

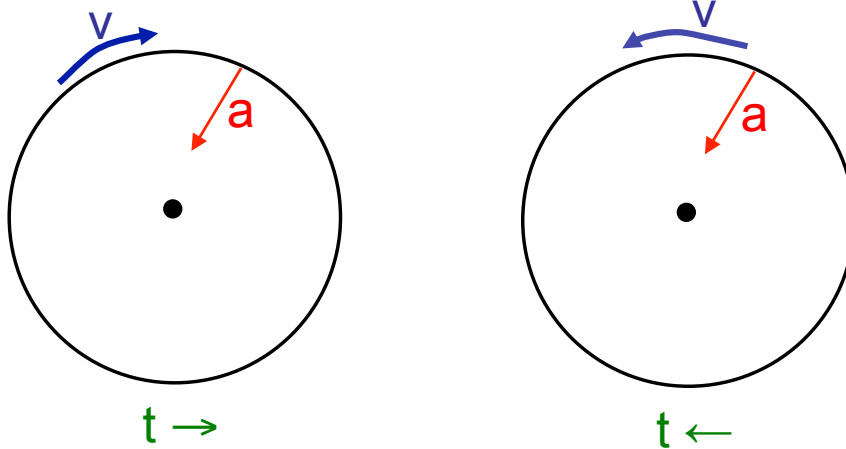
NEWTON'S 2ND LAW

$$\text{FORCE} = \text{MASS} \times \text{ACCELERATION} \quad (\text{a})$$

↑
e.g. Gravity

↑
Rate of Change of Velocity (v)

If time is run backwards, velocity is reversed: e.g. merry-go-round:



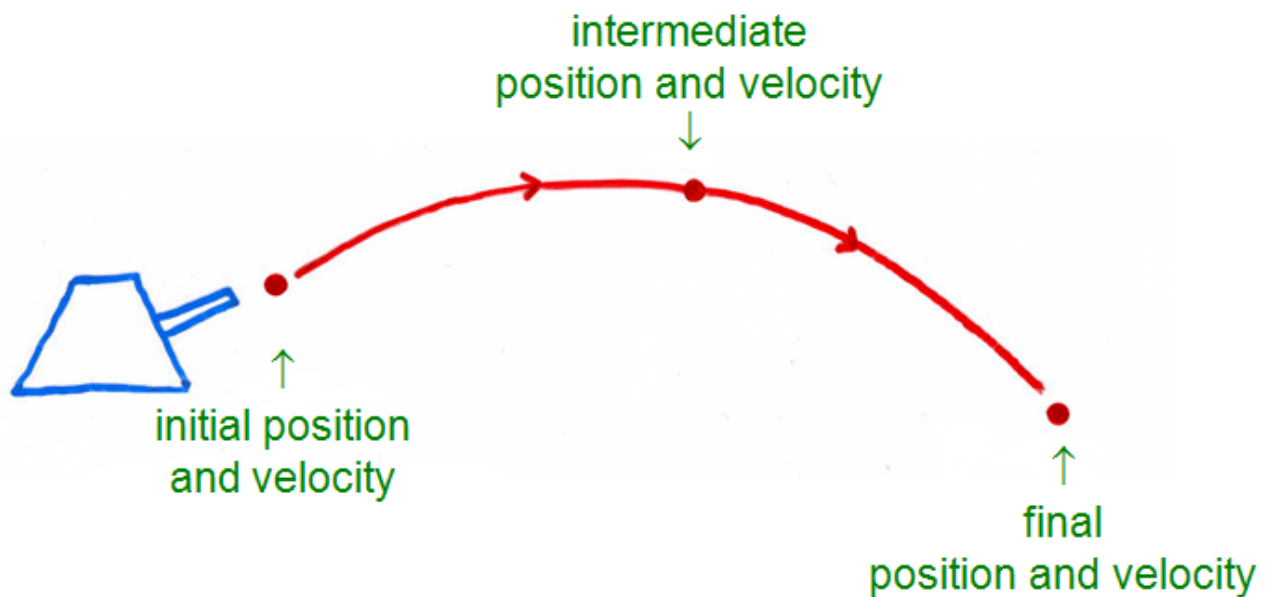
but **a** is unchanged

⇒ Newton's 3 laws work as well backwards as forwards!

(what about magnetic fields?)

(what about quantum mechanics?)

Does the Past “Cause” the Future?



If we know initial position and velocity, can determine exact trajectory

⇒ initial conditions “cause” subsequent motion? (Laplace. . .)

but:

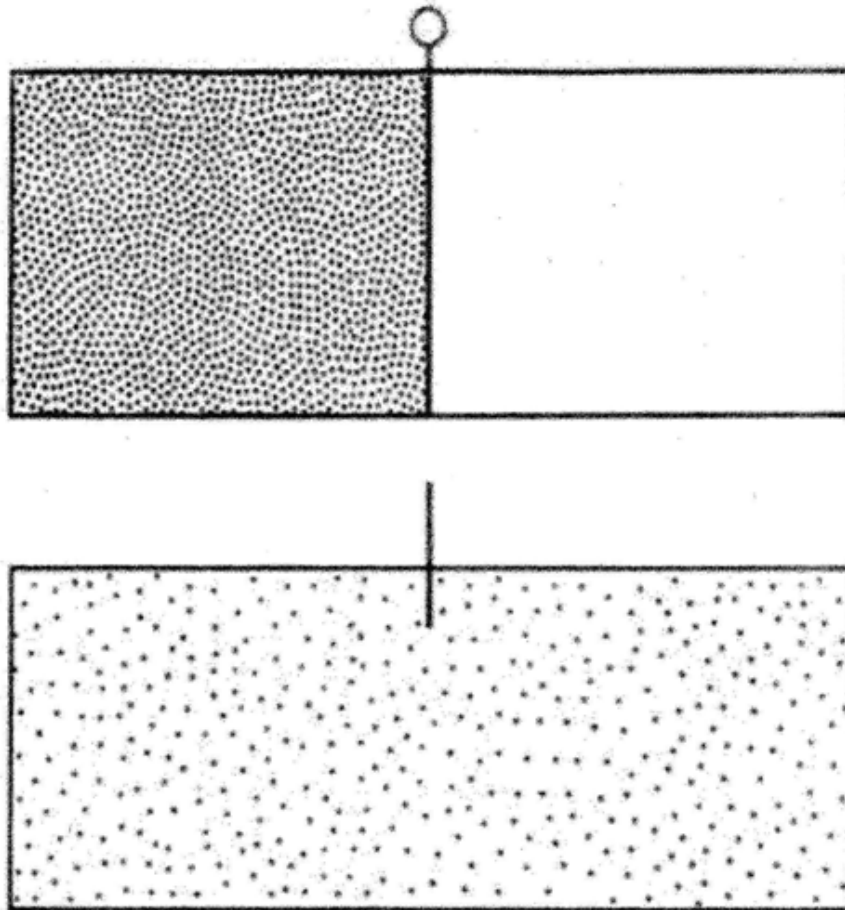
can also infer complete trajectory from final position and velocity

or from intermediate position and velocity

or from initial and final positions . . .

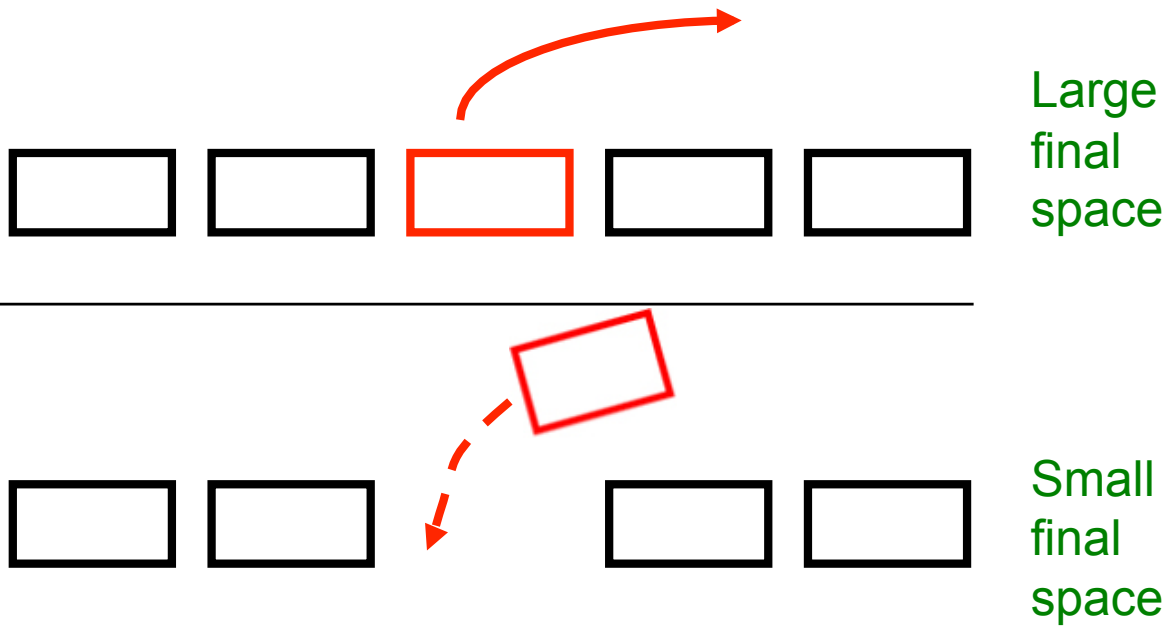
or . . .

[Technically: Newton’s 2nd law 2nd order in time ⇒ any 2 pieces of information suffice]



A gas confined to a small volume which is part of a larger one (*top*); the same gas after expanding into the whole large volume

Reversibility and Parking



“Disorder” is proportional to (log of) available space/number of available states

“Entropy (S)” is measure of disorder

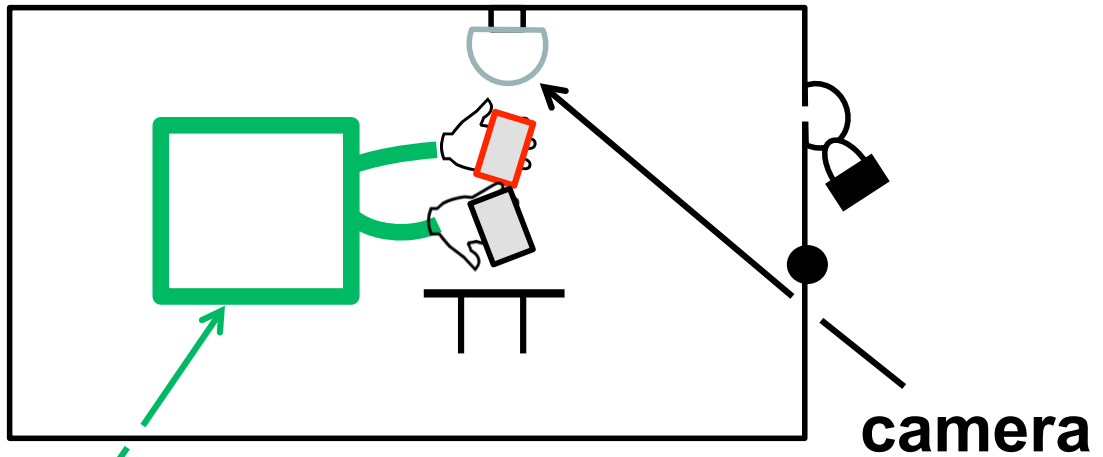
L. Boltzmann: $S = k \log W$

↑ Entropy ↑ no. of available states

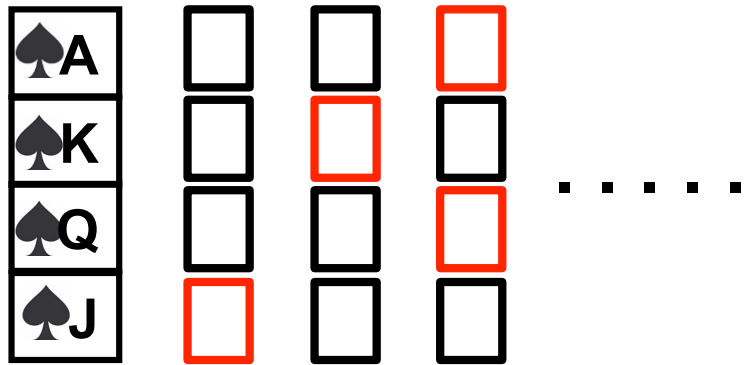
2nd law of thermodynamics: entropy always increases with time.

Origin of time asymmetry?

↑ : WHY DO INITIAL STATES HAVE LOW DISORDER?



mechanical shuffler

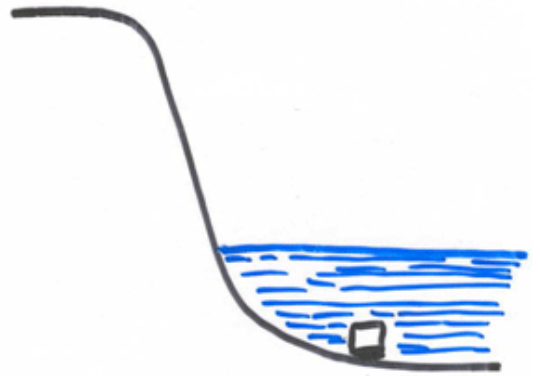
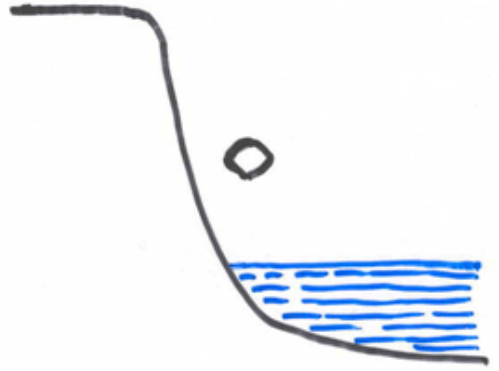
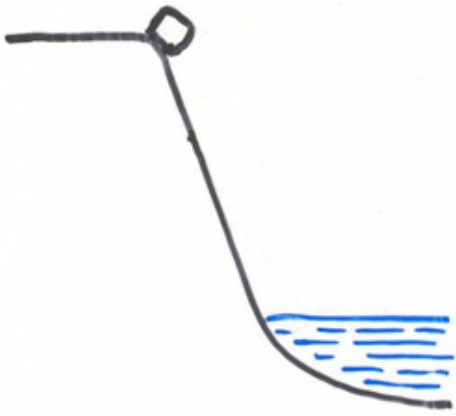


time →

but: inverse of shuffling process is itself a shuffling process!

?





$$S = k \cdot \log W$$

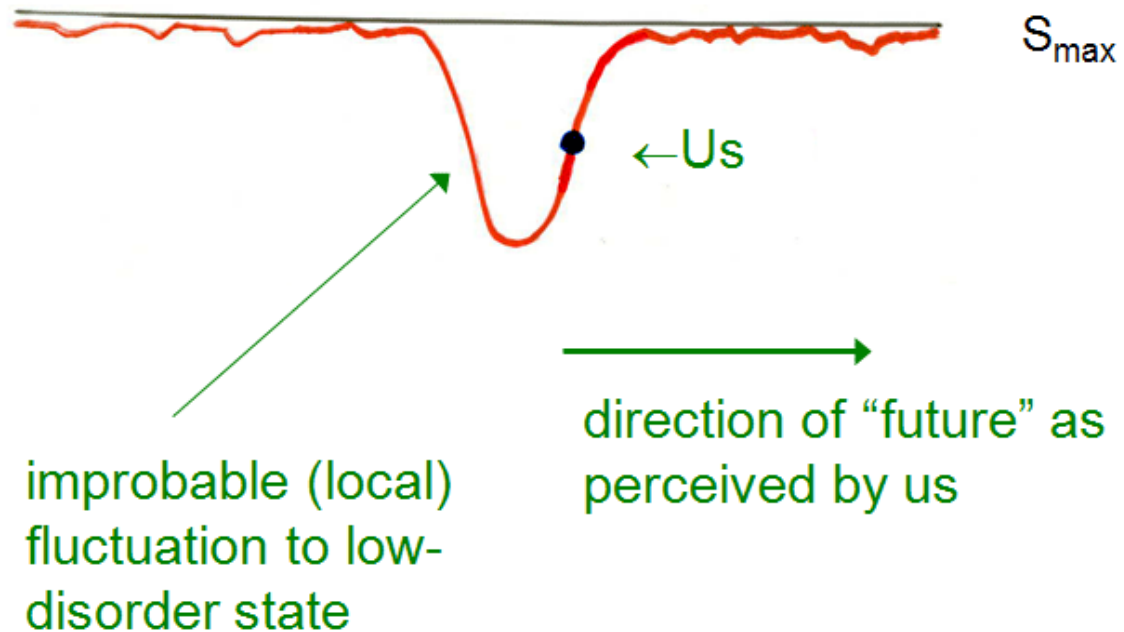


LVDWIG
BOLTZMANN
1844 - 1906

DR PHILPAULA
BOLTZMANN
GEB. CHIARI
1891 - 1977
ARTHUR
BOLTZMANN
DIPL. ING. DR. PHIL. HOFRAT
1881 - 1932
LVDWIG
BOLTZMANN
1923 - 1943
ETER MÄNNLICHER NACHKOMME.
GEFALLEN BEI SMOLENSK

HENRIETTE
BOLTZMANN
GEB. EDLE VON AIGENTLER
1854 - 1936

BOLTZMANN'S SOLUTION



“ANTHROPIC” PRINCIPLE!

⤴ : alas, seems in 2007 that almost the whole observable Universe is “like” us!

i.e.

Stars radiate rather than absorbing energy

(⤴ : would we know?)

THE “ARROWS” OF TIME*

PSYCHOLOGICAL — can remember past,
affect future.

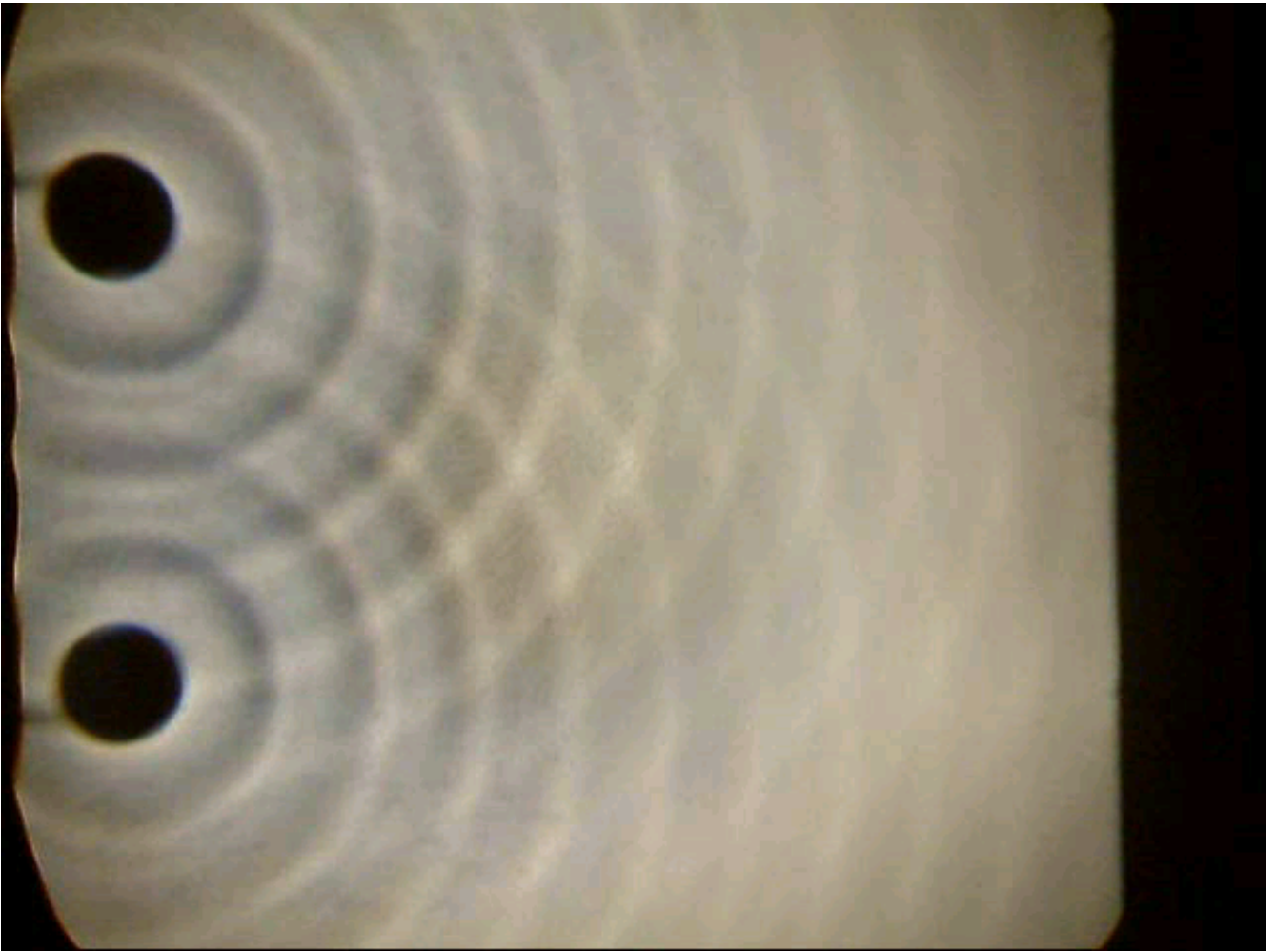
BIOLOGICAL — plants/animals start small,
grow bigger

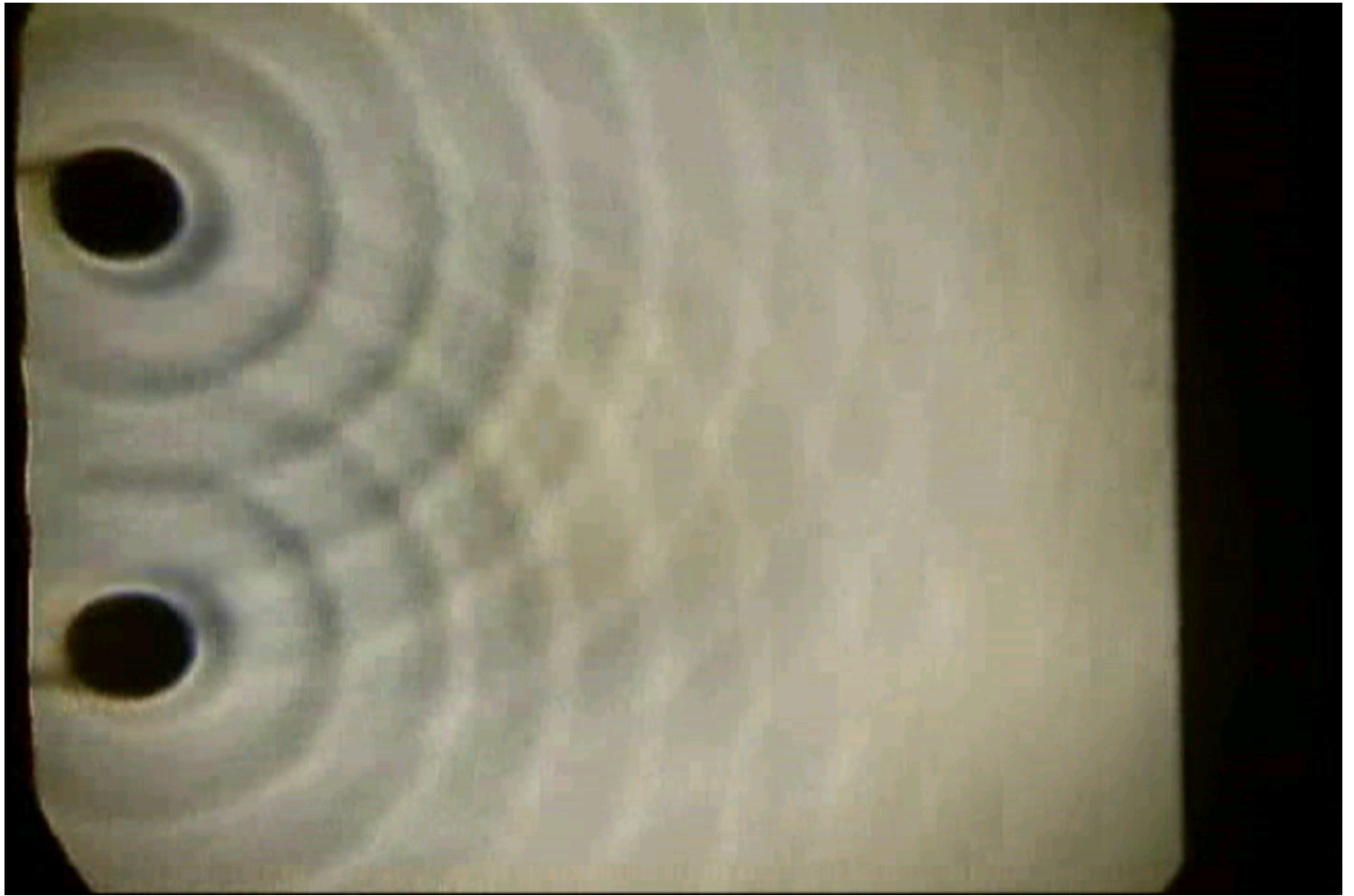
ELECTROMAGNETIC — both light bulbs
and stars emit radiation, don't absorb it.

THERMODYNAMIC — disorder (entropy)
increases

COSMOLOGICAL — Universe expanding

*Excluding “CP-violating” arrow detected in
high-energy experiments.



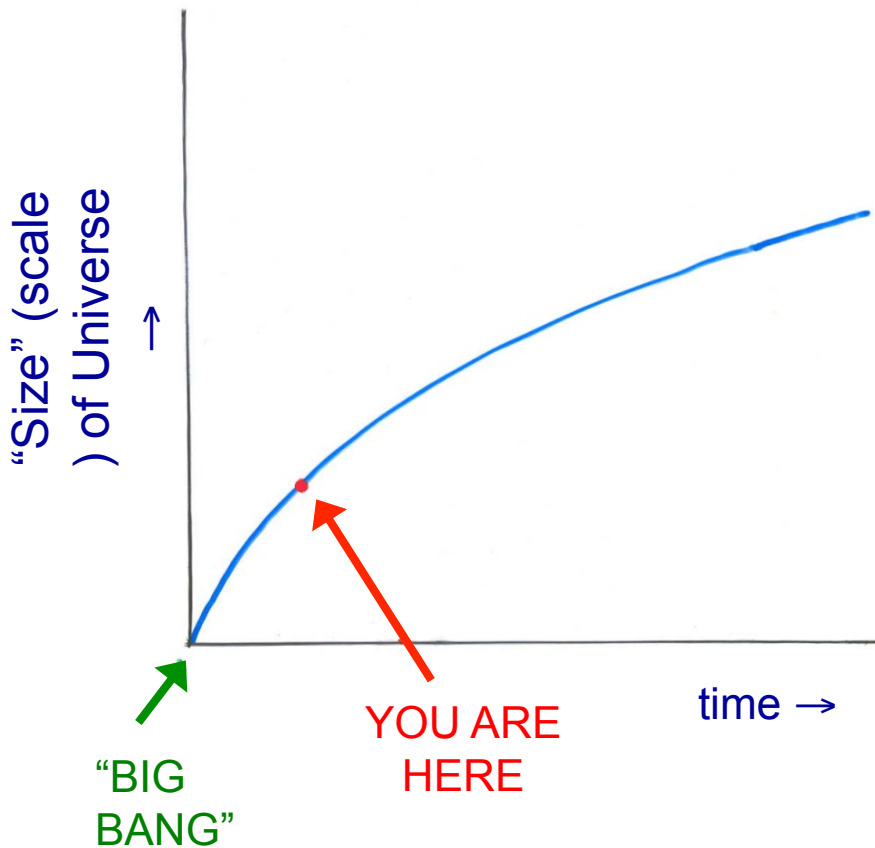


CAN COSMOLOGY EXPLAIN THERMODYNAMICS?

Friedmann-Robertson-Walker

In standard ("FRW") model, all scenarios (independently of Ω) agree about the **past**:

↑
reduced mass density



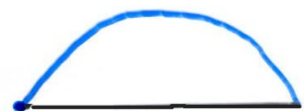
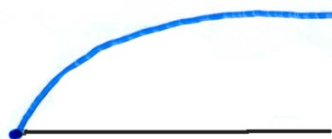
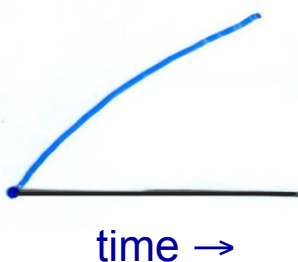
WHY IS DISORDER LOW AT "SMALL" END?

Possible futures of the universes:

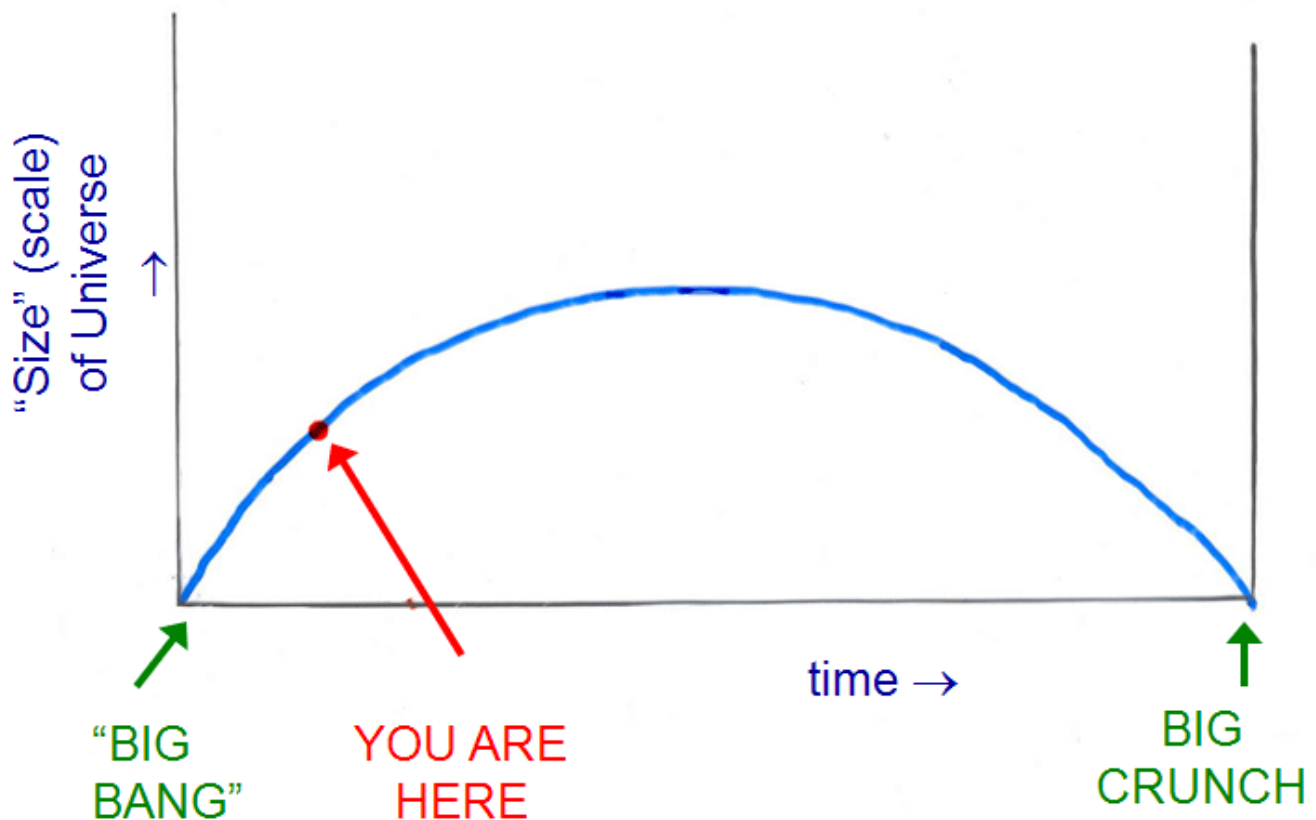
open ($\Omega < 1$)

flat ($\Omega = 1$)

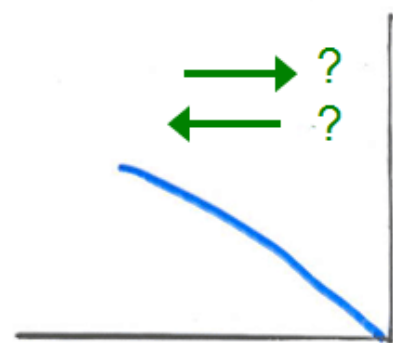
closed ($\Omega < 1$)



WHAT IF THE UNIVERSE IS "CLOSED"?

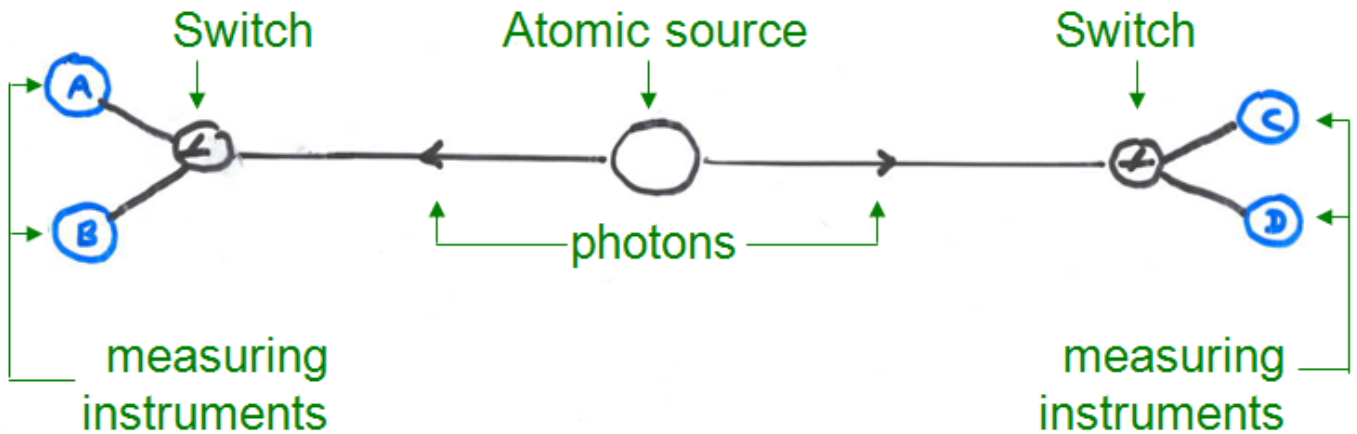


disorder increasing or decreasing?



WHICH WAY IS THE "FUTURE"?

COULD THE “ARROW OF TIME” REVERSE LOCALLY (AND TEMPORARILY)?



Experimental fact:

The observed correlations are (consistent with QM, but) inconsistent with any theory embodying

- objectivity
- locality
- induction** — i.e., “past causes future, not vice versa”

Could the outcome of the measurements propagate “backwards in time” and affect the initial state?

Formally OK: can it be reconciled with the (macroscopic) 2nd law (increase of entropy)?

IMPLICATIONS FOR “FREE WILL”??