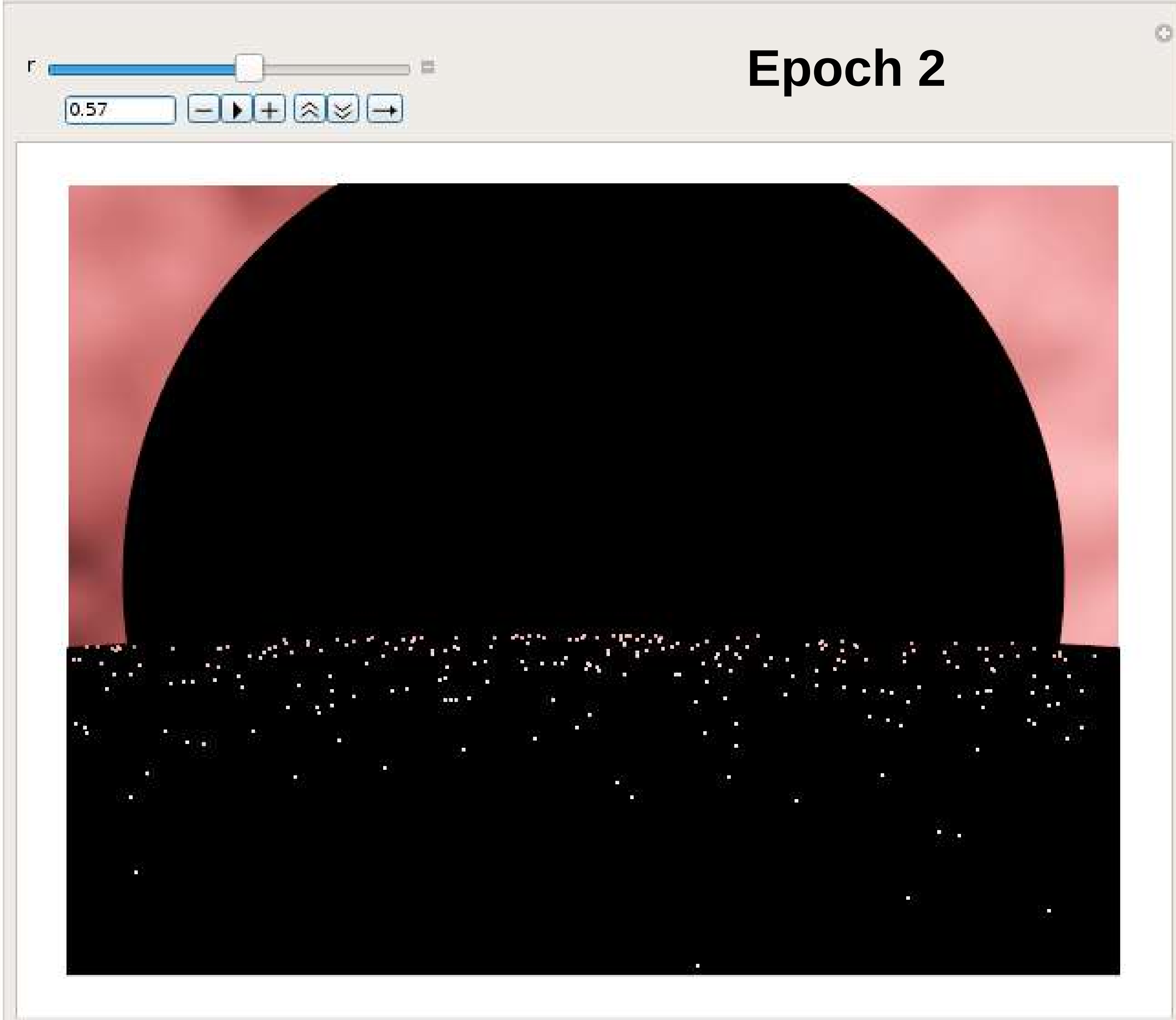
Epoch 2

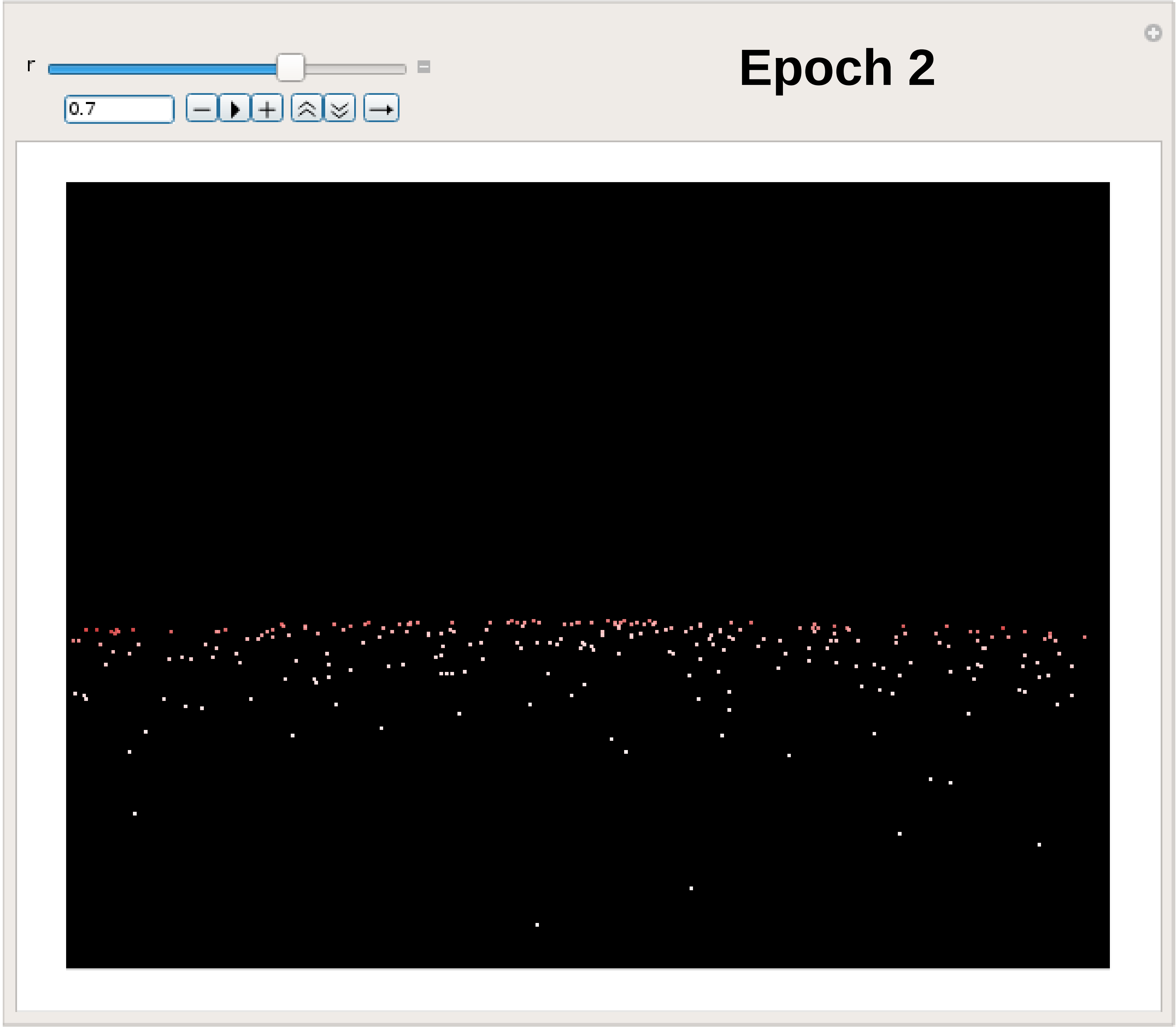


Epoch 2



Epoch 2





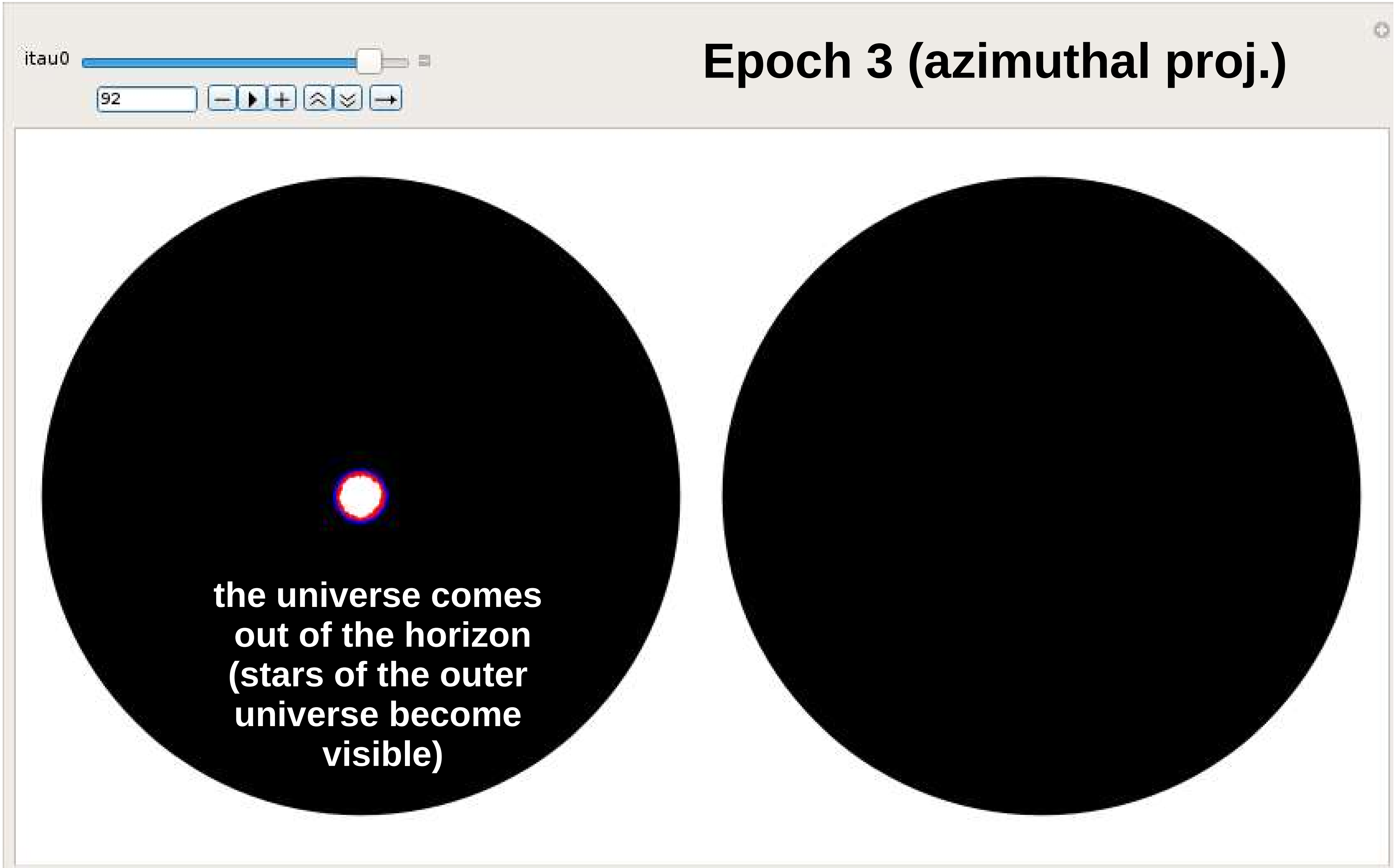
r
0.7
Epoch 2

Epoch 2

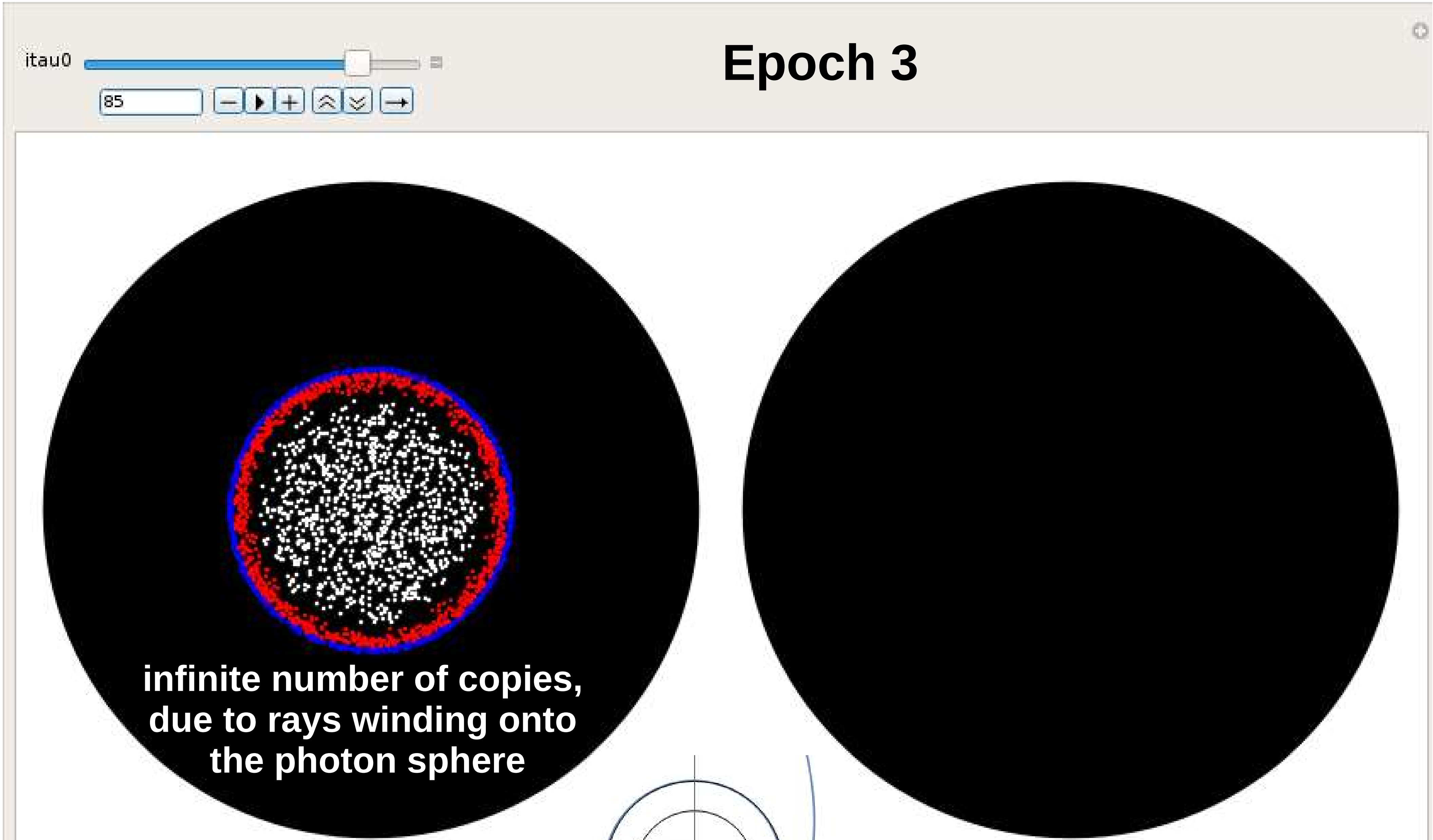
r

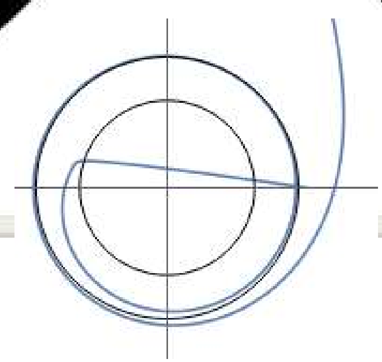
1

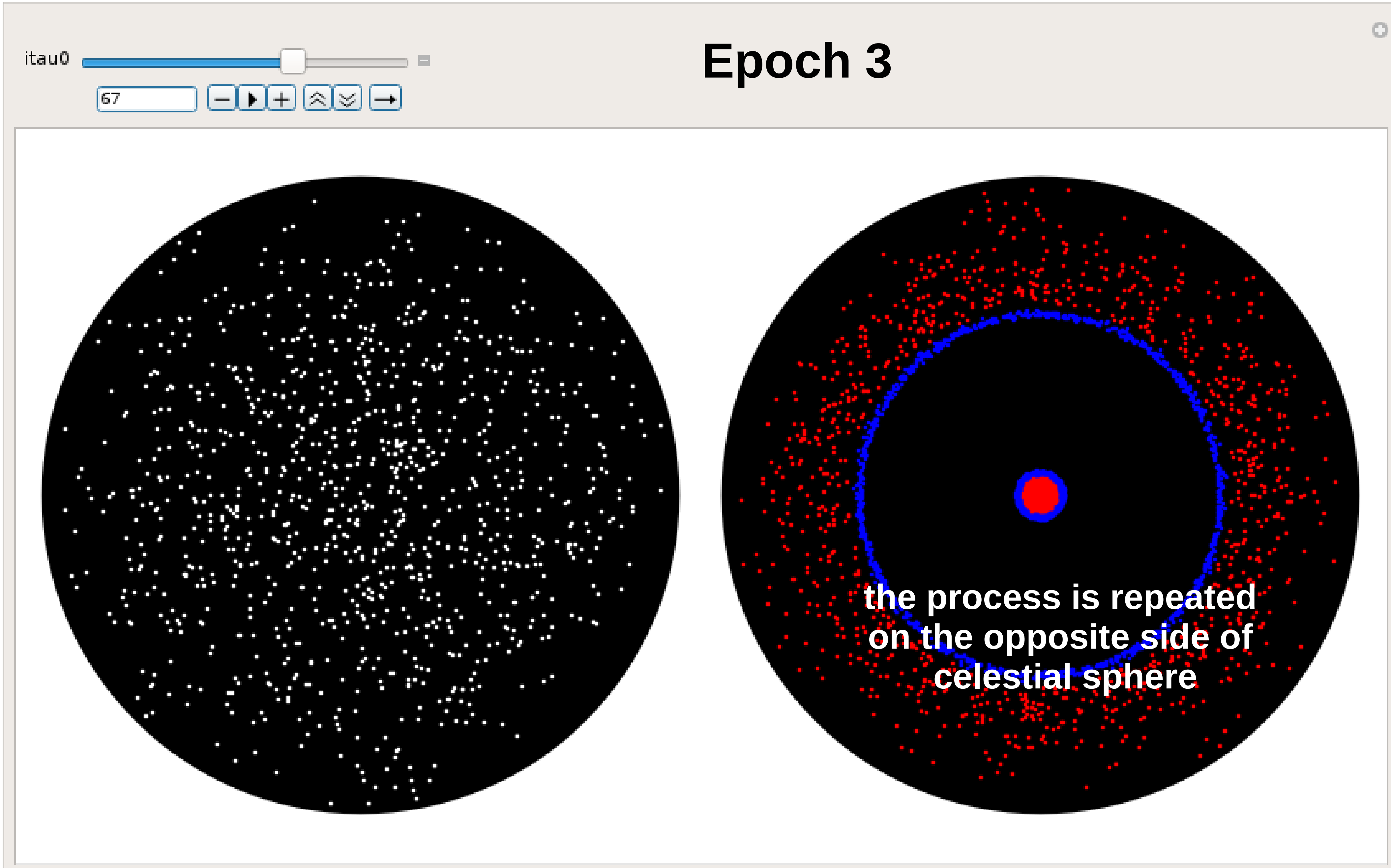
Epoch 3 (azimuthal proj.)

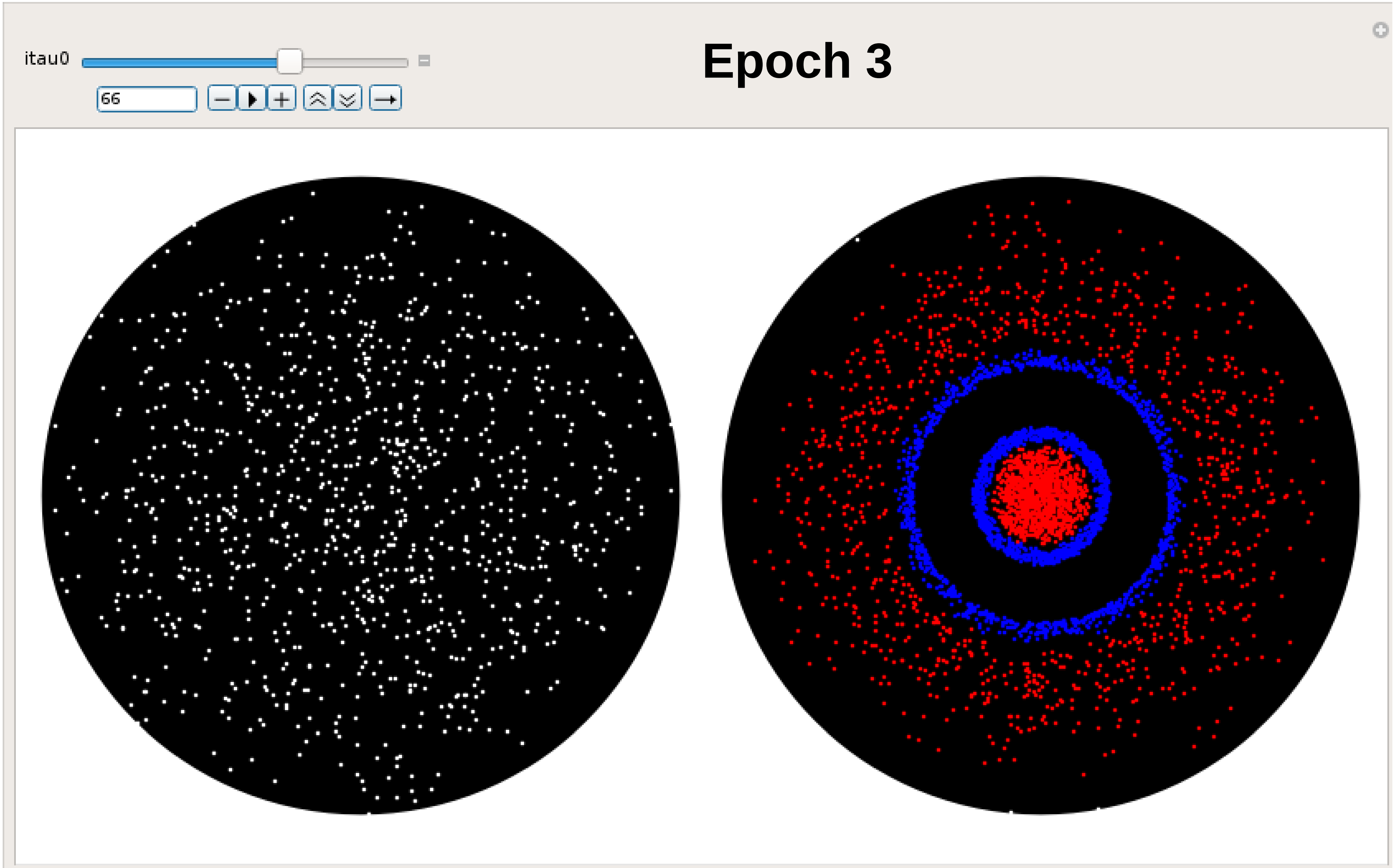


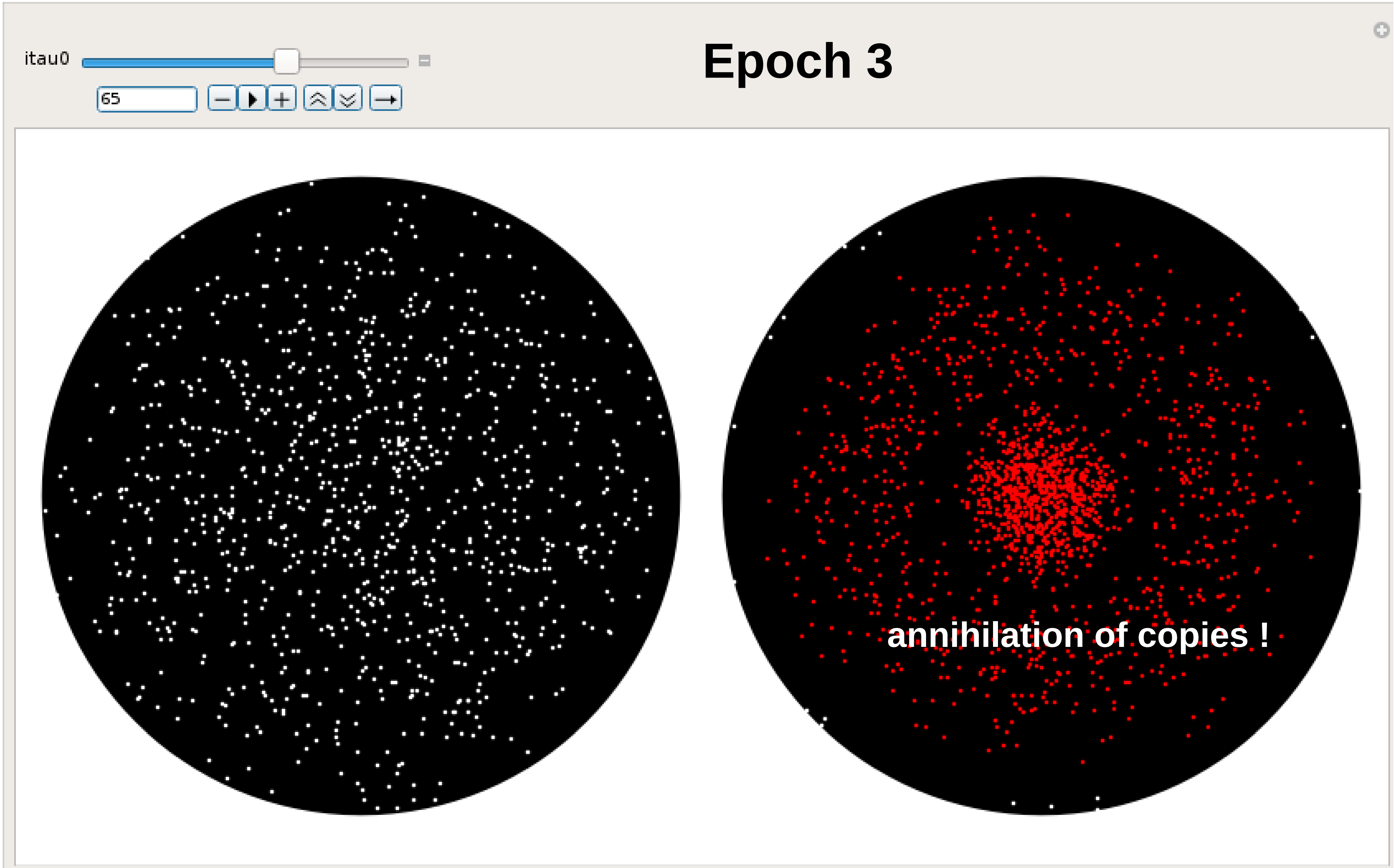
Epoch 3

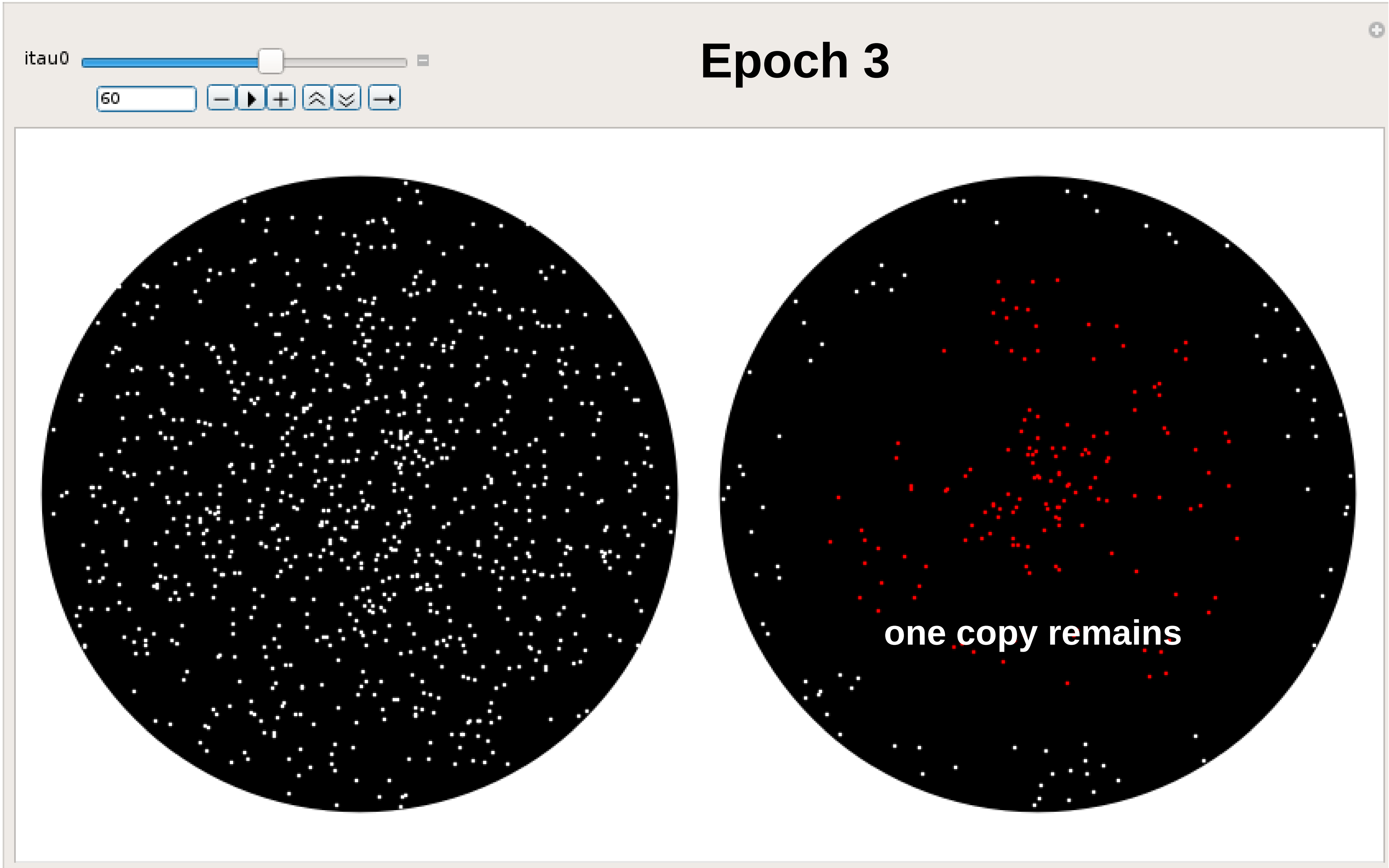

itau0
85
infinite number of copies, due to rays winding onto the photon sphere

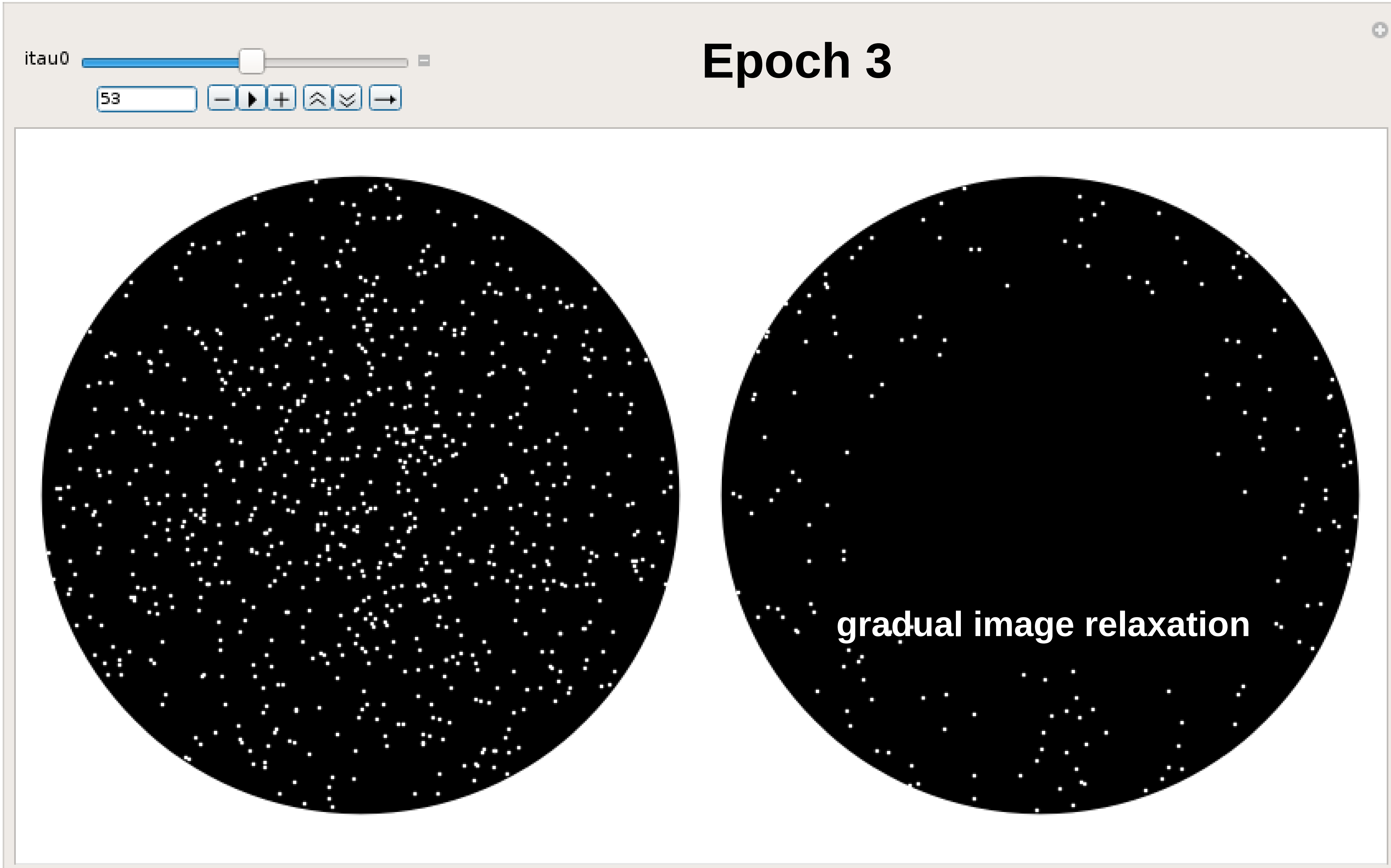


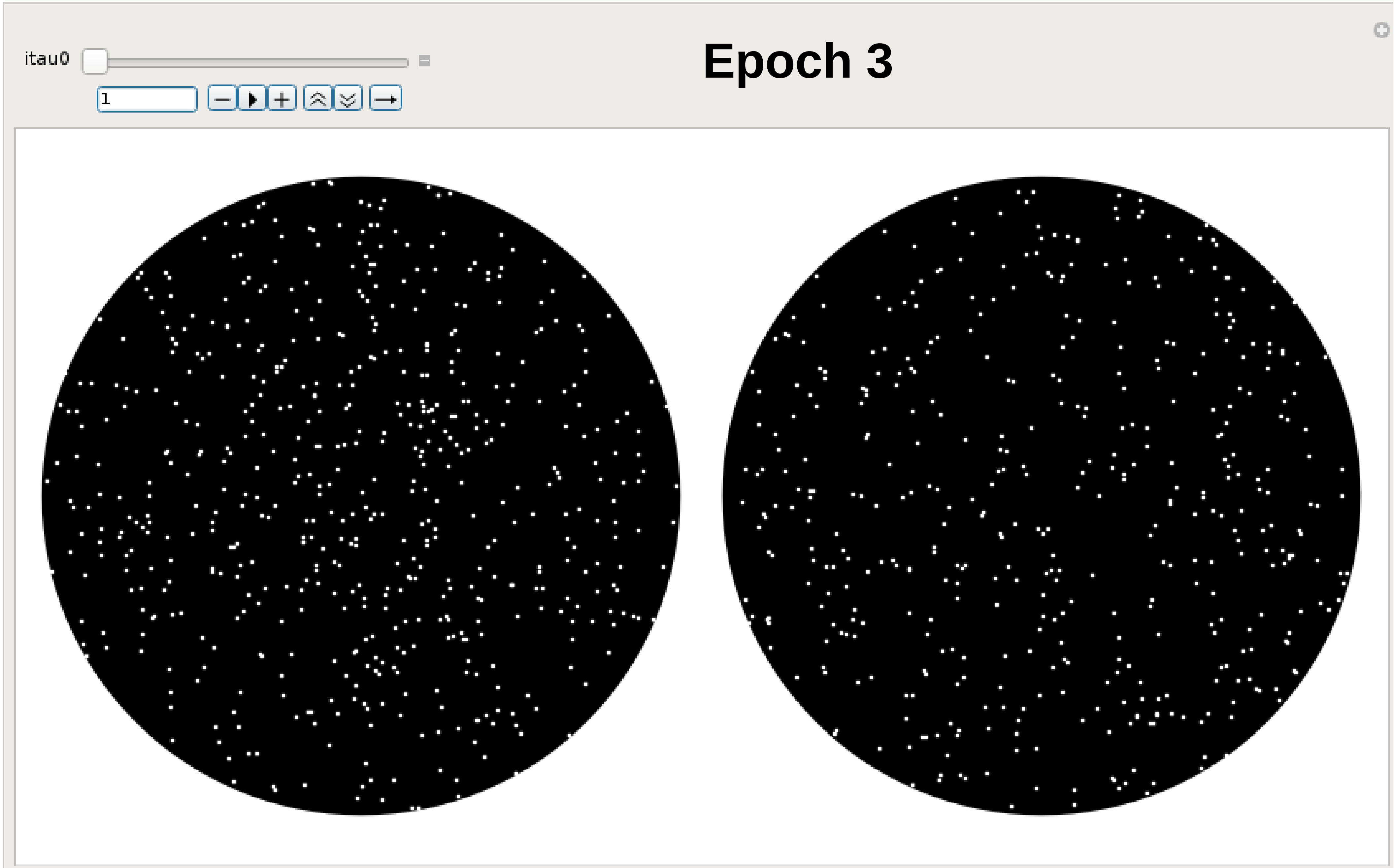

itau0
67
Epoch 3
the process is repeated
on the opposite side of
celestial sphere


itau0
66
Epoch 3


itau0
65
Epoch 3
annihilation of copies !


itau0
60
Epoch 3
one copy remains

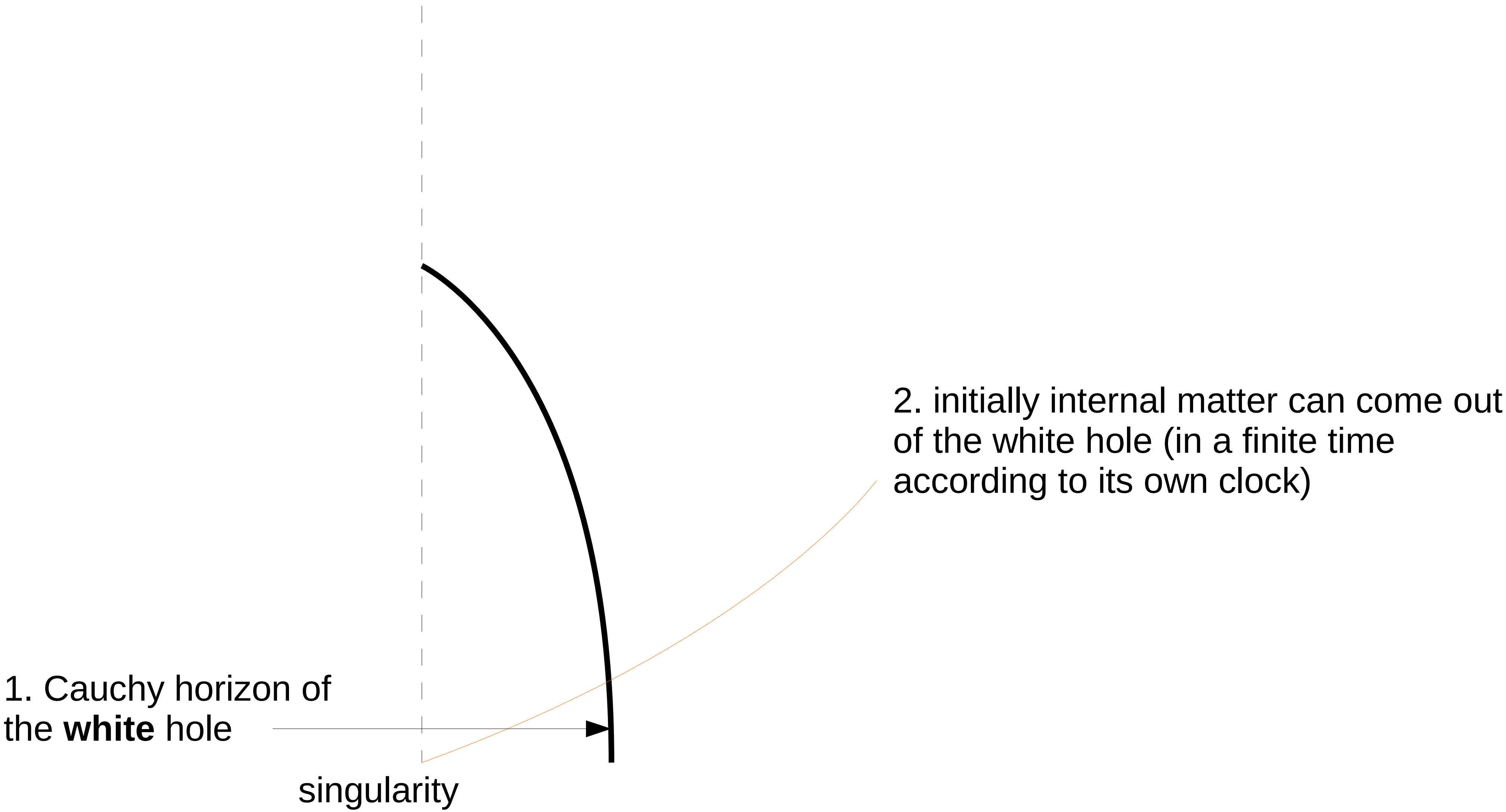

itau0
53
Epoch 3
gradual image relaxation



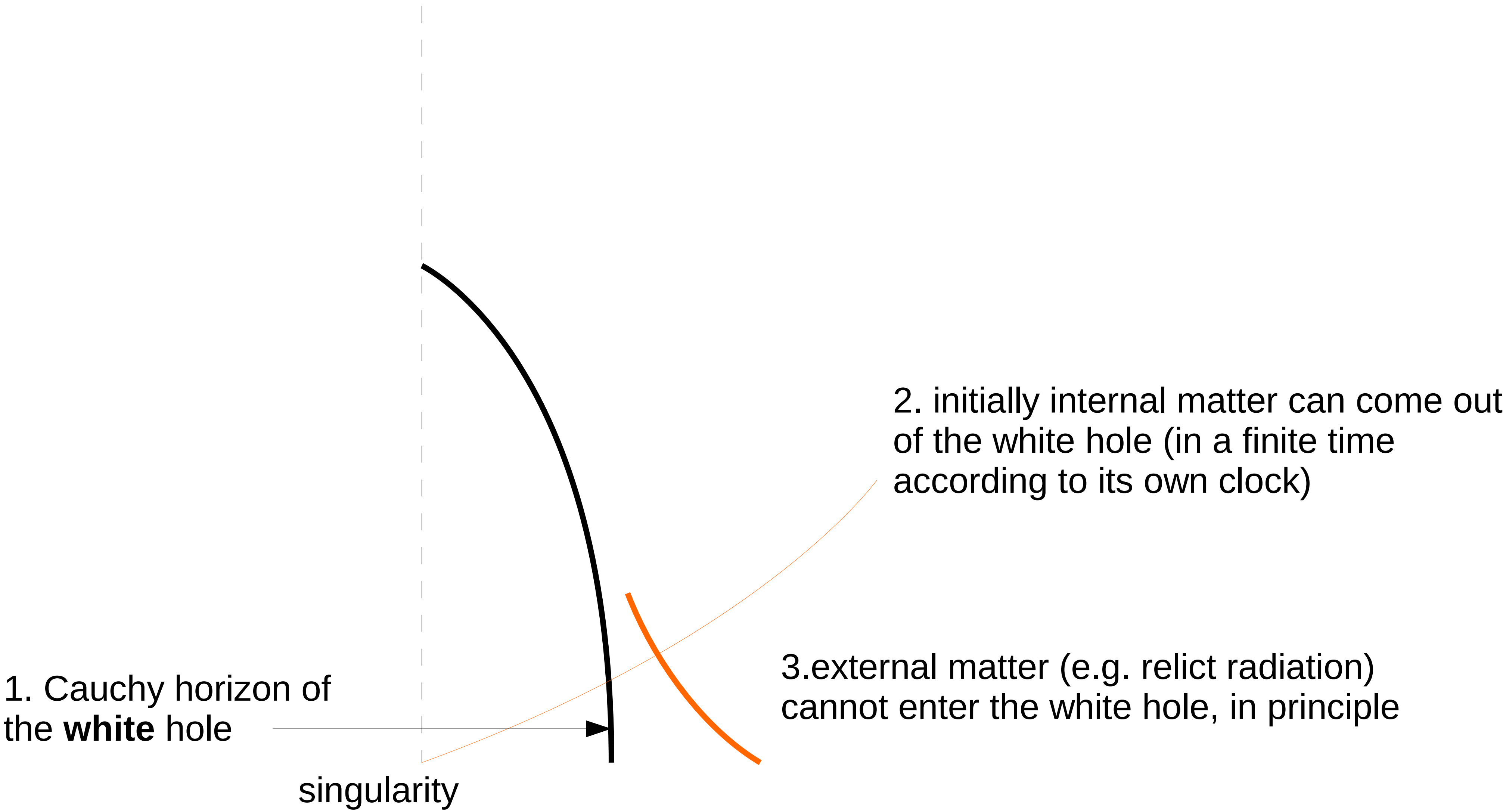
the universe is completely out of the horizon

White hole (it is not as simple)

- Eardley instability (1974) – one should take into account the interaction with external matter

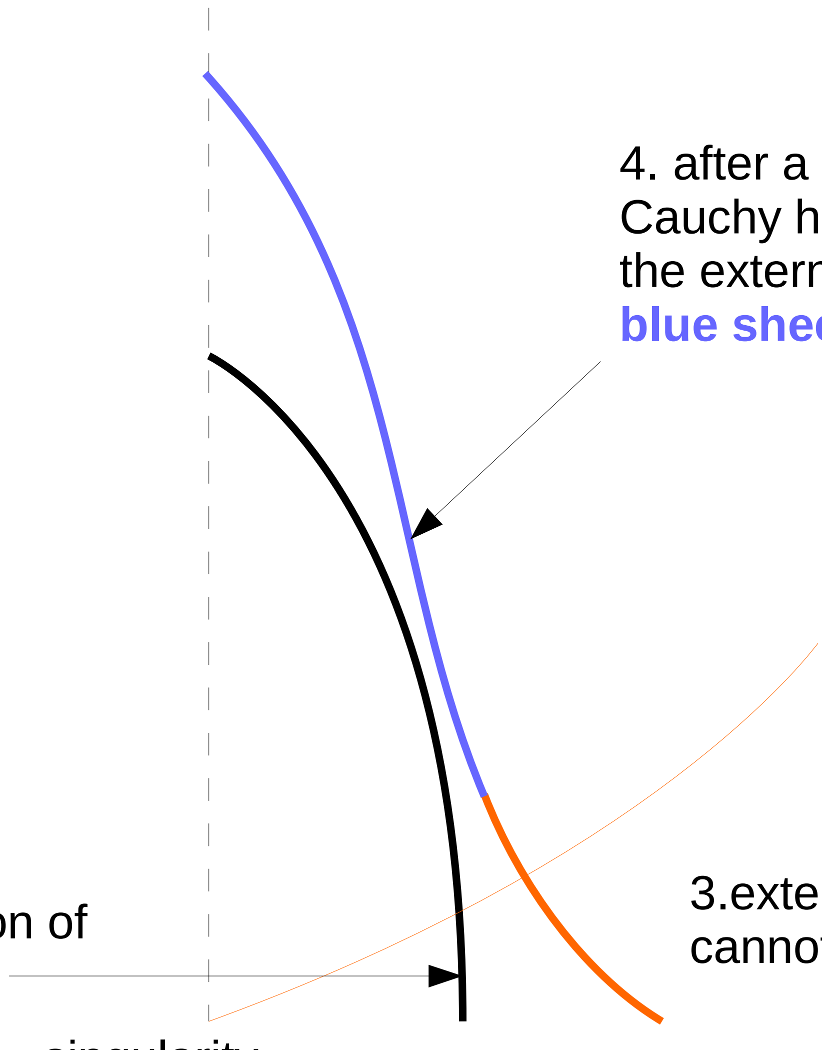


White hole (Eardley instability)



White hole (Eardley instability)

the exponential process:
(value doubled every minute)
$r_s=1.2*10^{10}$m, t=13.8 Gyears,
$A^{-1/2}\sim\exp(tc/(2r_s))\sim$**$\exp(10^{16})$!!!**



4. after a long (13.8 billion years) wait at the Cauchy horizon and superstrong blue shifting the external matter forms a thin super-energetic **blue sheet**

2. initially internal matter can come out of the white hole (in a finite time according to its own clock)

3.external matter (e.g. relict radiation) cannot enter the white hole, in principle

1. Cauchy horizon of the **white** hole

singularity

White hole (Eardley instability)

the exponential process:
(value doubled every minute)
r_s=1.2*10^{10}m, t=13.8 Gyears,
$A^{-1/2} \sim \exp(tc/(2r_s)) \sim$ **$\exp(10^{16})$!!!**

5. as a result, a **black** hole is formed, under the event horizon of which the blue sheet falls, together with the internal matter that didn't had time to escape the white hole

=> *the external matter prevents the eruption of the white hole, only a small part of the internal matter can go outside*

4. after a long (13.8 billion years) wait at the Cauchy horizon and superstrong blue shifting the external matter forms a thin super-energetic **blue sheet**

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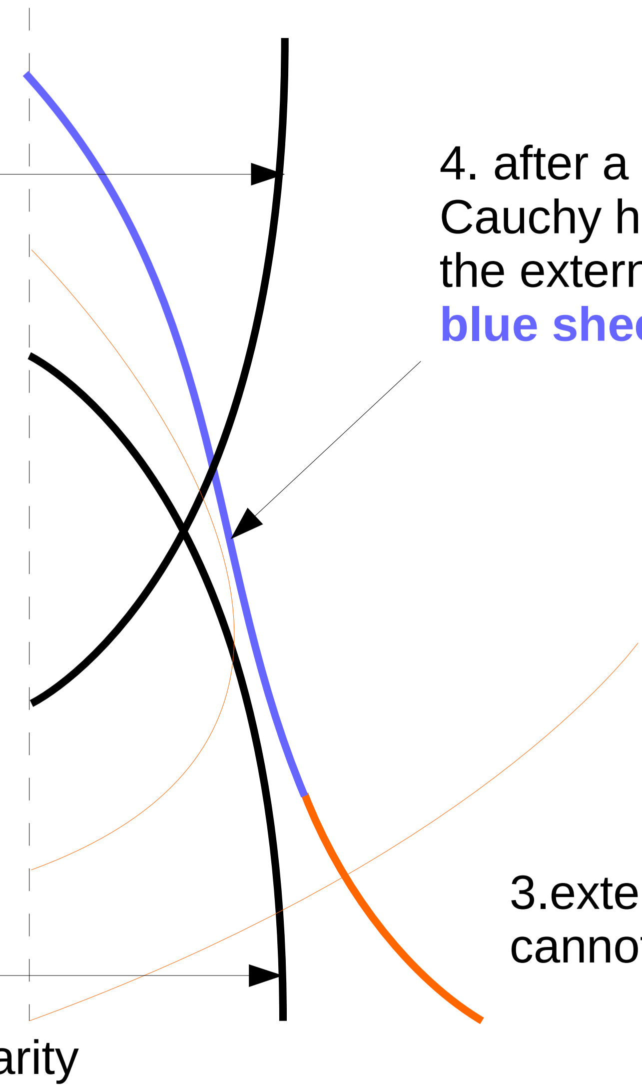
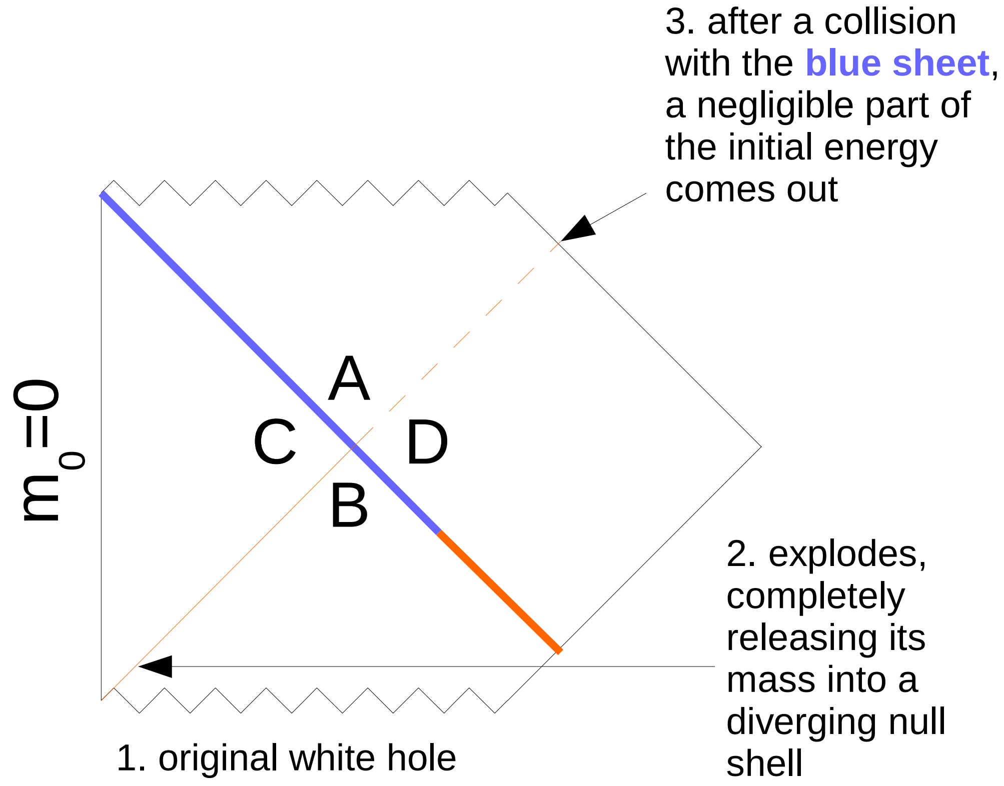
1. Cauchy horizon of the **white** hole



White hole (null shell model)

- Ori-Poisson model (1994)
- gravitational interaction of null shells
- M is the mass of the white hole,
  dm is the mass of the input shell,
  E is the mass / energy of output shell
  (G = c = 1), m_0 - remainder

$$m_A = M - E, \; m_B = M - dm,$$
$$m_C = m_0, \; m_D = M$$



White hole (null shell model)

The proof uses Dray-'t Hooft-Redmount (DTR) relation:

$$f_A f_B = f_C f_D, \;\; f_i = 1 - 2m_i/R, \;\; i = A, B, C, D$$

$$\xi = R/(2M) - 1, \;\; \alpha = dm/M,$$

$$\beta = m_0/M, \;\; \eta = E/M,$$ ← efficiency of white hole eruption

$$\xi = \xi_0 \exp(-\tau/(4M))$$ ~ **exp(-10^{16})**

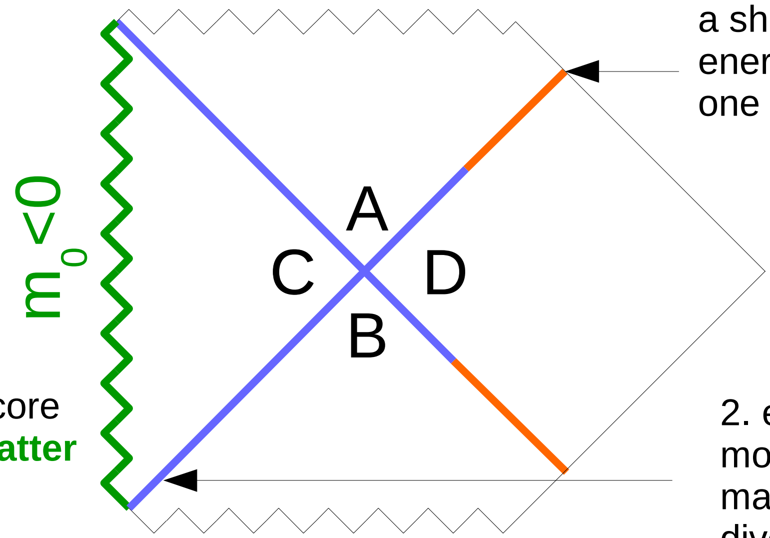
$$\eta \sim \xi/\alpha$$ ~ **exp(-10^{16})**

exponential process of approaching of the ingoing null shell
to the Cauchy horizon

White hole (null shell model)

- so, the black holes are stable, but the white holes aren't ... **what is about T-symmetry?**
- the paradox resolution: there is a T-symmetric scenario according to the principle "for every incoming **blue sheet** there is **the same** outgoing ..."
- negative mass remaineder required in solution (**exotic matter**)

5. **the negative mass** of the core is compensated by the incoming **blue sheet**, a black hole of the same mass as the original white hole formed



4.after the collision of **two blue sheets**, a shell of the same energy as ingoing one comes out

3. leaves behind the core of **exotic matter**

2. explodes, emitting more energy than its own mass in the form of a diverging **blue sheet**

1. original white hole

White hole (null shell model)

- calculation with β<0 shows self-consistency of the solution:

$$\eta = (1 - \alpha - \beta)\,\xi/(\alpha + \xi)$$

$\beta \sim -\alpha/\xi$ $\qquad \eta \sim 1$ (100% efficiency)

T-symmetric case:

$$\eta = \alpha, E = dm,\ \beta = -(\alpha^2 - \xi + 2\alpha\xi)/\xi$$

Negative masses

Energy conditions (Einstein, Hawking):
- there are *no* negative masses

Critics of energy conditions
- Barceló, Visser, Twilight for the energy conditions?, 2002

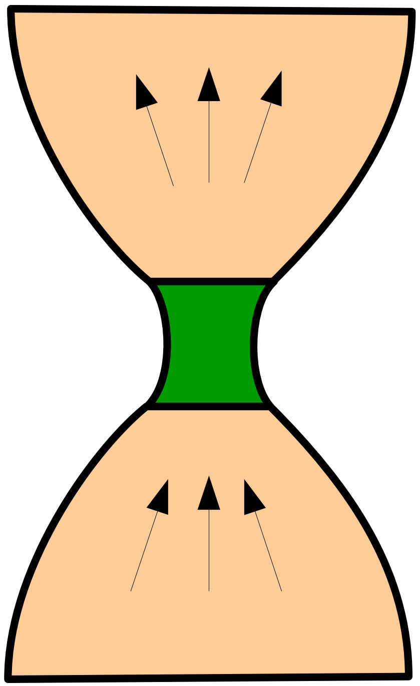
Other models requiring negative masses:

- wormholes (Morris-Thorne 1988)
- warp drives (Alcubierre 1994)
- Planck stars (Rovelli-Vidotto 2014, Barceló et al. 2015)
- RDM stars (arXiv:1701.01569)
- TOV stars with QG core (arXiv:1811.03368)

QG able to generate effectively negative mass densities:

$\boldsymbol{\rho_X = \rho\ (1-\rho/\rho_P)}$ (Ashtekar et al. 2006)

- $\rho=\rho_P \Rightarrow \rho_X=0$ at Planck density the gravity is switched off
- $\rho>\rho_P \Rightarrow \rho_X<0$ in excess of Planck density the effective negative mass appears (**exomatter**), gravitational repulsion (antigravity)



QG bounce
of Planck star:
collapse replaced
by extension,
black hole turns white

RDM and TOV stars

- static spherically symmetric solutions of Einstein field equations (EFE)
- differ by the equation of state (EOS)

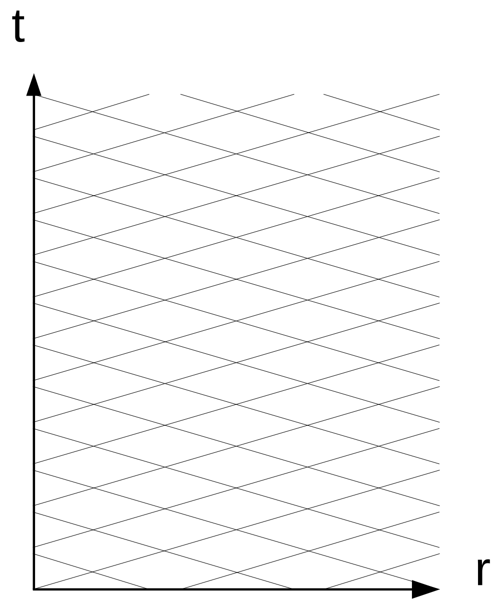
$\rho = p_r$, $p_t = 0$, null radial dark matter (NRDM)

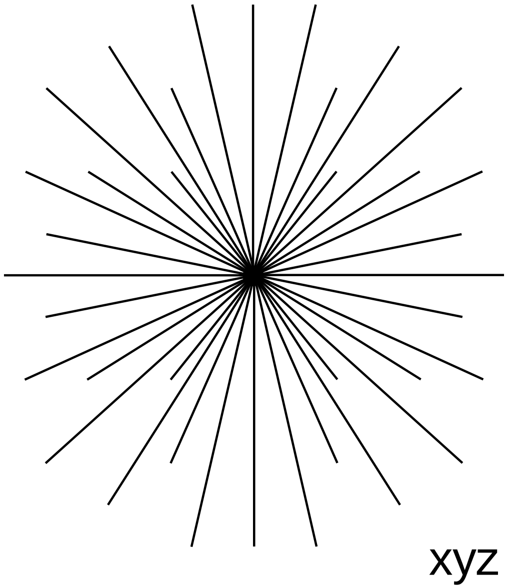
$w\rho = p_r = p_t$, Tolman-Oppenheimer-Volkoff (TOV), w=1/3 photon gas

- in the considered scenario, both contain a core of negative mass
- behave like T-symmetric combination of black and white hole solutions
- permanently absorb and eject (dark) matter
- similarity with Planck star model: QG bounce repeats continuously
- similarity with Ori-Poisson null-shell model: T-symmetric ingoing and outgoing shells repeat continuously, blue sheet formation equivalent to mass inflation phenomenon
- mass inflation (Hamilton, Pollack 2005), a positive feedback loop in black hole solutions with counterstreaming matter flows: (a) increasing energy of the crossing flows => (b) increasig pressure => (c) increasing gravity => (a); leads to an accumulation of very large mass in the counterstreaming region

RDM stars (COSMOVIA 05-Jul-2019)

Static solution, including
T-symmetric superssposition
of ingoing and outgoing radially
directed flows of dark matter

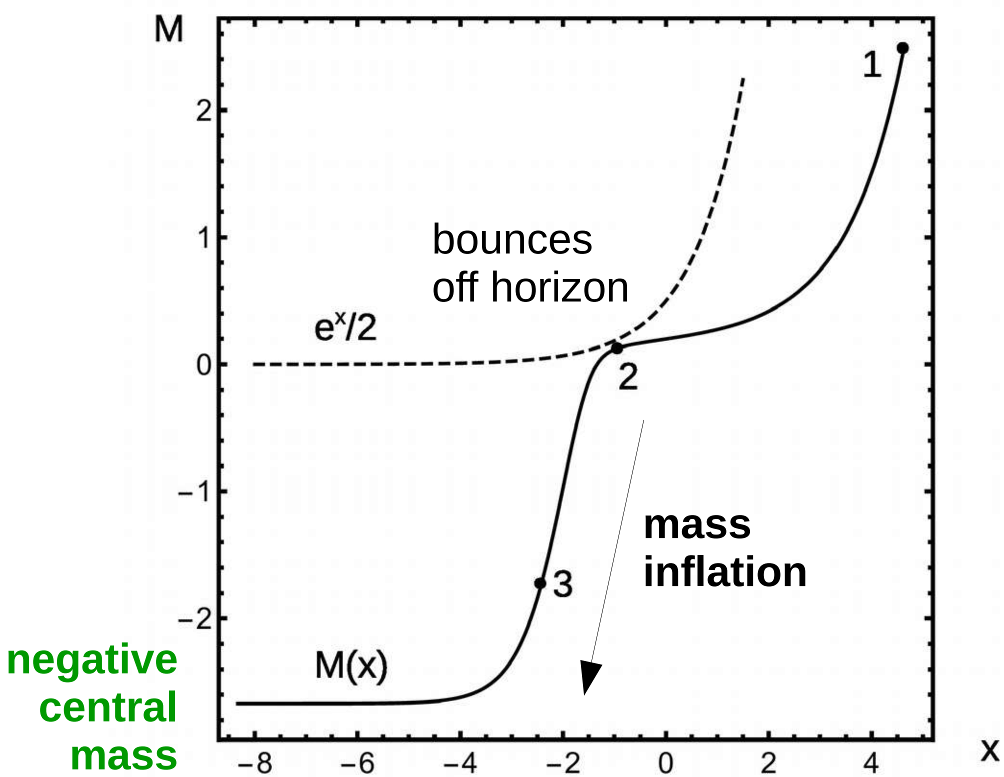




$$ds^2 = -Adt^2 + Bdr^2 + Dr^2(d\theta^2 + \sin^2\theta\ d\phi^2)$$

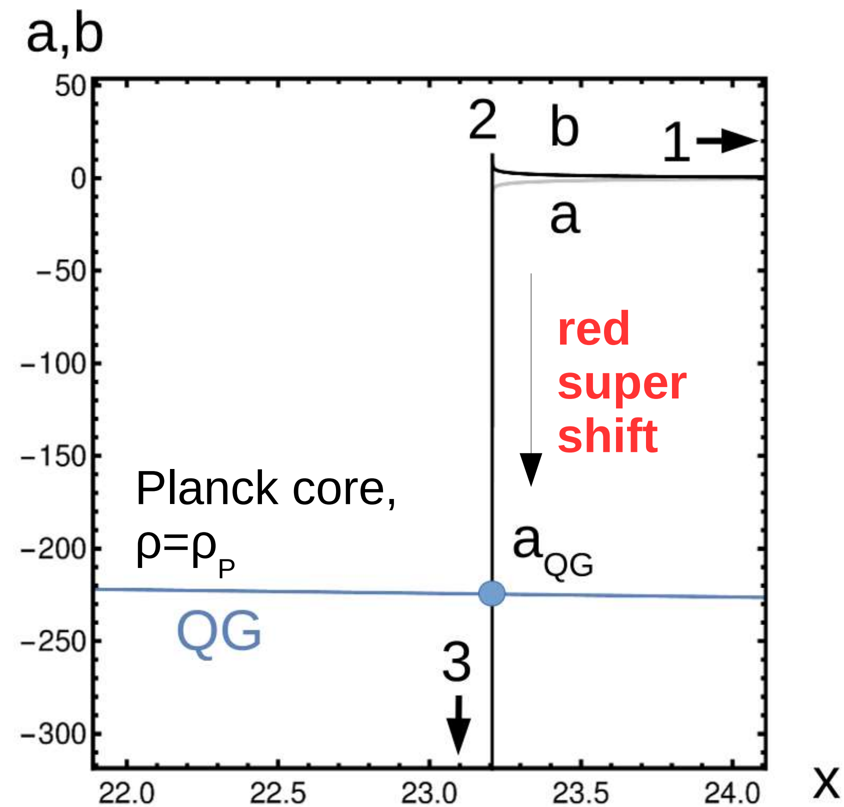
standard metric, A>0, B>0, D=1

RDM stars (COSMOVIA 05-Jul-2019)



$$M = r/2\ (1 - B^{-1})$$

Misner-Sharp mass



calculation for the Milky Way galaxy

$$x = \log r,\ \ a = \log A,\ \ b = \log B$$

New: TOV stars with QG core (QG-bubbles)

TOV equations:

$$w\rho'_r = -(\rho M/r^2)(1+w)(1+4\pi r^3 w\rho/M)(1-2M/r)^{-1}$$
$$M'_r = 4\pi r^2\rho,\ h'_r = 4\pi r(1-2M/r)^{-1}\rho(1+w)$$

metric: $A = e^{2h} f,\ B = f^{-1},\ f = 1-2M/r$

- EFE for static spherically-symmetric solution with $w\rho = p_r = p_t$ EOS
- usually solved assuming regularity in the center: $M(0)=0$
- this condition relates background density and total mass: $\rho(r_1)$, $M(r_1)$, at large r_1
- we will solve the eqs without this precondition
- a concentrated mass can be located in the center

QG-bubbles

Equivalent form:

$$r(p+\rho)A'_r + 2Arp'_r = 0$$

hydrostatic equation
(a consequence of TOV system)

$$4\pi w\rho = k_3 A^{k_4}$$

analytical solution

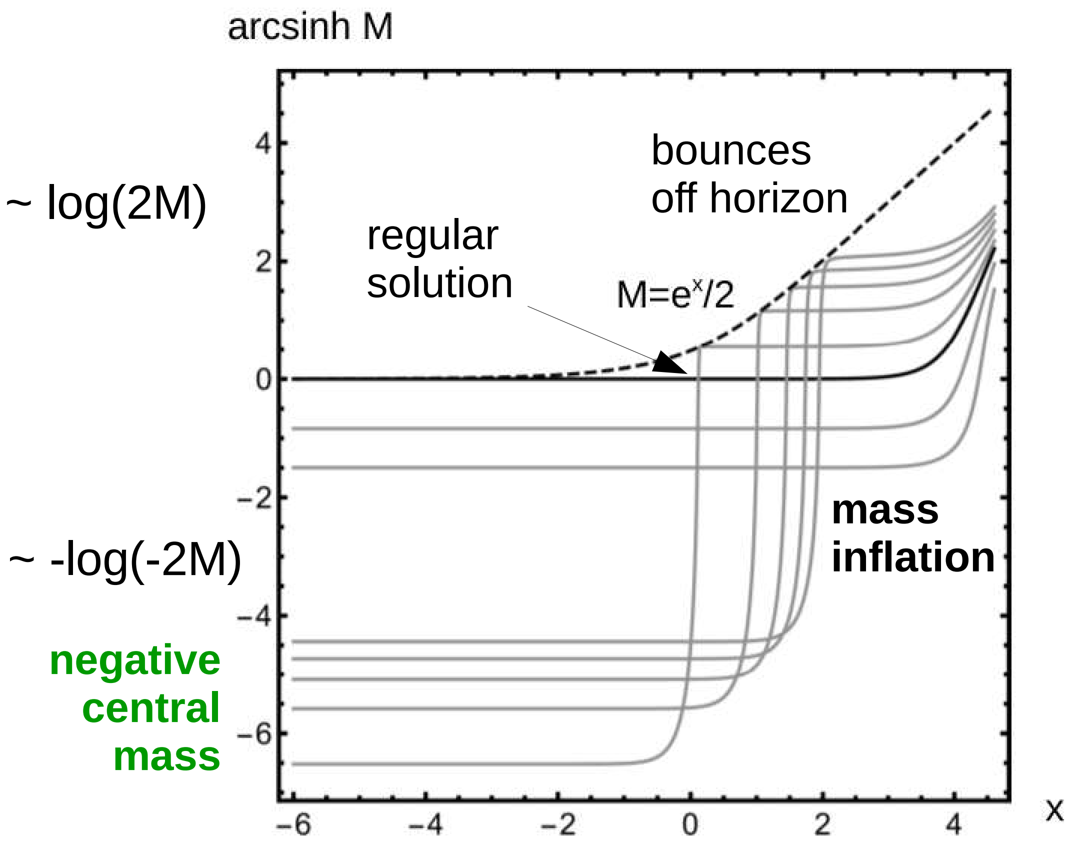
$$k_1 = 1/w,\ k_3 = 4\pi\rho_1 w,$$
$$k_4 = -(1+k_1)/2,\ k_6 = \log k_3$$

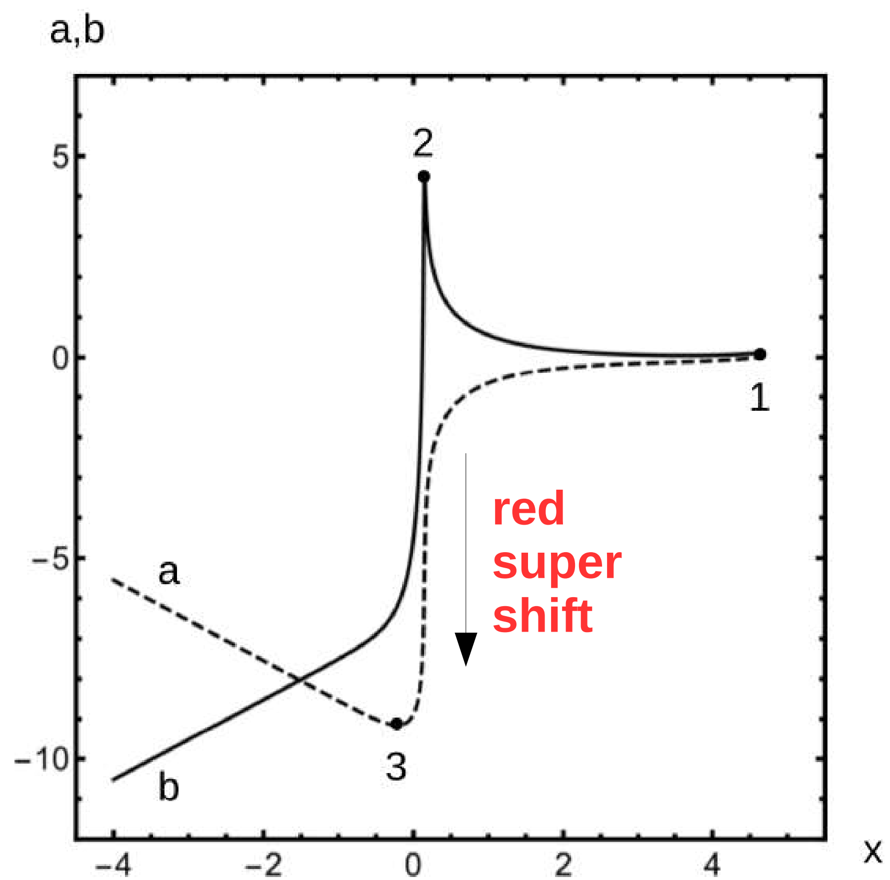
photon gas: w=1/3, k_4=-2

$$a'_x = -1 + e^b + 2e^{2x+k_4 a+b+k_6},$$
$$b'_x = 1 - e^b + (2/w)e^{2x+k_4 a+b+k_6}$$

ODE system in logarithmic vars, more convenient for numerical solution

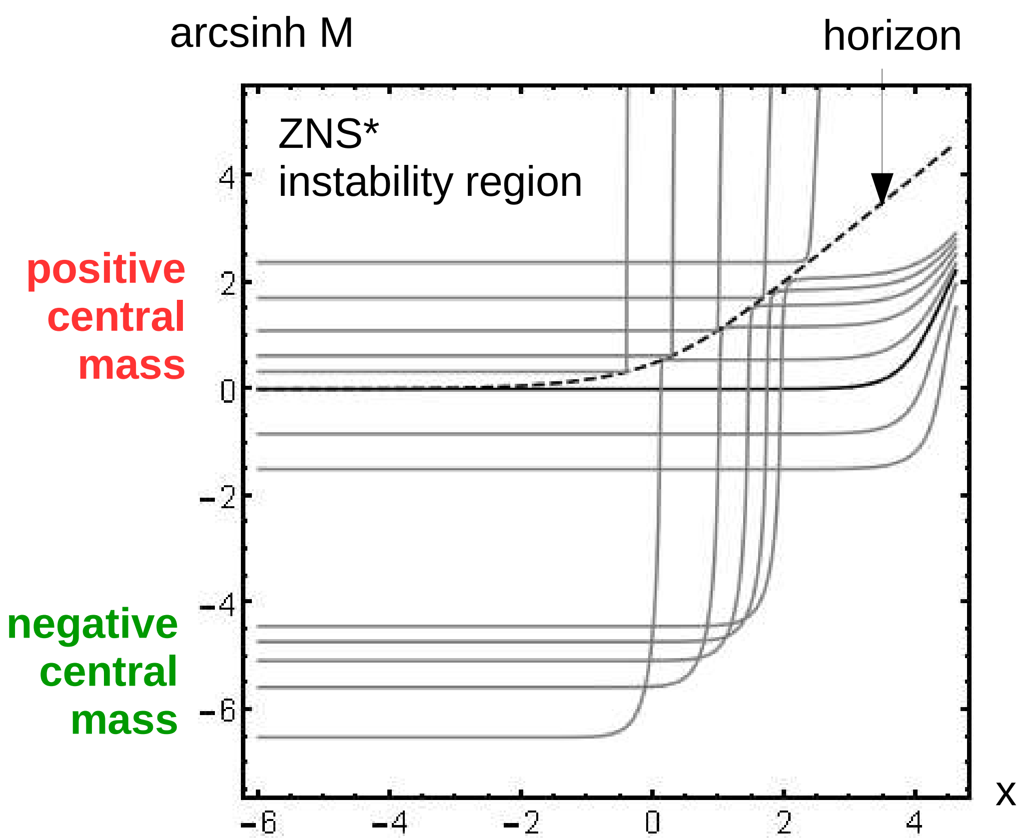
QG-bubbles

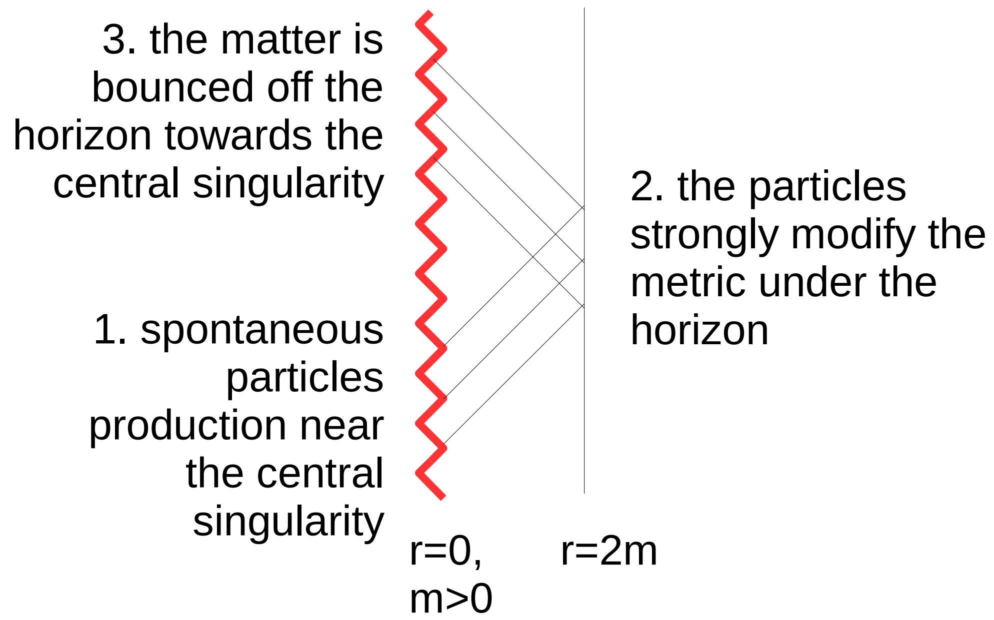




- the regular solution subdivides the set of solutions to two regions
- for solution with initial mass smaller than regular value, the solution just goes to the negative mass in the center
- for solution with initial mass larger than regular value, instead of forming the black hole, the solution bounces of horizon, goes through the mass inflation and ends in even more negative mass in the center
- behavior is similar to RDM-star, just the achieved (a,b,M) values are more moderate

QG-bubbles





- solving TOV-alike system at r<2M for diff. EOS
- solutions resemble: FLRW cosmology of closed type; NRDM model at r<2M
- common property : the matter bounces off horizon and cannot go outside

- *Zeldovich, Novikov, Starobinskiy, Quantum effects in white holes (1974)
- describes the other type of white holes instability
- white hole with the space-like singularity (**m>0**) is unstable, the ejected matter modifies the equations in a way that it cannot come out of the horizon
- we consider the solution with time-like singularity (**m<0**), outside of the instability region

QG-bubbles

Table : TOV model scenario with a stellar mass compact object in cosmic microwave background

model parameters	$M_1 = 10M_\odot$, $w = 1/3$, $\rho_1 = \rho_{cmb} = 4 \cdot 10^{-14}$ J/m^3
starting point of the integration	$r_1 = 10^6$m, $a_1 = 0$, $b_1 = 0.0299773$, $M_1/M_\odot = 10$
supershift begins	$r_2 = 29532.4$m, $a_2 = -54.2719$, $b_2 = 53.7265$, $M_2/M_1 - 1 = -3.64729 \cdot 10^{-23}$, $\boxed{r_2 - 2GM_2/c^2 = 1.37139 \cdot 10^{-19}\text{m}}$
supershift ends	$r_3 = 20638.1$m, $a_3 = -107.522$, $b_3 = -104.685$, $\boxed{\log_{10}(-M_3/M_\odot) = 46.3087}$
minimal radius (Planck length), end of the integration	$r_4 = 1.62 \cdot 10^{-35}$m, $a_4 = -17.6594$, $b_4 = -195.278$, $M_4 = 1.728\ M_3$

QG-bubbles

Comments:

- **r2-rs~10^{-19}m**, the extremely small gap separating the object from the gravitational collapse. At this distance initially inactive matter terms, describing relic radiation, wake up and begin to influence strongly the structure of the solution. This is the result of purely classical model, quantum considerations can change this number.

- log10(-M3/Msun)~46, for comparison: log10(Muni/Msun)~23. Thus, QG-bubble contains a core of negative mass **|M3| >> Muni**, compensated by the coat of TOV matter with (almost) the same positive mass. The numbers for null shell and RDM models are even larger: log10(-M3/Msun)~10^{15}, 10^{5}.

- These enormous numbers could be the result of model idealization. Their origin is the unrestraint phenomenon of **mass inflation**. It can be changed if a (non-gravitational) interaction between the counterstreaming flows and corresponding corrections to EOS will be taken into account.

QG-bubbles

Comments:

- The other origin of large numbers is Planck density: $\rho_P = c^5/(\hbar G^2)$ = **5×10^{96} kg/m^3**. Straightforward estimation for the Planck density core of only **R = 1mm** radius gives the mass $M = (4/3)\pi R^3 \rho_P = 2 \times 10^{88}$kg, gravitational radius: $Rs = 2GM/c^2 = 3 \times 10^{61}$m, compare to the mass and the radius of the observable universe Muni = 10^{53}kg, Runi = 4×10^{26}m => such a core will immediately cover the universe by its gravitational radius, with a large margin. A mechanism for mass compensation is necessary to place such objects in our universe.

- Enormous reserve of energy hiding inside QG-bubble can fuel extremely high-energy phenomena. Figuratively speaking, *if a QG bubble bursts somewhere, the consequences can be felt throughout the universe.*

QG-bubbles as possible sources of FRBs

- take solution of TOV hydrostatic equation: $\rho \sim A^{-2} \Rightarrow \rho_P/\rho_{cmb}=A_{QG}^{-2}$
- consider $\rho_P=4.633*10^{113}$ J/m^3; $\rho_{cmb}=4.19*10^{-14}$ J/m^3, in energetic units $\Rightarrow A_{QG}=(\rho_{cmb}/\rho_P)^{1/2}=3*10^{-64}$
- consider a photon of initially Planck energy, $E_{in}\sim E_P$, $\lambda_{in}\sim L_P$ $\Rightarrow$ after applying the redshift, outgoing wavelength $\lambda_{out}=L_P\ A_{QG}^{-1/2}=$**0.9mm**
- compare with $\lambda_{exp}=$**37.5mm** (for the highest 8GHz FRB detection of FRB121102) deviation $\lambda_{exp}/\lambda_{out}$ **~40**
- can be considered as a good hit, taking into account 127 orders of difference in the input density parameters
- technically can be compensated by an attenuation factor $E_{in}= E_P/N$, the initial photon is N~40 weaker than Planck energy
- a part of this factor can be related with (1+z) Hubble redshift, z~0.2-0.3, N~30

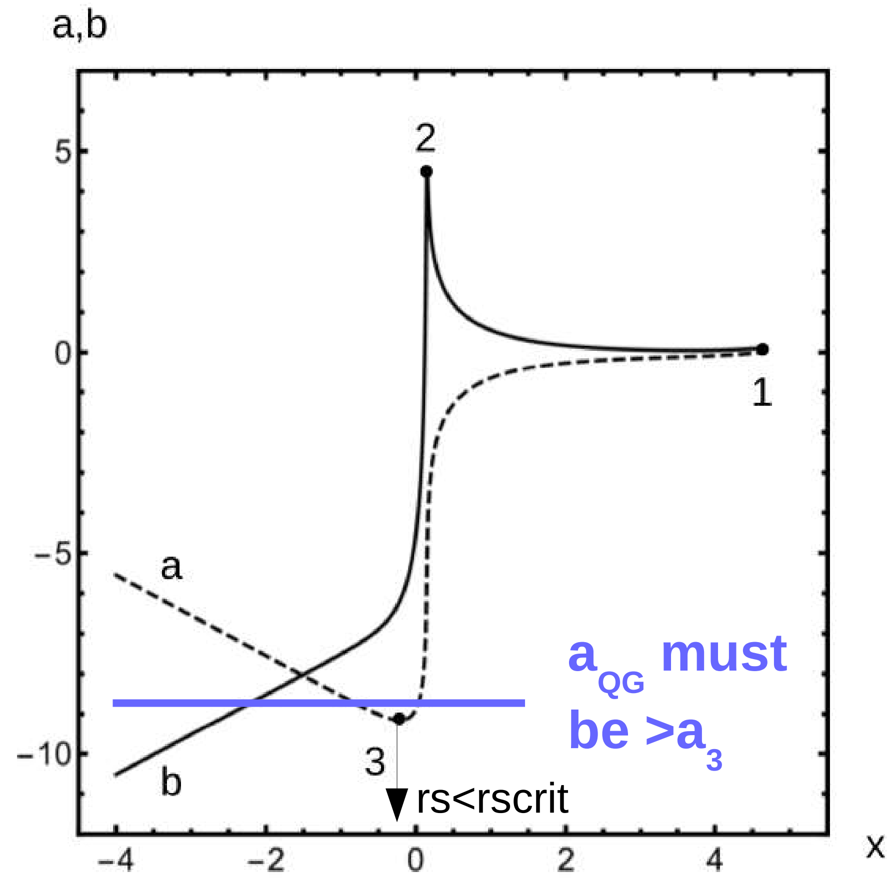
QG-bubbles as possible sources of FRBs

- **can the pulse duration be estimated?** depends on scattering:
- (a) let the initial duration be in the Planck range: $t_{in} \sim T_P$, after applying the time dilation $t_{out} \sim T_P A_{QG}^{-1/2} = 3*10^{-12}$ s << $t_{exp} \sim$ ms (ok), then the scattering on intergalactic, destination and host galaxy medium* can stretch a picosecond pulse to the observed ms duration
- (b) let the initial duration be $t_{in} \sim 10^9 T_P$, then $t_{out} \sim$ ms (scenario without scattering)

* Weishan Zhu, Long-Long Feng, Fupeng Zhang, The scattering of FRBs by the intergalactic medium: variations, strength and dependence on dispersion measures (2018), arXiv:1808.05739

QG-bubbles as possible sources of FRBs

- **can the Planck density be reached?**
- in point 3 solution has a minimum of the redshift factor
- reachability of Planck density: $a_{QG} > a_3$
- fixing $\rho_{bgr} = \rho_{cmb}$ and varying solution mass, this condition is satisfied at $M < 7.6 \cdot 10^{22}$ kg ~ Moon's mass, rs<rscrit=0.11mm (micro QG-bubbles)



QG-bubbles as possible sources of FRBs

Table : micro QG-bubble, the critical case

model parameters	$w = 1/3$, $\rho_1 = \rho_{cmb} = 4 \cdot 10^{-14}$ J/m^3, $\boxed{a_{QG} = -146.264}$
starting point of the integration	$r_1 = 1.13042 \cdot 10^{-2}$m, $a_1 = 0$, $b_1 = 0.0100503$, $M_1 = 7.61132 \cdot 10^{22}$kg
supershift begins	$\boxed{r_2 = 1.13042 \cdot 10^{-4}\text{m},}$ $a_2 = -73.6529$, $b_2 = 73.0876$, $r_2 - 2GM_2/c^2 = 2.04973 \cdot 10^{-36}$m
supershift ends	$r_3 = 7.89967 \cdot 10^{-5}$m, $\boxed{a_3 = -146.264,}$ $b_3 = -143.408$, $\log_{10}(-M_3/M_\odot) = 54.7085$
minimal radius (Planck length), end of the integration	$r_4 = 1.62 \cdot 10^{-35}$m, $a_4 = -75.7824$, $b_4 = -214.619$, $M_4 = 1.72898\ M_3$

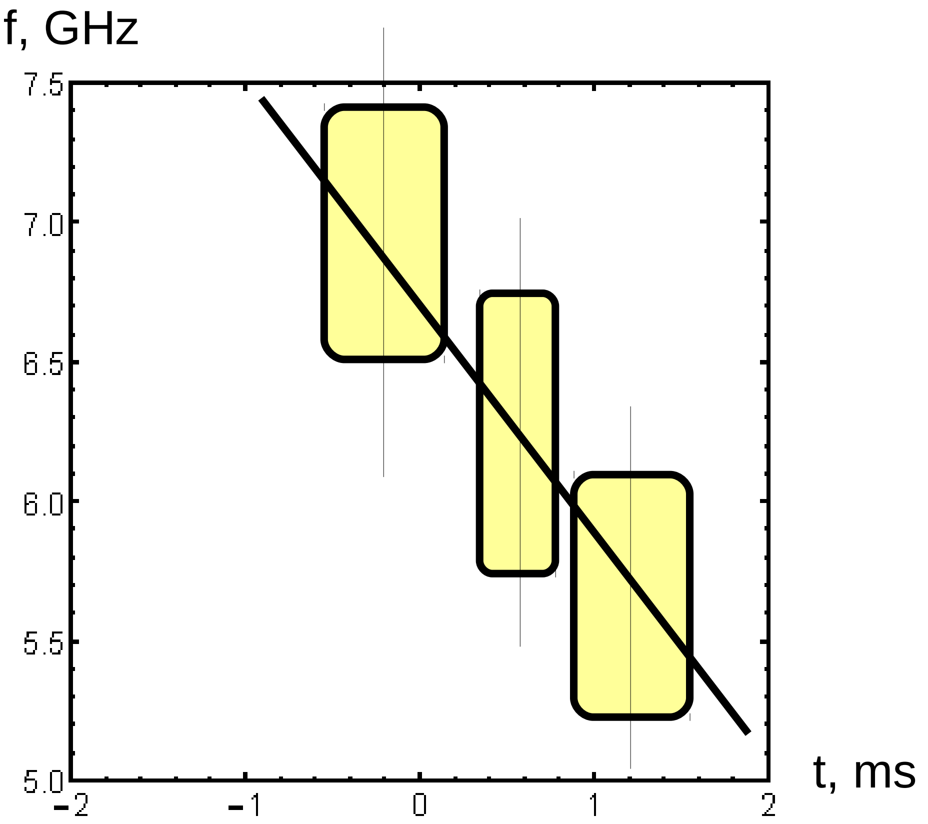
QG-bubbles as possible sources of FRBs

- **can the bursts repeat?**
- there is an inner reserve of energy for $7.6 \cdot 10^{22}$kg*c^2/($10^{32\text{-}34}$J)~$10^{6\text{-}8}$ bursts
- the energy can be also refilled from the environment (e.g., a companion, an asteroid belt,...)
- in this refilling, when the threshold is rs>rscrit passed, the conditions for QG-core existence disappear; this can trigger the FRB, that will return the system to rs<rscrit state (autonomous oscillations)
- if the refilling mechanism is responsible for FRB generation, the difference between repeating/non-repeating FRB populations is in their environment, active refilling – repeating, empty space – non-repeating FRBs

QG-bubbles as possible sources of FRBs

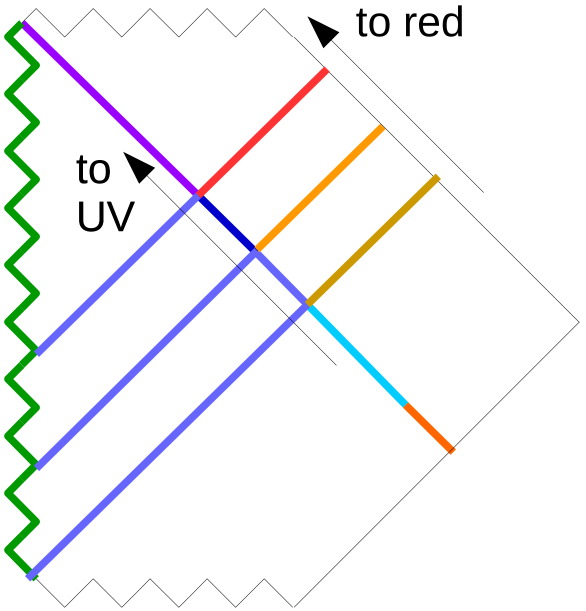
FRB signals show **substructure**, consisting of sub-bursts with downward frequency drift

- DM-compensated FRB121102 signal (vertical sub-bursts)
- sub-bursts have downward frequency drift
- a schematic representation of data from Gajjar et al., arXiv:1804.04101



QG-bubbles as possible sources of FRBs

- **qualitative explanation**, using null-shell model
- consider sequential outgoing shells colliding with ingoing blue sheet
- apply DTR relation after every collision
- in this process, the blue sheet is shifted more towards ultraviolet, while the outgoing shell – more to red
- this can explain downward frequency drift
- between the main bursts the system is regenerated by energy exchange with the environment
- next time the burst can start from a large frequency again

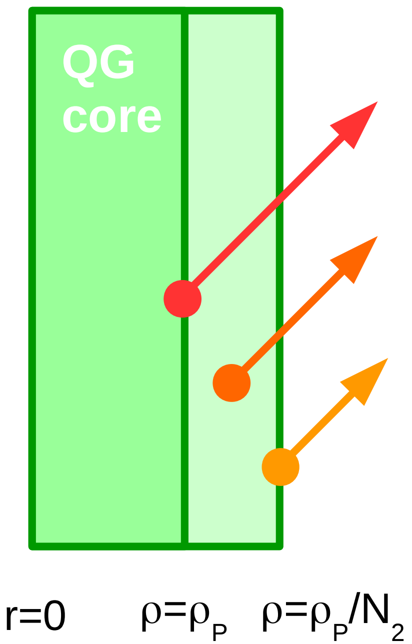


QG-bubbles as possible sources of FRBs

- **estimation** for stationary TOV model
- assuming that the surface of QG core is fuzzy, starting at density $\rho=\rho_P/N_2$, ending at $\rho=\rho_P$, N_2~2-10
- redshift factor $A^{-1/2}\sim\rho^{1/4}$ increases with the depth
- sub-bursts start at higher layers, proceeding to deeper layers, with increasing redshift
- $\lambda_{start}/\lambda_{end}\sim N_2^{-1/4}\sim$**0.6-0.8**
- experimentally:

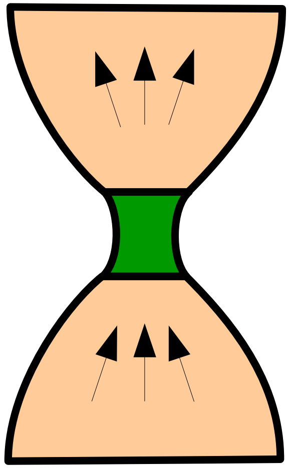
  0.7-0.8 Gajjar et al., arXiv:1804.04101

  0.6-0.8 Hessels et al., arXiv:1811.10748



QG-bubbles as possible sources of FRBs

- **Barrau, Rovelli, Vidotto, *Fast Radio Bursts and White Hole Signals (2014)***
- the paper considers the model of Planck stars: collapse to black hole goes through the quantum bounce to the eruption of the white hole
- estimates a time of recollapse depending on the mass of the star: $t=0.2M^2$, in Planck units
- equating it with Hubble time, obtains an estimation of the mass and the size of Planck stars, created at the Big Bang and exploding „today“: $M=(5t_H)^{1/2}=1.2*10^{23}$kg, $rs=2M=(20t_H)^{1/2}=0.2$mm



QG bounce of Planck star (a reminder)

QG-bubbles as possible sources of FRBs

- BRV model predicts an observable signal at λ~rs~**0.2mm**
- the cosmological redshift correction is also applied
- the result is numerically similar to our model (λ~**0.9mm**), although obtained in completely different consideration (recollapse of Planck stars vs the redshift of photons of initially Planck energy that arise in stationary TOV solutions with a QG-core in thermal equilibrium with CMB)
- BRV formula $\boldsymbol{\lambda \sim (20 t_H)^{1/2}}$ and our prediction $\boldsymbol{\lambda \sim \rho_{cmb}^{-1/4}}$ coincide upto numerical factor ~4.7, if one takes into account cosmological constraints $\Omega_{cmb}=\rho_{cmb}/\rho_{crit}=4.2*10^{-5}$, $\rho_{crit}=3H^2/(8\pi)$, $t_H=1/H$
- in BRV model of Planck stars only non-repeating FRBs are possible

QG-bubbles as possible sources of FRBs

- **Barceló, Carballo-Rubio, Garay, Jannes, *The lifetime problem of evaporating black holes: mutiny or resignation (2015)***
- proposes repeating recollapses and final stabilization of an object due to dissipative effects
- such a stationary object can be equivalent to RDM-stars and QG-bubbles discussed here; it can produce both repeating and non-repeating FRBs depending on the environment

- **Barceló, Carballo-Rubio, Garay, *Black holes turn white fast, otherwise stay black: no half measures (2016)***
- the paper seems to „close“ the topic of Planck stars, referring to Eardley instability of the white hole part (the white holes under the influence of external radiation turn into black holes, not having time to emit the FRB)
- now we have shown that Eardley instability can be eliminated if the core of the white hole possesses negative mass (as the result of QG corrections when the Planck density is reached)
- => Planck star models and the FRB estimates based on them have right to exist

Conclusion

- equivalence of white holes and the cosmological models (white hole Big Bang) is considered
- visualization of evolution in Lemaître-Tolman white hole model is performed
- Eardley instability and Zeldovich-Novikov-Starobinskiy instability of the white holes are considered
- 3 models of combined black-white holes are considered: Ori-Poisson null shell, RDM- and TOV-stars
- both instabilities in all models can be eliminated if the system has a core of negative mass
- QG is able to generate negative mass effectively, when Planck density is exceeded

Conclusion

- QG-bubbles (TOV-stars with QG-core in thermal equilibrium with CMB) are considered
- produce the redshift of photons from initially Planck energy to FRB range
- can explain repeatability and substructure of FRB
- pulse duration can be explained by standard scattering mechnanisms
- QG-bubbles should be small (<0.11mm) for stability
- related model of Planck stars is considered
- produces similar sizes and FRB parameters as QG-bubbles