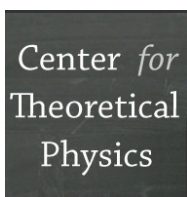
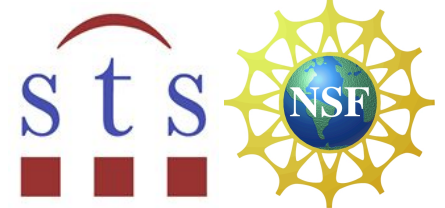


The Physics of Free Will



Dr. Andrew Friedman
National Science Foundation
Research Associate, MIT



SPEAKERS



Dr. David Brin
(UCSD)



Prof. Brian Keating
(UCSD)



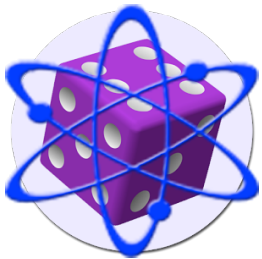
Dr. Andrew Friedman
(MIT)



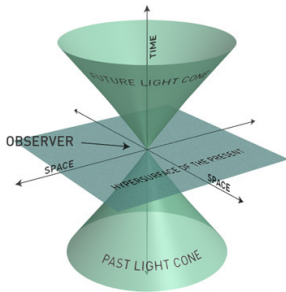
OUTLINE



Defining **Free Will**



Determinism vs.
Quantum Randomness



Freedom and Quantum
Entanglement



Cosmic Bell Experiment

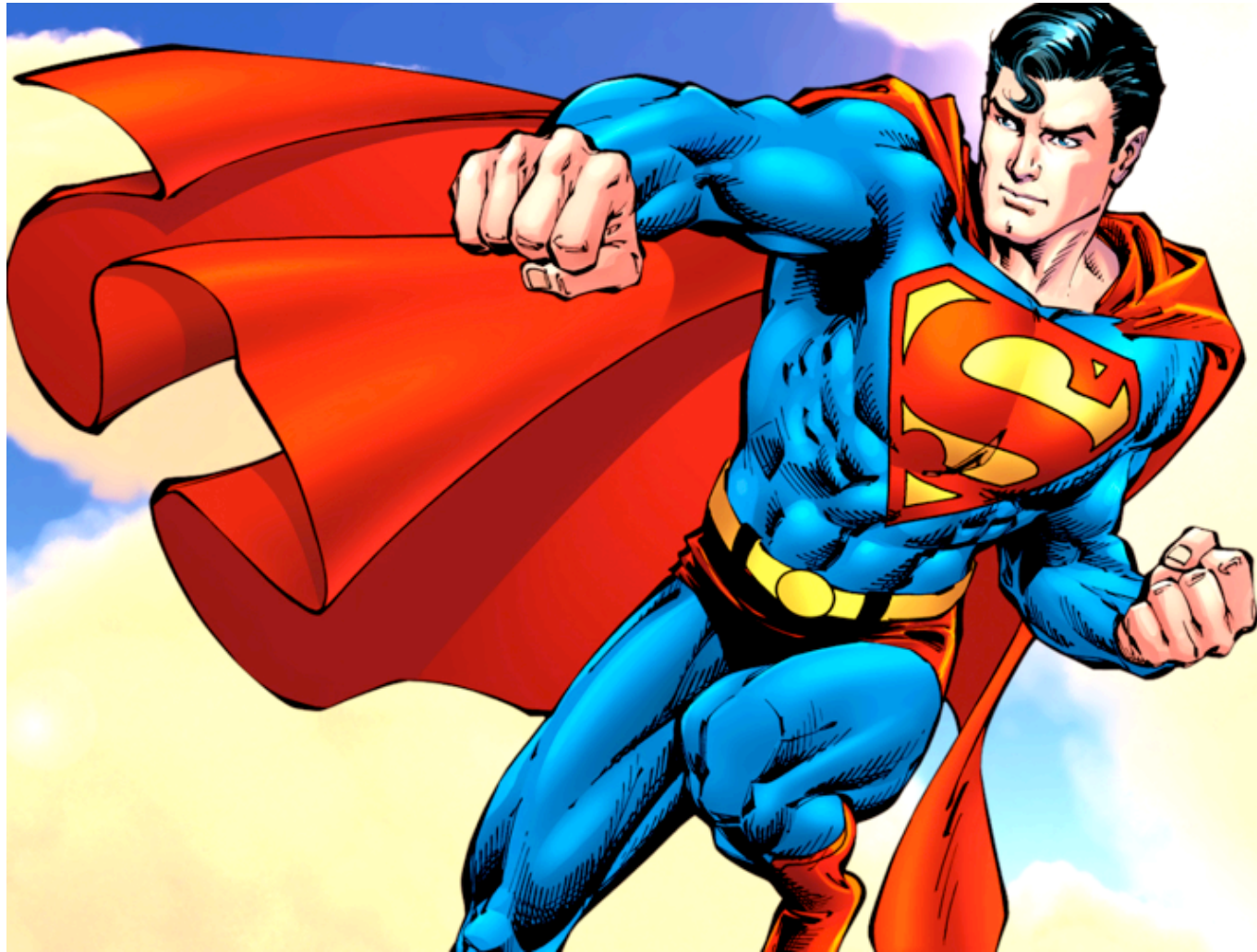
DO WE HAVE FREE WILL?



<http://thecoinfront.com/wp-content/uploads/2014/05/what-is-forking-in-cryptocurrency-The-CoinFront-your-news-source-for-bitcoin-altcoin-digital-and-cryptocurrencies.jpg>

***“All theory is against the freedom of the will;
all experience for it.” - Samuel Johnson***

WHAT FREE WILL IS NOT



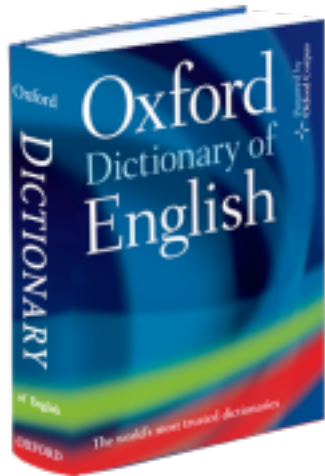
<http://static.comicvine.com/uploads/original/11111/111113523/3605753-1936874063-31646.png>

Not all or
nothing

Does not
mean
“complete”
freedom!

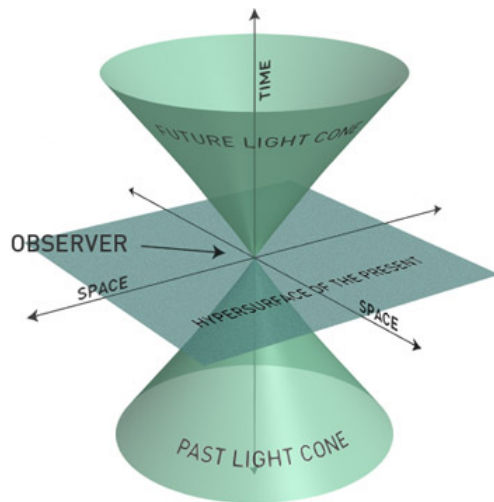
Physics imposes **constraints** on freedom.

DEFINING FREE WILL



free will (*common usage*)

the power of acting without the constraint of necessity or fate; the ability to act at one's own discretion. -OED



free will (*physics*)

the ability of observers to make choices *as independently as possible** from anything in the history of the universe -ASF

**But how independent is good enough?*

WILL VS. FREEDOM



WILL

“I” made the choice!

**But what is a conscious
observer?**



FREEDOM

These were my options!

**The laws of physics don't
allow everything.**

FREE WILL AND DETERMINISM

Determinism: The past and future states of a system are completely determined by its state at another time.



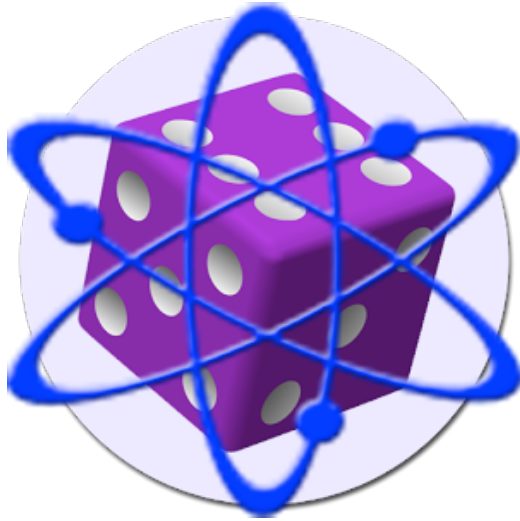
https://img1.etsystatic.com/000/0/5199882/il_fullxfull.247302193.jpg

Laplace's Demon

...An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed...for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

—Pierre Simon Laplace, *A Philosophical Essay on Probabilities*

FREE WILL AND QUANTUM THEORY



Randomness

Quantum systems intrinsically
non-deterministic.

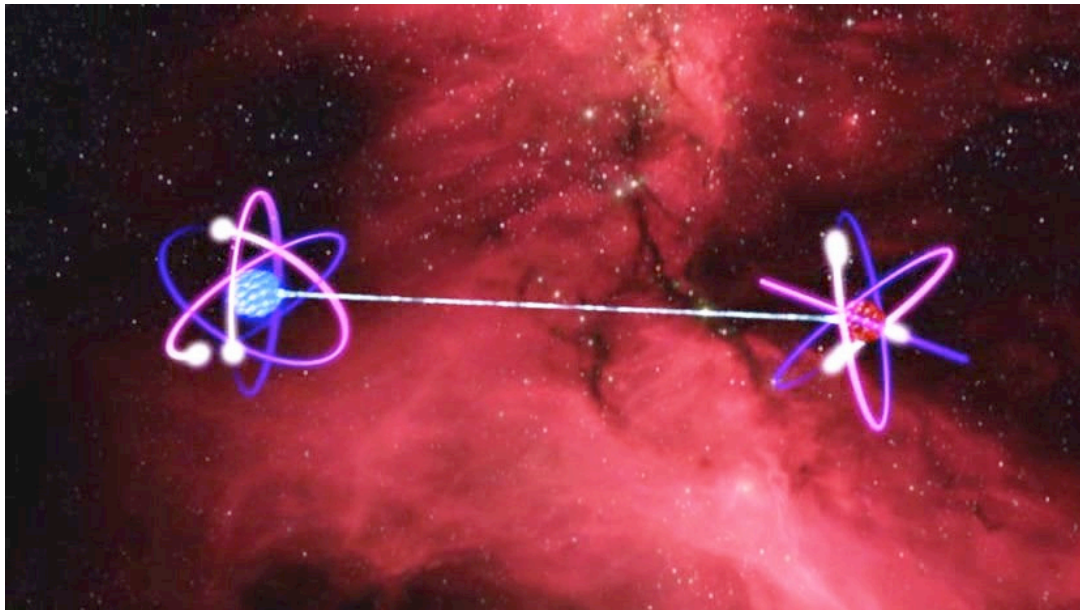
Can only predict probabilities

**Are quantum choices
independent of the past?**

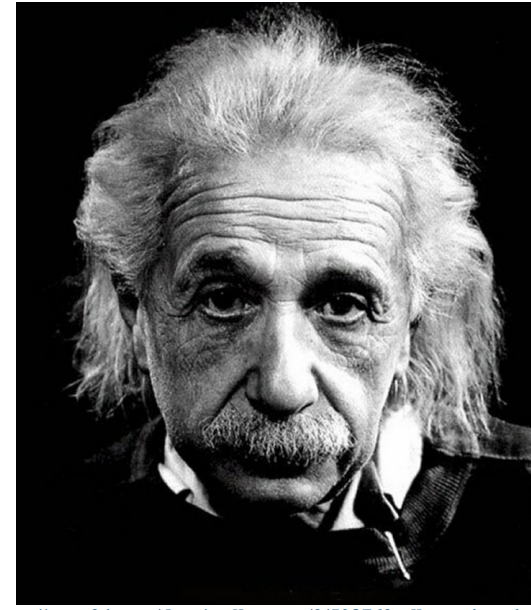
QUANTUM ENTANGLEMENT 101

Entanglement: Paired systems with correlated (or anti-correlated) properties

Measure #1, instantly know something about #2



<https://kuleuvenblogt.files.wordpress.com/2014/06/entangled-atoms.jpg>



<http://xeon24.com/data/wallpapers/2/508769-albert-einstein.jpg>

Is quantum mechanics complete or just spooky?

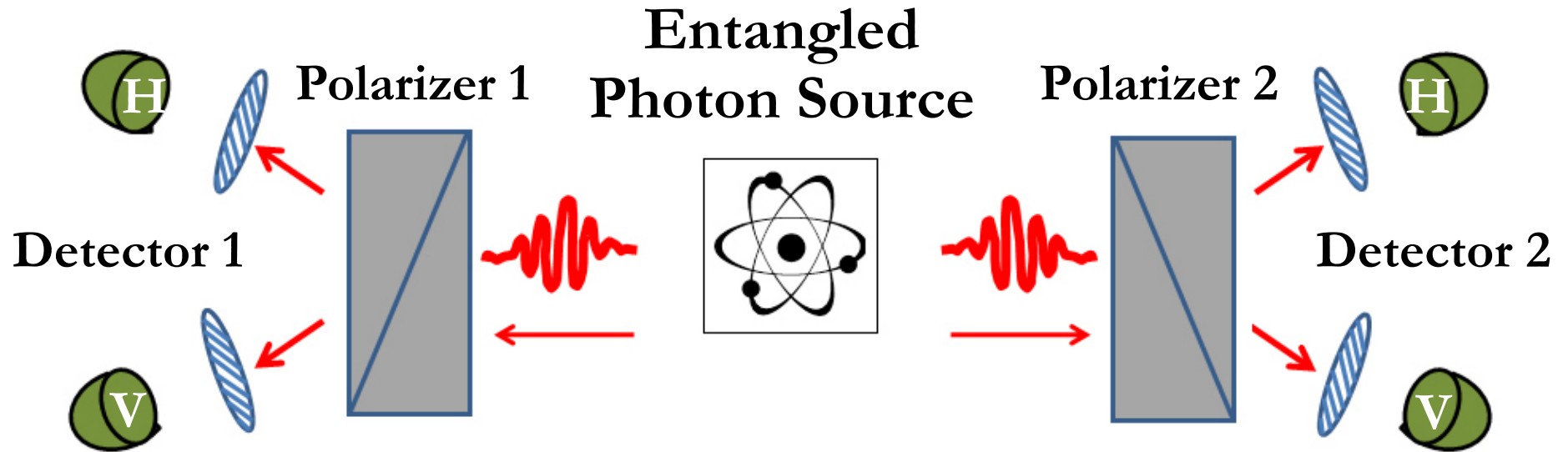
WHY CAUSAL EXPLANATIONS FAIL

Quantum correlation is **NOT**
like classical correlation!



ENTANGLED PARTICLE EXPERIMENTS

“Bell Test”



H=horizontal V=vertical

Can rotate polarizer's relative angle

BELL'S THEOREM ASSUMPTIONS

1. Realism
2. Locality
3. Freedom



http://images.iop.org/objects/cer/cern/54/7/19/CCfac8_07_14.jpg

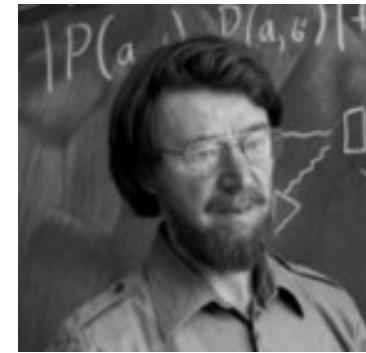
John S. Bell (1928-1990)

1,2,3 → Bell's Limit

Limits on “classical” correlated measurements

RELAXING BELL'S ASSUMPTIONS

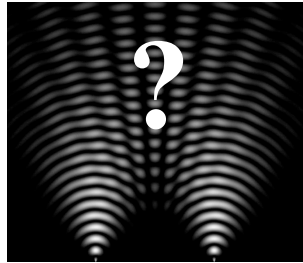
Experiments violate
Bell's limit as predicted
by quantum mechanics!



1. Realism 2. Locality 3. Freedom

→ At least one of 1,2,3 are false!

BELL'S THEOREM LOOPHOLES



Why Does it Matter?

Quantum foundations!

Quantum encryption security



Locality

Hidden communication



Detection Efficiency

Measured detections biased



Free Will

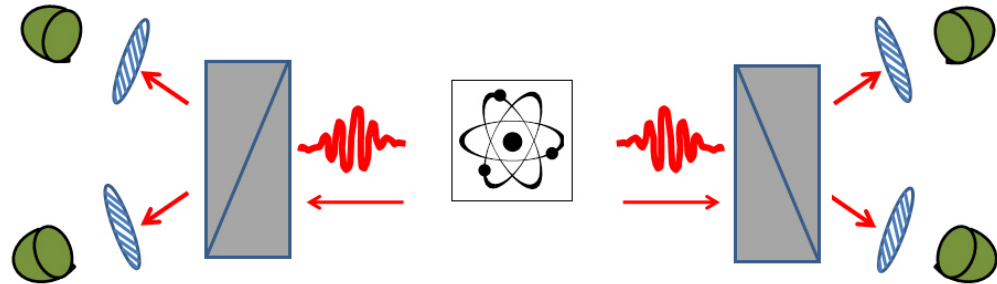
Detector settings correlated with past events

partially?



FREE WILL LOOPHOLE

X Shrimp & Chicken Fajita	\$12.99
X Fajita Salsas (for One) <i>A Combination of steak, chicken & shrimp.</i>	\$13.25
Fajita Salsas (for Two)	\$21.99
Fajita Mixed <i>Strips of steak & chicken.</i>	\$12.25
Fajita Mixed (for Two)	\$19.50
Fajita Quesadilla <i>2 flour tortillas grilled & stuffed with chicken or steak & cheese.</i>	\$ 9.50
X Shrimp Fajitas	\$14.25
Fajitas <i>Steak or Chicken</i> for One	\$11.99
for Two	\$18.99
X Parillada Mexicana (for One) <i>Pork tips, shrimp, chicken, chorizo & steak.</i>	\$13.99
X Parillada Mexicana (for Two)	\$22.99

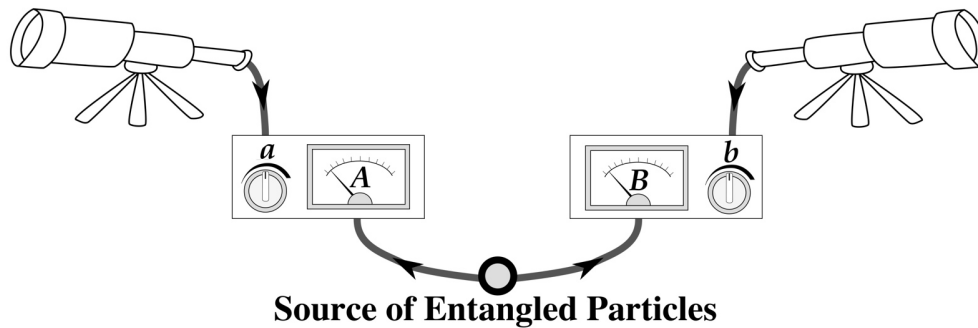
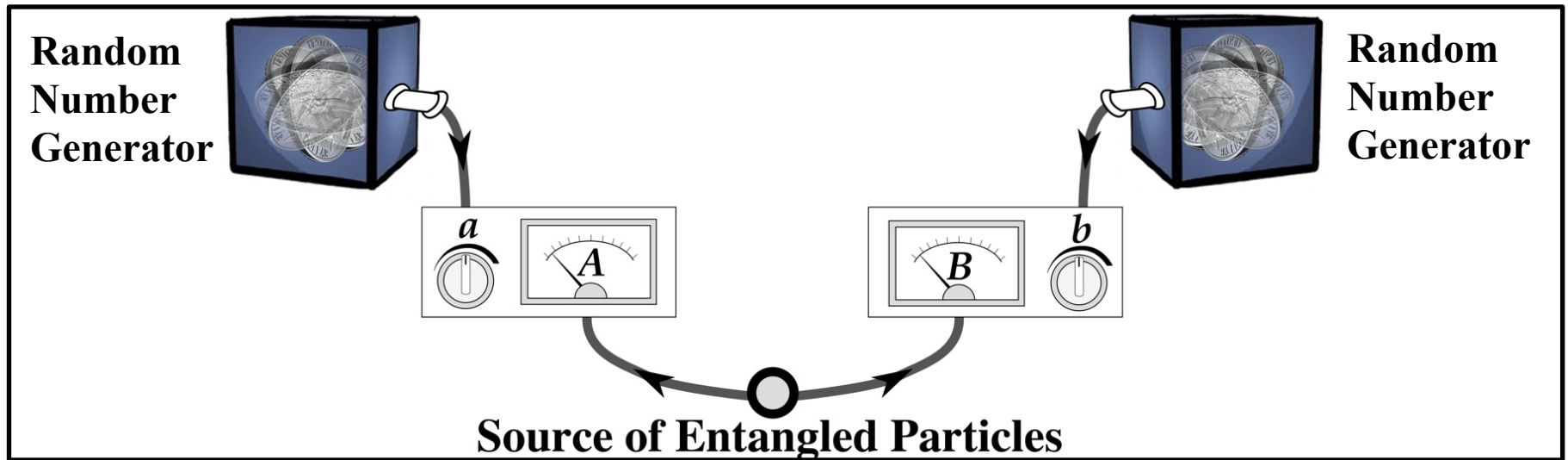
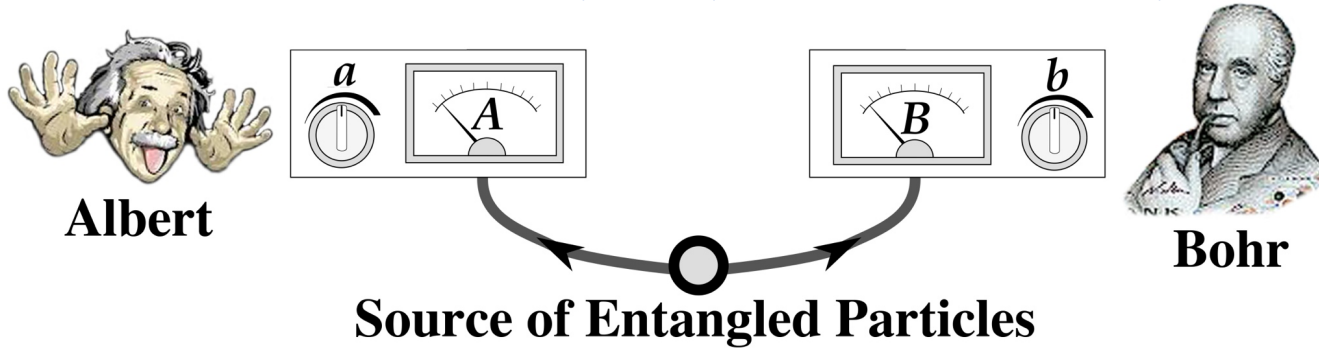


If detector settings depend on shared past events, our choices might not be free!

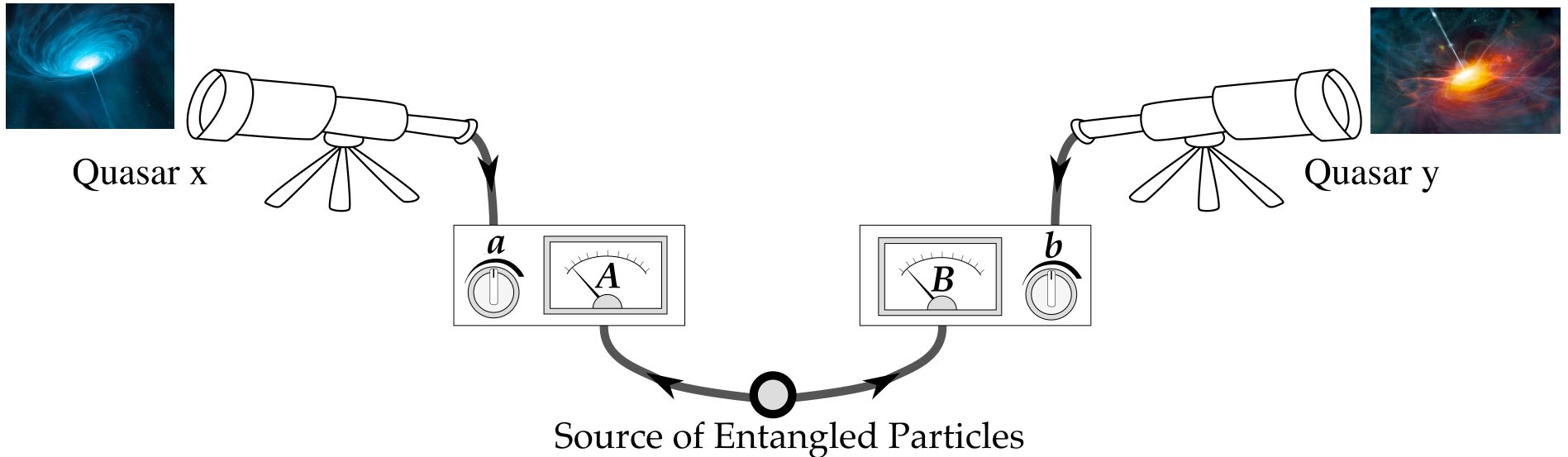
Still have free will!

But limited freedom

CHOOSING DETECTOR SETTINGS



COSMIC BELL TEST



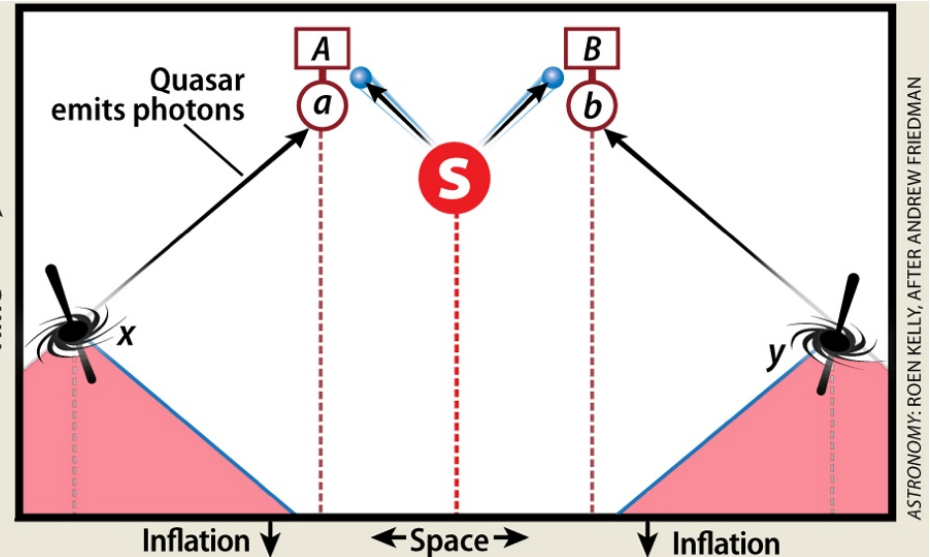
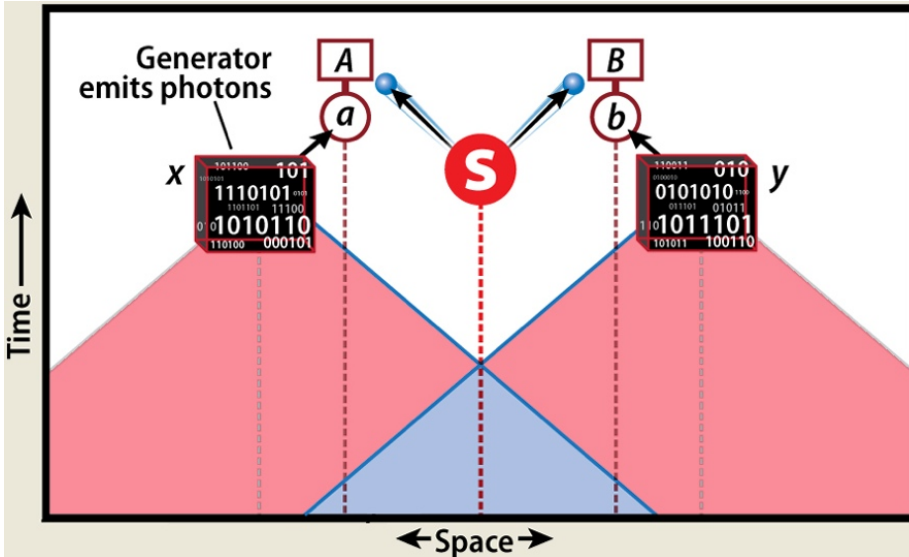
**Let the Universe decide how
to set up experiment!**

**Use quasars as cosmic random
number generators**

SPACE-TIME DIAGRAMMS

Standard Bell Test








Cosmic Bell Test



ASTRONOMY: ROEN KELLY, AFTER ANDREW FRIEDMAN

Past light cones from random number generators overlap milliseconds before test.

Past light cones from quasars don't overlap since big bang, 13.8 billion years ago.

	Source of entangled particles		Random-number generator			Measurement outcomes
	Quasar			Detectors set		

COSMIC BELL TEAM



Dr. Jason Gallicchio³



Dr. Andrew Friedman^{1,2}



Prof. David Kaiser^{1,2}



Prof. Brian Keating⁴



Prof. Anton Zeilinger⁵



Prof. Alan Guth¹

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*Dr. Johannes Kofler*⁶,
*Johannes Handsteiner*⁵,
*Marissa Giustina*⁵,
*Isabella Sanders*¹,
*Anthony Mark*¹



1:MIT Physics/CTP, 2:MIT STS,
3:U. Chicago KICP / Harvey Mudd,
4: UCSD, 5: Vienna IQOQI,
6: Max Planck

ZEILINGER GROUP EXPERIMENTS



Prof. Anton Zeilinger



CANARY ISLANDS TELESCOPES



**Roque de los Muchachos
Observatory on La Palma**

**Teide Observatory
on Tenerife**



POSSIBLE COSMIC BELL OUTCOMES

Safe Bet



Quantum predictions always observed.

Rule out alternative theories, close free will loophole as much as possible.

Longshot

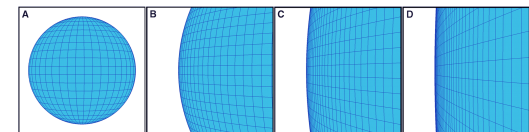
Results depends on which quasars we look at.

Maybe a deeper theory explains quantum mechanics.



Perhaps experimenter's lack complete freedom!

Early Universe Inflation?



NEXT TALKS



**Prof. Brian Keating
(UCSD)**

- Evidence for inflation
- Free will in the multiverse

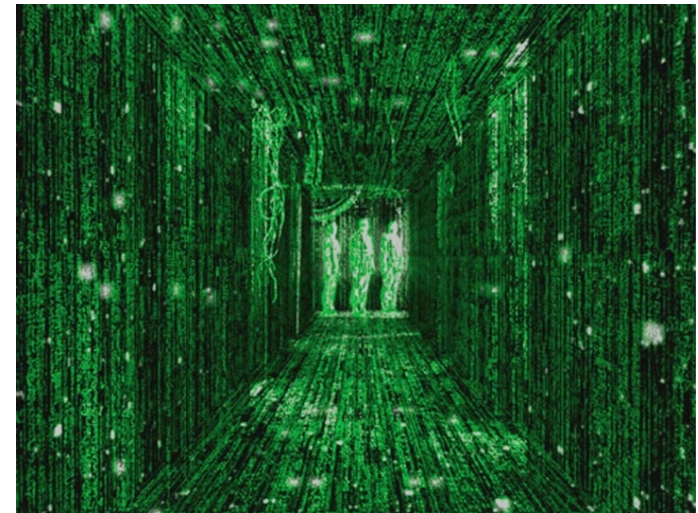


Photograph: Keith Vanderlinde/NSF



**Dr. David Brin
(UCSD)**

- Free will if we live in a simulation?
- Predicting human behavior?



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