The Universe Has Three Edges, and Galaxies Receding Faster Than Light Are Visible

— The edge of light already arrived is 46.137971716 billion light years, the edge of light still to arrive 16.679341150, and the distance at which recession reaches the speed of light 14.507302992. In the time light keeps, only 0.265521405 of the whole remains — the separator is past light, future light or present speed — [Paper 1043]

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September 2026

— From thinking to syncing. —

Abstract

What is called the edge of the universe is not one thing.This paper counts three of them in the same model and shows that all three are different numbers.No new theorem and no new law is claimed. First, and this is the core. There are three edges and all three differ——the edge of light already arrived (the particle horizon) is 46.137971716 billion light years, the edge of light still to arrive (the event horizon) is 16.679341150, and the distance at which recession reaches the speed of light is 14.507302992. The ratios are 2.766174713, 3.180327297 and 1.149720328 (Section 3). **Second, galaxies receding faster than light are visible——recession reaches the speed of light at redshift 1.482226257, and everything beyond that is receding faster than light right now. The microwave background recedes at 3.117598650 times the speed of light today and was receding at 66.655782301 times when it emitted its light. It arrives all the same**(Section 4). **Third, what decides visibility is not the present recession speed——the edge of light already arrived is itself receding at 3.180327297 times the speed of light. What decides is an integral: how much space stretched while the light was travelling**(Section 4). **Fourth, the light still to arrive is limited——light emitted now by anything beyond redshift 1.869562199 will never arrive. That edge exists because of the cosmological constant: in a universe of matter alone the same integral diverges, growing from 18.000000 to 1475.286892 as the lower limit falls from a hundredth to a millionth**(Section 3 and Section 5). **Fifth, in the time light keeps, three quarters have already passed——in conformal time the past is 3.180327297 and the future 1.149720328, so only 0.265521405 of the whole remains**(Section 5). **Sixth, the separator is past light, future light or present speed——the three edges answer three different questions. In the far future the event horizon grows and settles at 17.529528913 billion light years, as the Hubble parameter falls to 0.827592291 of its present value**(Section 6). **Keywords**: cosmological horizon, particle horizon, event horizon, recession velocity, conformal time, cosmological constant.

Scope of this paper (scope note): **No new theorem and no new law is claimed——that the particle horizon, the event horizon and the Hubble radius are different quantities, that galaxies receding faster than light can be observed, and that a cosmological constant produces an event horizon are all standard (Rindler 1956, Davis and Lineweaver 2004).No claim is made about real observations——H0 = 67.4 km/s/Mpc, a matter fraction of 0.315 and a radiation fraction of 9.1 times 10 to the minus 5 are representative values for comparison, and the disagreement over H0 (Paper 297) is not entered.No cosmology is built——only a flat model of matter, radiation and a cosmological constant is used, with dark energy held constant.No claim is made about the fate of the universe——the extrapolation in Section 6 assumes the constant stays constant and says nothing about how the universe ends.Not to be mixed with the black-hole horizon——the event horizon here is cosmological and differs from the surface treated in Paper 485 and Paper 1006.Observability is not discussed——which galaxies can actually be seen is a question for telescopes; only geometry is counted here.Relation to earlier papers：The scope note of Paper 779 stated that only four names for distance are used and that other names are not treated——this paper takes that seat and counts a fifth and a sixth: the distances to the two horizons (no earlier occupant).Paper 779 showed that distance is speed times time only nearby, and obtained an observable radius of 46.137971716 billion light years and a factor 3.345573 over age times the speed of light——this paper reproduces both by a different integral before adding the remaining edges.Paper 297 showed that cosmic distance is a ladder of seven rungs of which only the first is measured directly——every distance used here is a quantity inside the model and the rungs are not touched.Paper 1001 showed that the radius of a dust-filled static universe is set by the growth of a disturbance and the reach of light——that universe is static, this one expands.Paper 1013 showed that acceleration begins at a higher redshift than the one where matter and the cosmological constant have equal density——the two redshifts obtained here, 1.482226257 and 1.869562199, are likewise close but answer different questions.Paper 1039 showed that a matter-free expanding universe has no particle horizon——this universe has all three edges; what separates them is what the universe is made of.**What is added is **setting the three edges side by side in one model with their ratios**, **obtaining the two redshifts by bisection**, **counting the recession speed of the edge itself**, **giving the remaining fraction of conformal time**, and **placing a universe without a cosmological constant as a control**.

1. Notation and the Question

Setting: **a flat universe of matter, radiation and a cosmological constant.$H_0 = 67.4$ km/s/Mpc, matter fraction 0.315, radiation fraction 9.1×10^{-5}, the rest (0.684909000000) the cosmological constant, the same representative values as Paper 779.Lengths are in billions of light years and times in billions of years.$c/H_0 = 14.507302992$ billion light years.**

Question: **when one says "the edge of the universe", which edge is meant?**

2. Reproducing the Figures of Paper 779 by a Different Integral

Computation 2.1: **integrating over the scale factor gives an age of 13.790751864 billion years ($H_0 t_0 = 0.950607558$) and an edge of arrived light at 46.137971716 billion light years, which is 3.345573336 times age multiplied by the speed of light.These match, within 10^{-5}, the values Paper 779 obtained by integrating over redshift.**

> **Observation 2.2**
>
> **the same numbers come out of two routes.One integrates over the scale factor, the other over redshift——every figure below rests on this footing.**

3. There Are Three Edges

Computation 3.1: **the three were obtained in the same model.**

edge	distance (billion ly)	ratio to c/H_0
light already arrived (particle horizon)	**46.137971716**	**3.180327297**
light still to arrive (event horizon)	**16.679341150**	**1.149720328**
where recession reaches the speed of light	**14.507302992**	**1**

The particle horizon is 2.766174713 times the event horizon.

Computation 3.2: **bisection gives the redshifts: recession reaches the speed of light at 1.482226257 and the event horizon lies at 1.869562199.Converting both back to comoving distance returns the original values within 10^{-9}.**

> **Observation 3.3**
>
> **the three answer three different questions.How far has light already come from, how far will light still come from, and beyond what distance is everything receding faster than light at this moment——one word, "edge", covers all three.**

4. Galaxies Receding Faster Than Light Are Visible

Computation 4.1: **for each redshift, the present recession speed and the speed at emission were obtained.**

redshift	comoving distance (billion ly)	speed now	speed at emission
0.5	6.364262907	0.438693733	0.386725073
1.0	11.092381186	0.764606708	0.684564837
1.482226	14.507302992	1.000000000	0.945316018
2.0	17.322752915	1.194071215	1.207087294
5.0	25.908399189	1.785886681	2.469630913
1100	45.227948219	3.117598650	66.655782301

Speeds are in units of the speed of light.

> **Observation 4.2**
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> everything beyond redshift 1.482226257 is receding faster than light and is visible.The microwave background recedes at 3.117598650 times the speed of light now and did so at 66.655782301 times when it emitted——and the edge of arrived light is itself receding at 3.180327297 times.

> **Observation 4.3**
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> visibility is not decided by the present recession speed.It is decided by an integral, how much space stretched while the light travelled——that integral is what Paper 779 meant in writing that distance is speed times time only nearby.

5. The Time That Light Keeps

Computation 5.1: conformal time, time divided by the scale factor, was counted. The past is 3.180327297 and the future 1.149720328, so the future is 0.265521405 of the whole and the past 0.734478595 (with c/H_0 set to 1).

Computation 5.2: as a control, removing the cosmological constant to leave a flat universe of matter alone makes the future integral diverge: lowering the limit to 10^{-2}, 10^{-4} and 10^{-6} gives 18.000000, 198.000000 and 1475.286892, growing without bound.

Observation 5.3

the event horizon exists because the cosmological constant does.In a universe of matter alone, light from any galaxy arrives if one waits——with the constant the integral converges and the arriving light is cut off. In the matter-free universe of Paper 1039 it was the particle horizon that was missing: which edges exist is decided by what the universe contains.

Observation 5.4

by the clock of light, three quarters have passed.Conformal time is exactly the comoving distance light can cover, so the remaining 0.265521405 is also the fraction of the range that will newly become visible.

6. The Separator, and What Comes Next

Computation 6.1: the event horizon was obtained at future scale factors.

scale factor	H/H_0	event horizon (billion ly)	c/H (billion ly)
1	1.000000000	16.679341150	14.507302992
2	0.851052106	17.406548339	17.046315832
10	0.827782586	17.528521327	17.525499139
100	0.827592481	17.529527906	17.529524882

In the limit of the constant alone, $H/H_0 = 0.827592291$ and the event horizon is 17.529528913 billion light years, equal to c/H.

Observation 6.2

the event horizon will grow.Matter still contributes today and keeps the Hubble parameter high, which keeps the horizon small——in future it settles at c/H and the two quantities become one.

Observation 6.3

the separator is past light, future light or present speed.The three edges answer different questions——in the far future the latter two coincide, but today they differ by a factor 1.149720328.

7. What Is Not Said

Observation 7.1

no claim is made about real observations.Representative values were used and the disagreement over the Hubble constant is not entered (Paper 297)——nor is a cosmology built.Nothing is claimed about the fate of the universe——Section 6 extrapolates on the assumption that the constant stays constant.Nor is this mixed with the black-hole horizon——the surface of Paper 485 and Paper 1006 is a different thing.

8. Census and Closing

1. **46.137971716**, **16.679341150**, **14.507302992** **billion ly** (Computation 3.1): **three edges.**
2. **ratios 2.766174713**, **3.180327297**, **1.149720328** (Computation 3.1): **all different.**
3. **redshifts 1.482226257 and 1.869562199** (Computation 3.2): **two boundaries.**
4. **background at 3.117598650 now, 66.655782301 at emission** (Computation 4.1): **visible.**
5. **the edge itself at 3.180327297** (Observation 4.2): **present speed does not decide.**
6. **conformal time 3.180327297 and 1.149720328** (Computation 5.1): **0.265521405 left.**
7. **without the constant, 18.000000 to 1475.286892** (Computation 5.2): **the control.**
8. **future 17.529528913 billion ly** (Computation 6.1): **settles at c/H.**
9. **past light, future light or present speed** (Observation 6.3): **the separator; Paper 297, Paper 779, Paper 1001, Paper 1013 and Paper 1039.**

Closing: **The universe has three edges, and galaxies receding faster than light are visible.The edge of light already arrived is 46.137971716 billion light years, the edge of light still to arrive 16.679341150, and the distance at which recession reaches the speed of light 14.507302992, with ratios 2.766174713, 3.180327297 and 1.149720328. Everything beyond redshift 1.482226257 recedes faster than light today; the microwave background does so at 3.117598650 times now and did at 66.655782301 times when it emitted——the edge of arrived light is itself receding at 3.180327297 times, so visibility is not decided by the present recession speed.In the time light keeps, the past is**

3.180327297 and the future 1.149720328, leaving 0.265521405 of the whole.The separator is past light, future light or present speed.Placed among the earlier papers——the scope note of Paper 779 limited distance to four names; this paper takes that seat and adds the two horizons. The matter-free universe of Paper 1039 has no particle horizon and a universe without a cosmological constant has no event horizon: which edges exist is decided by what the universe contains.To be honest——every integral here is in a textbook. What is added is setting the three side by side, counting the recession speed of the edge itself, and giving what remains on the clock of light.

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