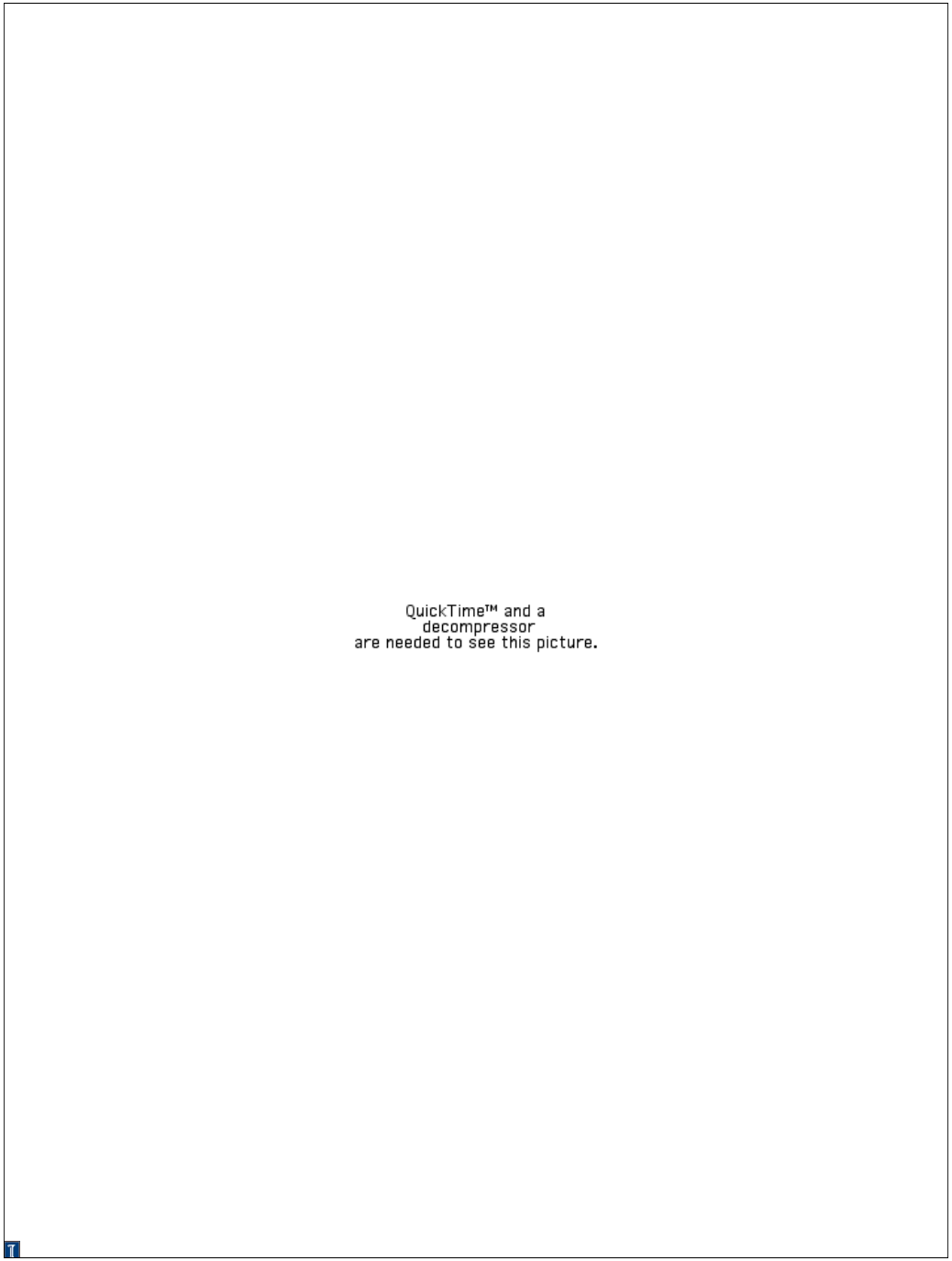
Why Can’t Time Run Backwards?

Anthony Leggett

Occam Lecture 6.05.11, Merton College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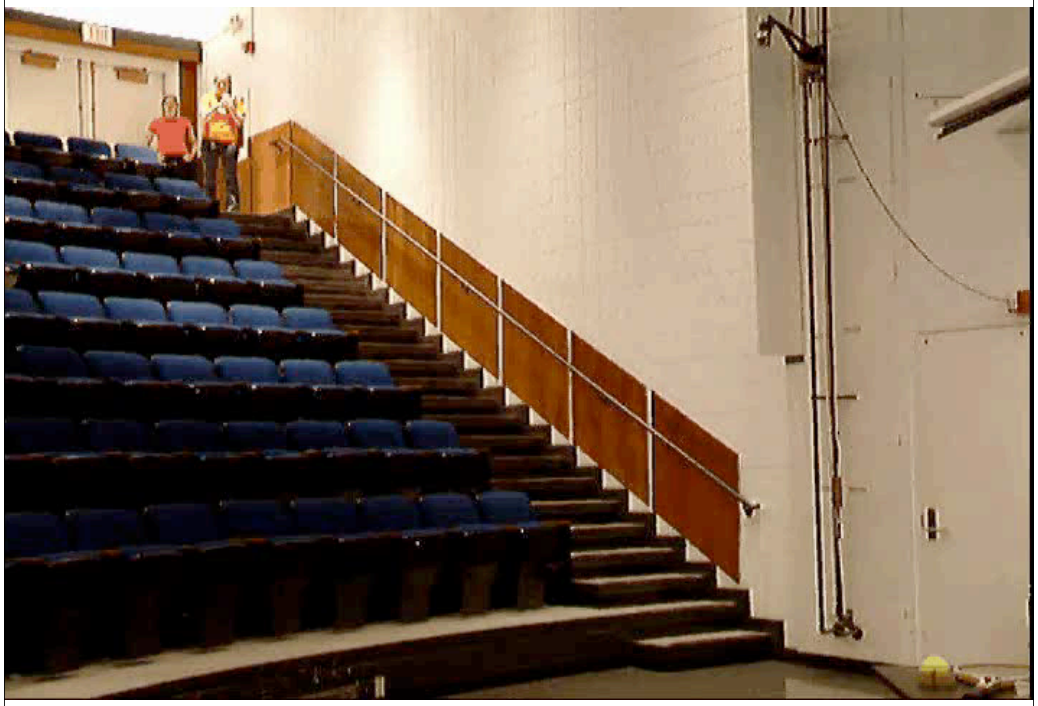
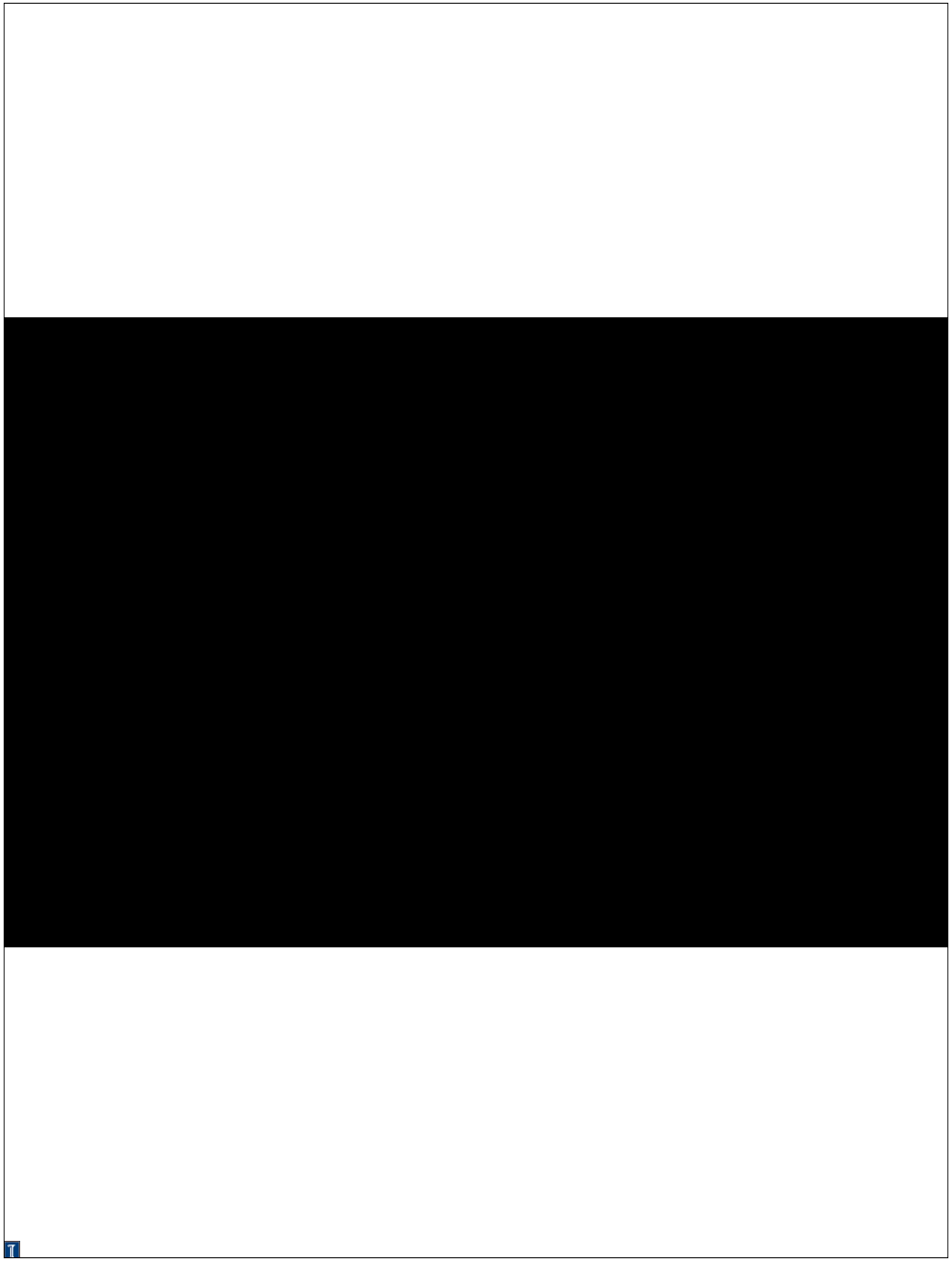
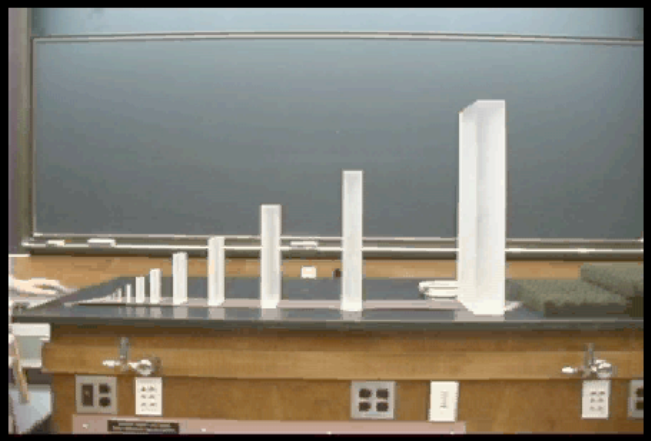




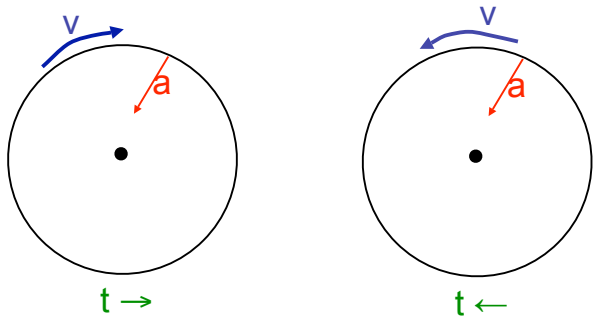


NEWTON'S 2ND LAW

FORCE = MASS × ACCELERATION (a)

e.g. Gravity ↑ Rate of Change of Velocity (v) ↑

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

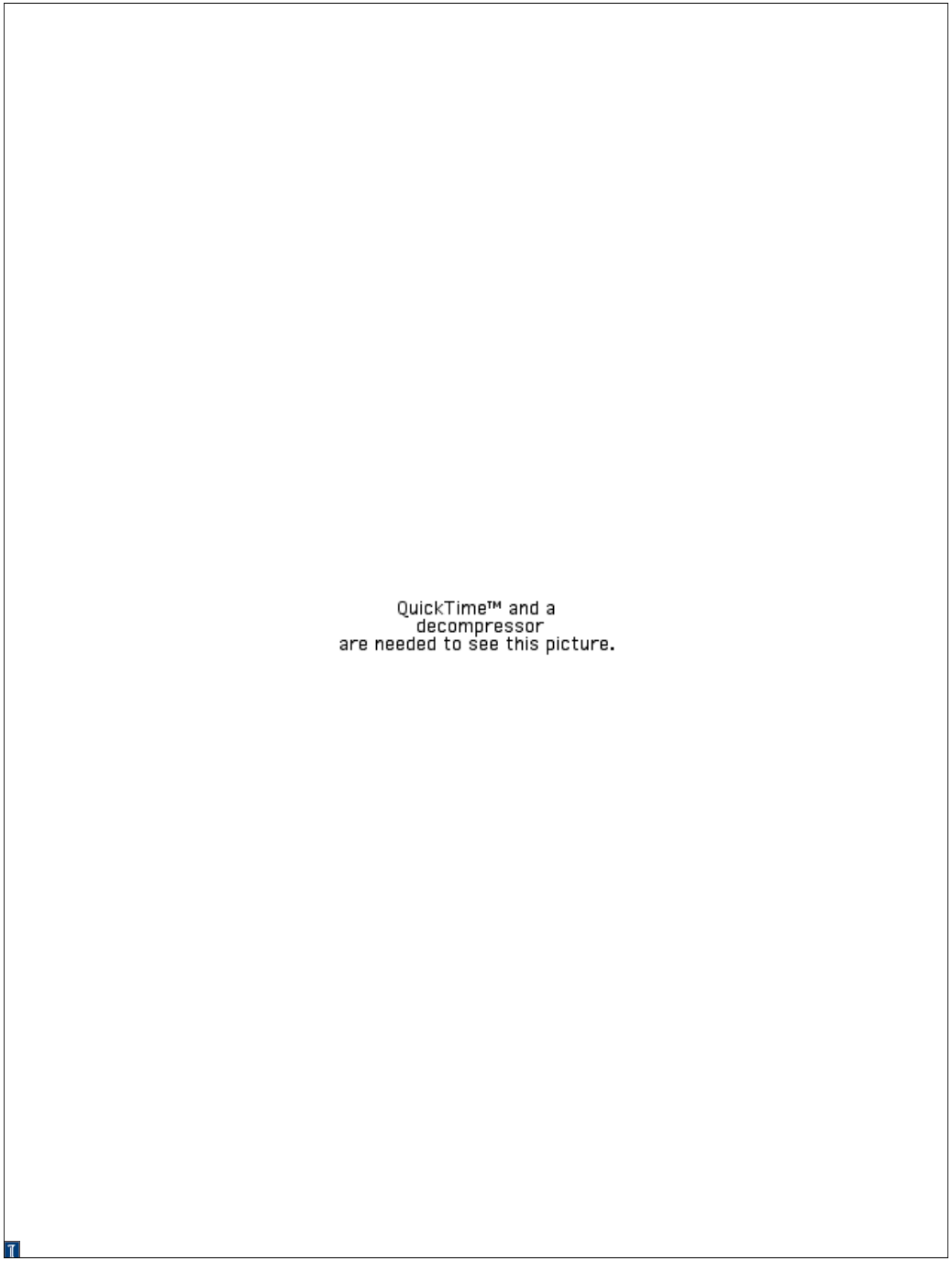


but a is unchanged

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

(what about magnetic fields?)

(what about quantum mechanics?)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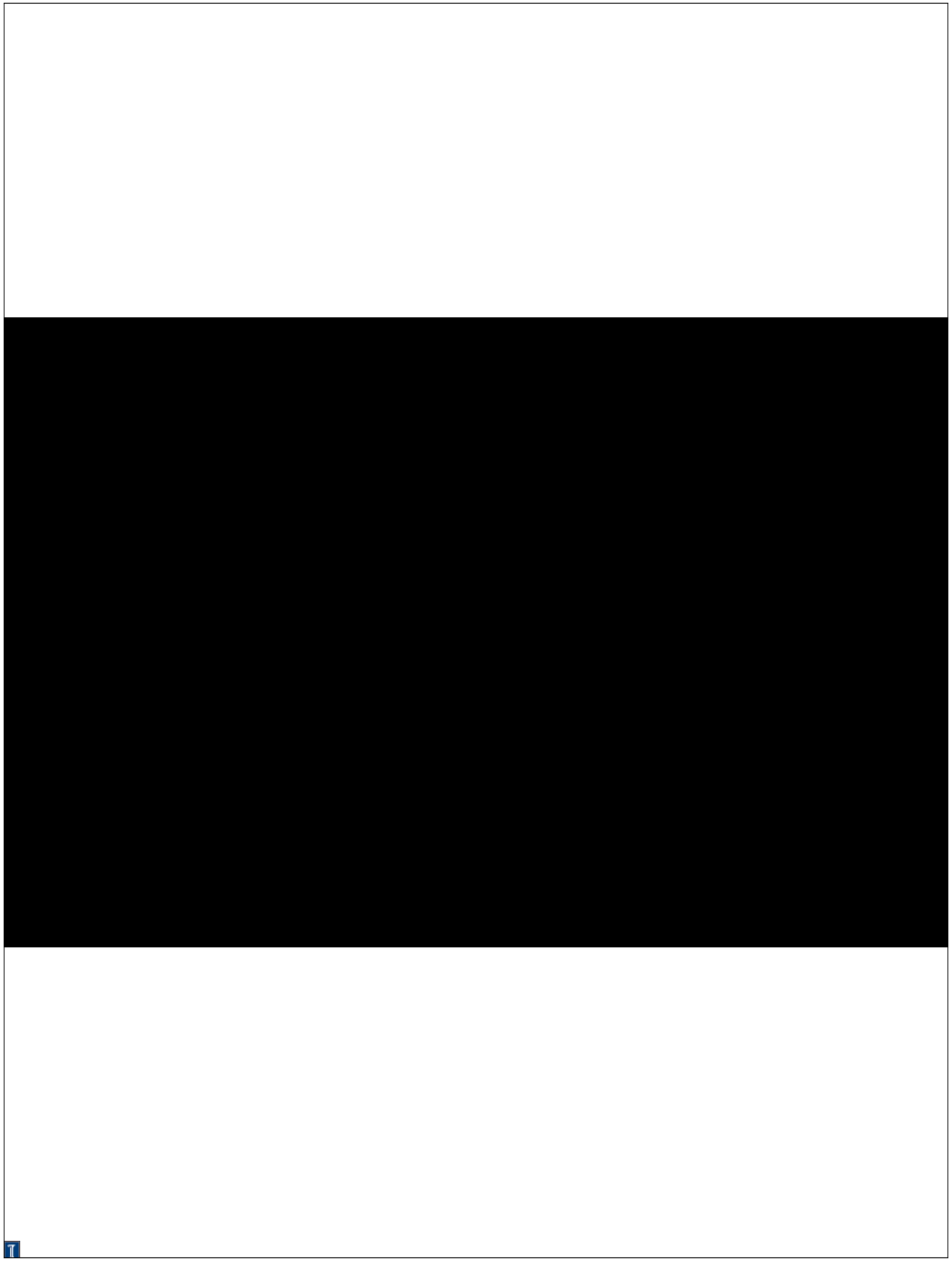
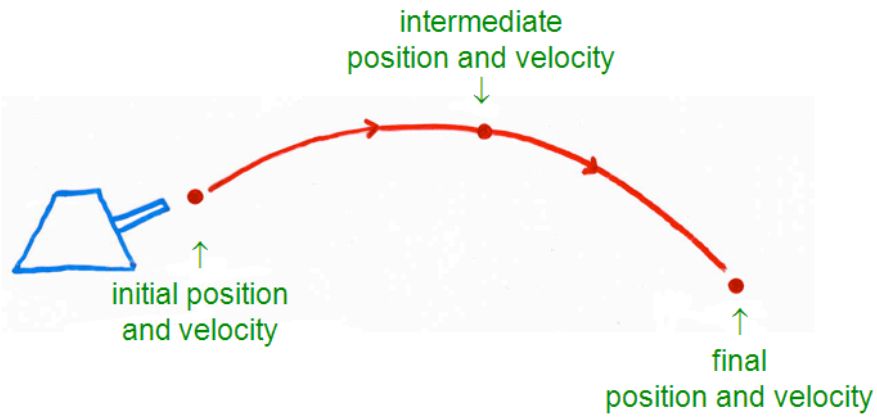


Does the Past "Cause" the Future?



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

⇒initial conditions "cause" subsequent motion? (Laplace. . .)

but:

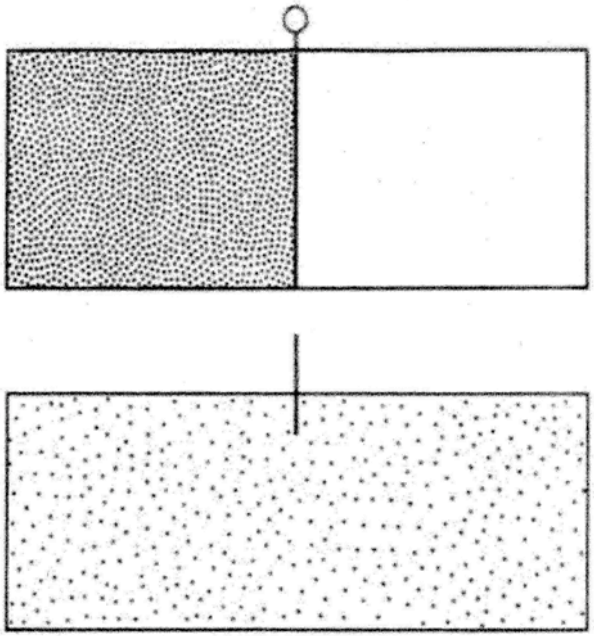
can also infer complete trajectory from final position and velocity

or from intermediate position and velocity

or from initial and final positions . . .

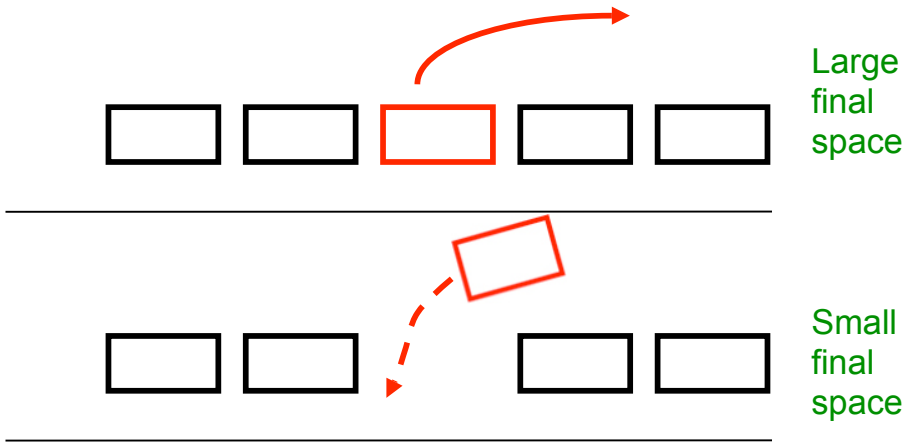
or . . .

[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

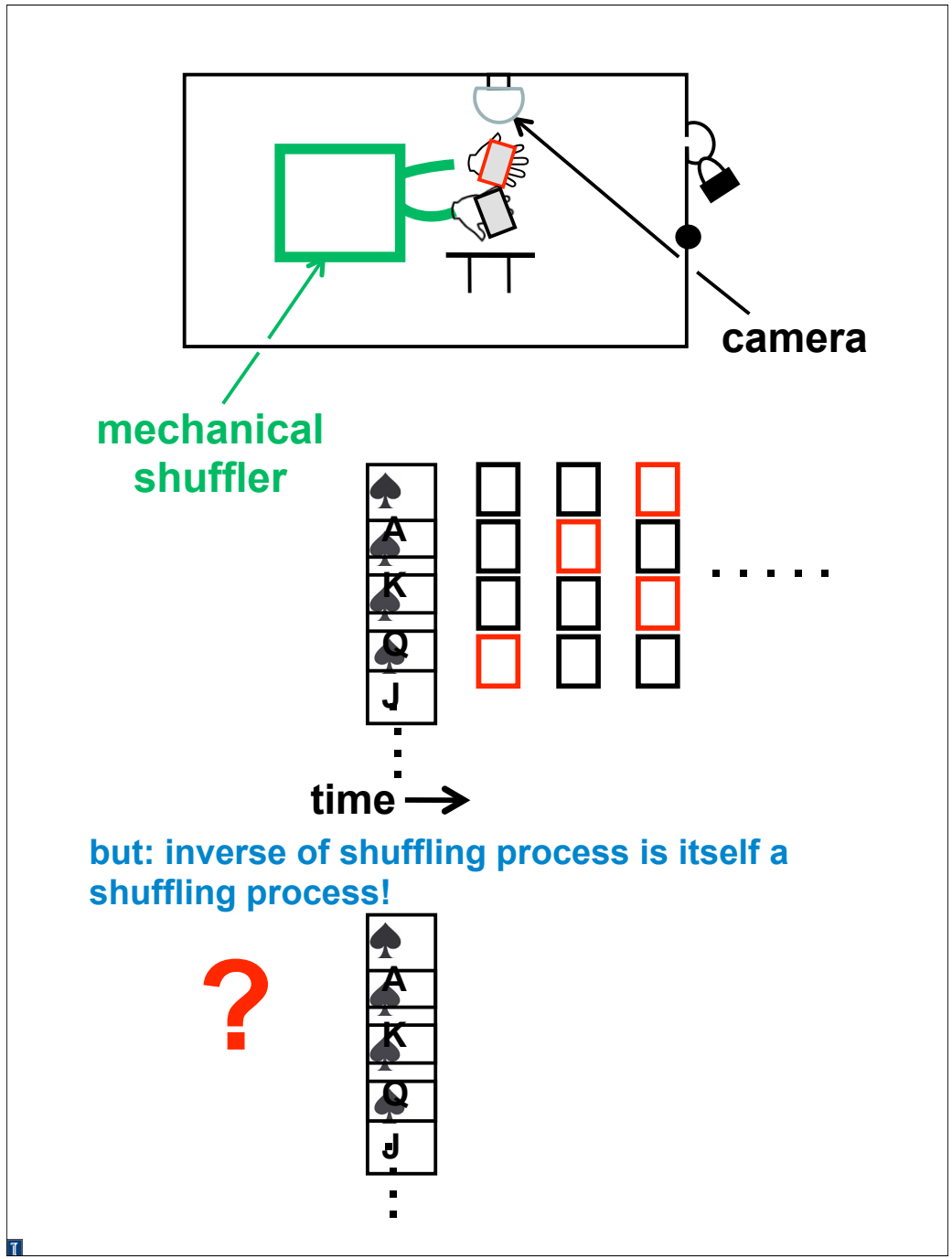
L. Boltzmann: $S = k \log W$

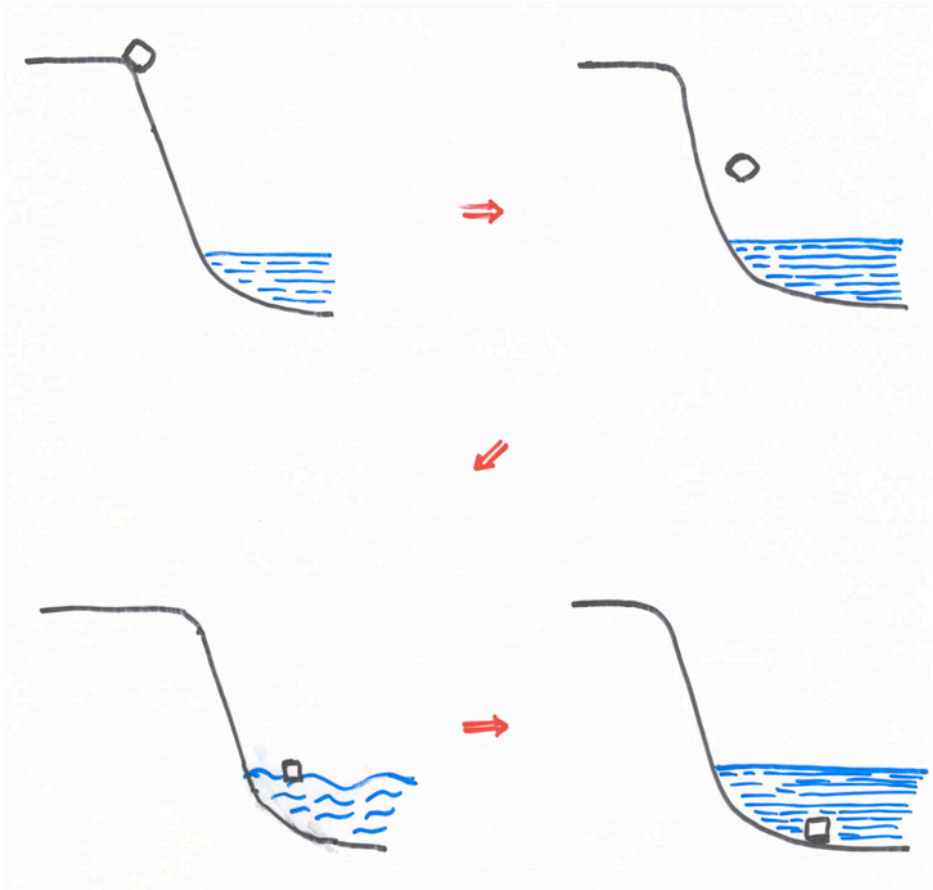
↑ Entropy ↑ no. of available states

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

Origin of time asymmetry?

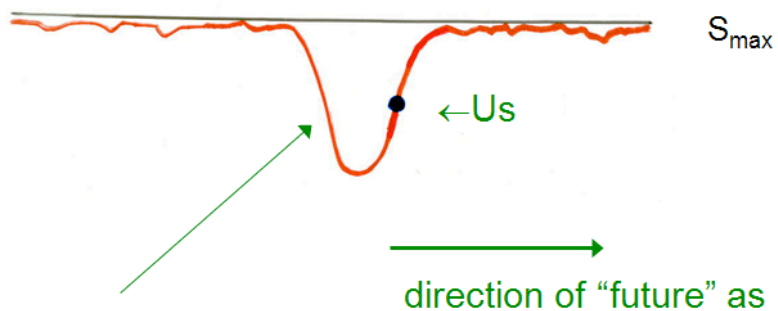
: **WHY DO INITIAL STATES HAVE LOW DISORDER?**


camera
mechanical
shuffler
A
K
Q
J
time
but: inverse of shuffling process is itself a
shuffling process!
?
A
K
Q
J




S = k. log W
LVDWIG
BOLTZMANN
1844 – 1906
HENRIETTE
BOLTZMANN
GEB. EDLE von ARGENTIER
1854 – 1938
Dr PHIL. PAULA
BOLTZMANN
GEB. CHIARI
1891 – 1977
ARTHUR
BOLTZMANN
DIPL. ING. Dr PHIL. HOFRAT
1881 – 1932
LVDWIG
BOLTZMANN
1923 – 1943
LETZTER MÄNNLICHER NACHKOMME,
GEFALLEN BEI SMOLENSK

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.

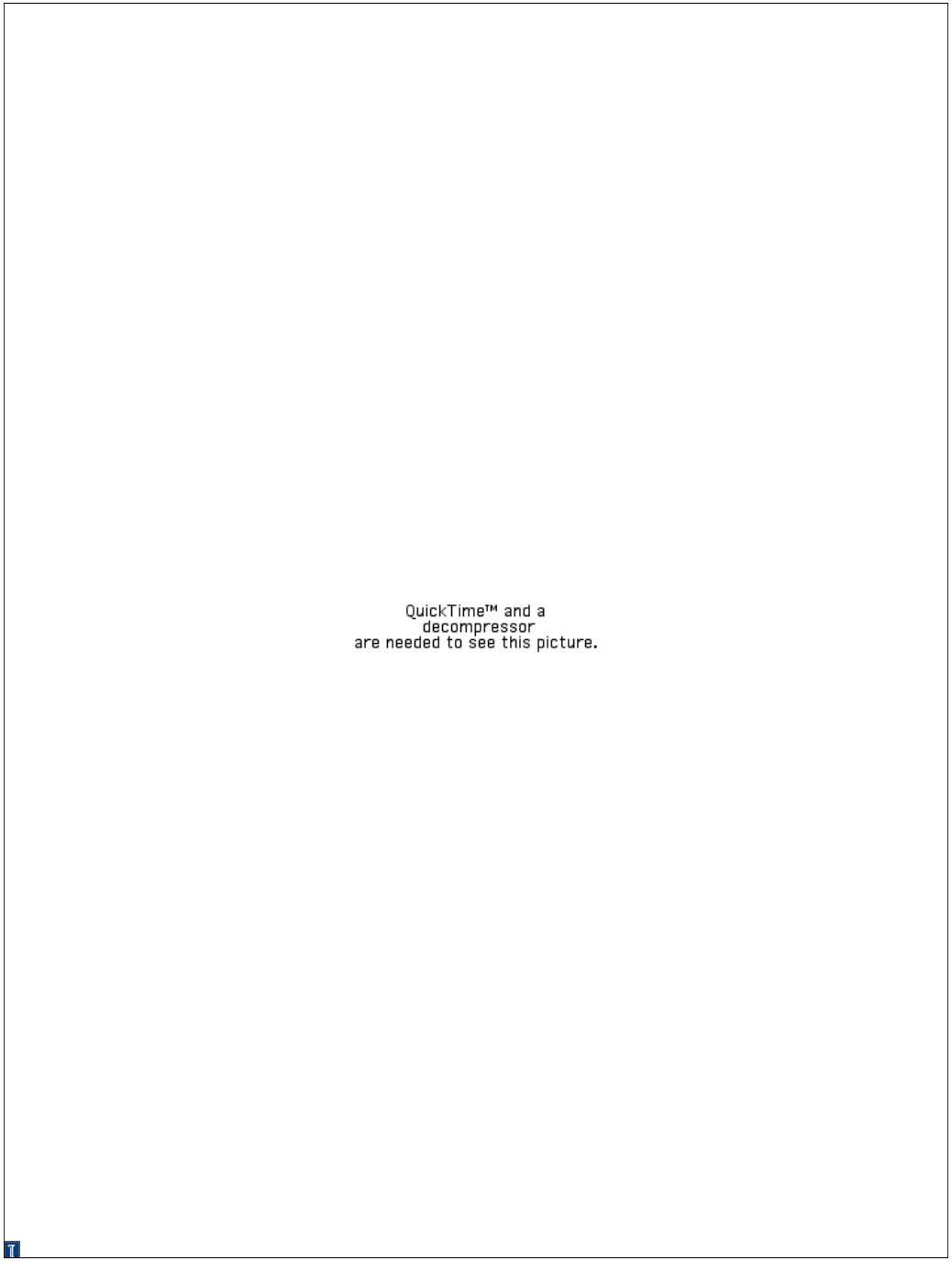
BIOLOGICAL — plants/animals start small, grow bigger

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.**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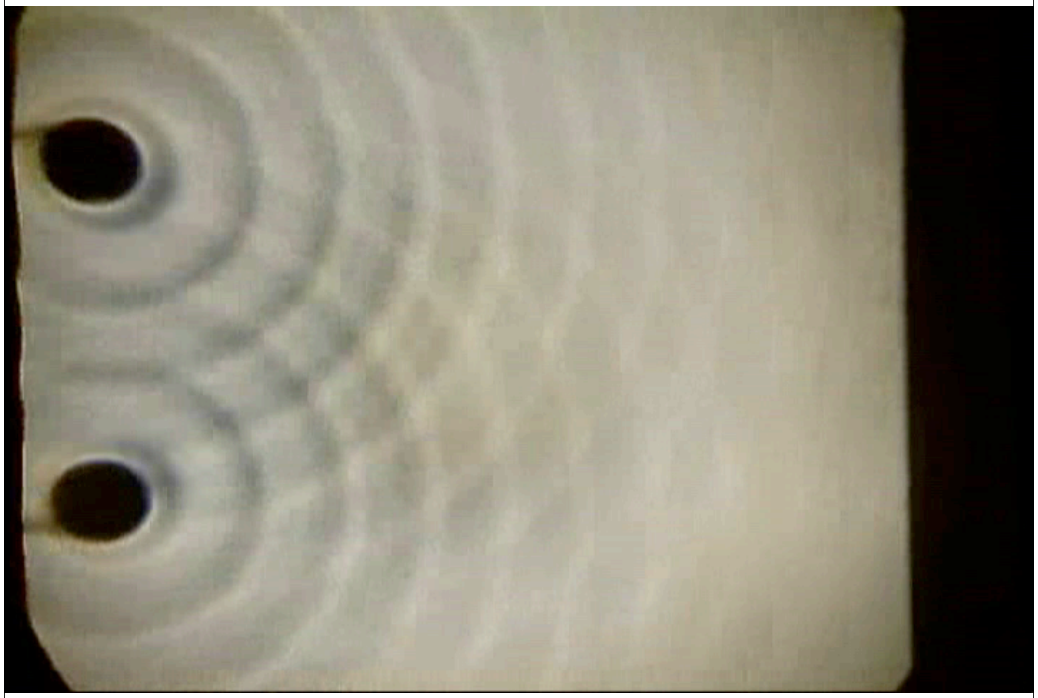
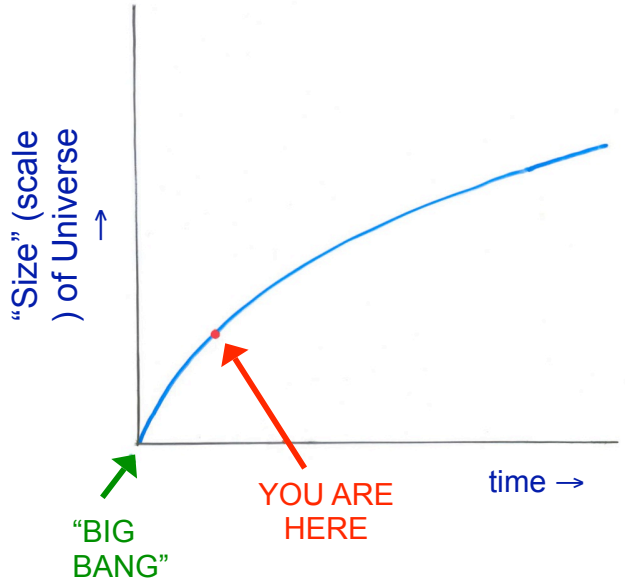


CAN COSMOLOGY EXPLAIN THERMODYNAMICS?

Friedmann-Robertson-Walker

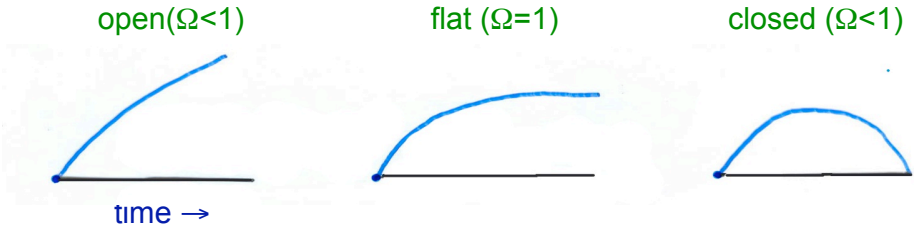
In standard ("FRW") model, all scenarios (independently of Ω) agree about the past:

reduced mass density

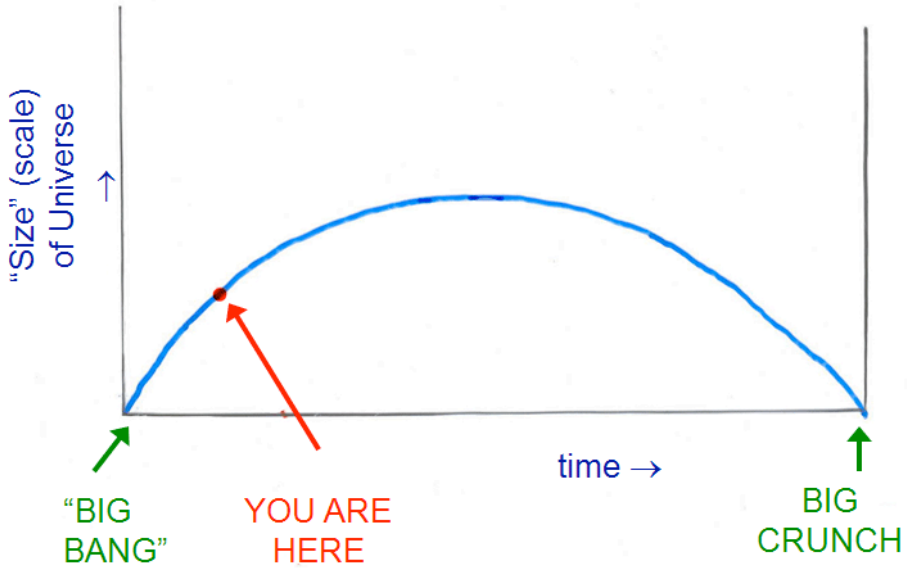


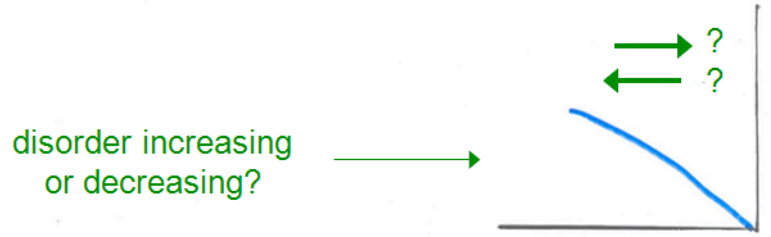
WHY IS DISORDER LOW AT "SMALL" END?

Possible futures of the universes:



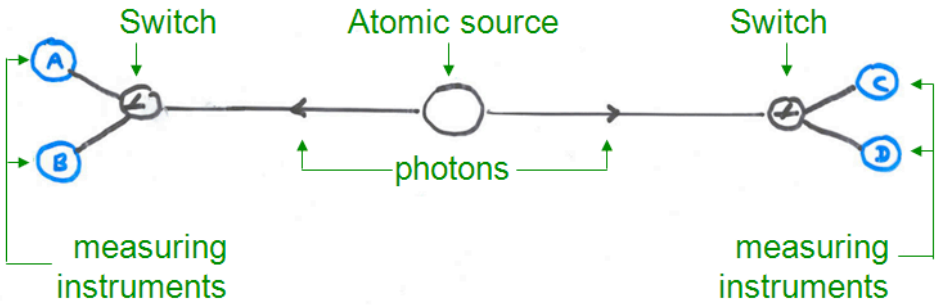
WHAT IF THE UNIVERSE IS "CLOSED"?





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"??