PBS NOVA SCREENING & PANEL DISCUSSION

BEHIND THE SCENES

EINSTEIN'S

QUANTUM

RIDDLE

A special screening of the PBS NOVA documentary & panel discussion with physicists Andrew Friedman (UCSD), Brian Keating (UCSD), Jason Gallicchio (Harvey Mudd) and David Brin (Hugo & Nebula award-winning author)

Monday, March 4, 2019
6-8pm, Atkinson Auditorium

Dr. Andrew Friedman
UC San Diego, Center for Astrophysics & Space Sciences
https://asfriedman.physics.ucsd.edu  asf@ucsd.edu

UCSD  Arthur C. Clarke Center for Human Imagination
COSMIC BELL TEST ON TV!

EINSTEIN’S QUANTUM RIDDLE

Premiering Jan 9 2019
**Cosmic Bell in the News**

**New Scientist**

The Quantum Cosmos

*We've looked at the whole universe, and it's all weird*

**Motherboard**

Ancient Starlight Just Helped Confirm the Reality of Quantum Entanglement

"The real estate left over for the skeptics of quantum mechanics has shrunk considerably."

**Scientific American**

Photons, Quasars and the Possibility of Free Will

Flickers of light from the edge of the cosmos help physicists advance the idea that the future is not predetermined.

By Steven Frankson on November 21, 2018

Discover

D-brief

Black Holes Bolster Case For Quantum Physics' Spooky Action

By Luke Driscoll August 21, 2018 | 21 min

**Gizmodo**

'Spooky' Quantum EntanglementConfirmed Using Distant Quasars

By Aiden Leitch August 21, 2018

**Physics World**

Cosmic Bell test uses light from ancient quasars

23 August 2018

**MIT News**

Light from ancient quasars helps confirm quantum entanglement

Results are among the strongest evidence yet for "spooky action at a distance."

Jennifer Ouellette | MIT News Online

August 13, 2018
Beginning in the 1930s, the great architects of quantum theory struggled to understand the notion of “entanglement.”
QUANTUM ENTANGLEMENT

Paired systems with correlated (or anti-correlated) properties

Is quantum mechanics incomplete or just spooky?
BELL’S INEQUALITY ASSUMPTIONS

1. Realism
2. Locality
3. Freedom

1, 2, 3 → Bell’s Inequality

Upper limits on entangled particle measurement correlations in a “local-realistic” model

John S. Bell (1928-1990)
**RELAXING BELL’S ASSUMPTIONS**

1. Realism       2. Locality       3. Freedom

Experiments violate Bell’s inequality as predicted by quantum mechanics!

→ **At least one of 1,2,3 are false!**

But relaxing any assumption → **LOOPHOLES**

*Alternative models could mimic quantum theory*
LOOPTHOLES & WHY THEY MATTER

The standard interpretation of Bell tests — that “local realism” is incompatible with experiment — relies upon several assumptions.

So What?!

Quantum foundations!

Understanding reality at a deep level. If universe exploits loopholes, does not mean QM is “wrong”, but perhaps derived from a more fundamental underlying theory. Quantum gravity?

Quantum cryptography security

Tech applications! Hackers could exploit loopholes to undermine entanglement-based quantum information schemes.
Are non-quantum, “local realist” explanations for entanglement viable? Are measurement choices $a,b$ really “free”? 

**ENTANGLED PARTICLE TESTS**

Entangled particle source

$a, b : \text{Settings}$

$A, B : \text{Outcomes}$
CHOOSING DETECTOR SETTINGS

Source of Entangled Particles

Adapted from: Gallicchio, Friedman, & Kaiser 2014
CHOOSING DETECTOR SETTINGS

Source of Entangled Particles

Quantum Random Number Generator

Albert

Bohr

Adapted from: Gallicchio, Friedman, & Kaiser 2014
Choosing Detector Settings

Choose settings with real-time observations of distant Milky Way stars

Requires alternative theories to act hundreds or thousands of years ago

Source of Entangled Particles

Quantum Random Number Generator

Star A

Star B

Albert

Bohr

Adapted from: Gallicchio, Friedman, & Kaiser 2014
**CHOOSING DETECTOR SETTINGS**

Albert

Source of Entangled Particles

Bohr

Quantum Random Number Generator

* Quasar B

Quasar A

Adapted from: Gallicchio, Friedman, & Kaiser 2014

Choose settings with observations of high redshift cosmic sources

Relegates alternatives to billions of years ago!
Cosmic Bell Test Using Random Measurement Settings from High-Redshift Quasars

Dominik Rauch,1,2,* Johannes Handsteiner,1,2 Armin Hochrainer,1,2 Jason Gallicchio,3 Andrew S. Friedman,4 Calvin Leung,1,2,3,5 Bo Liu,6 Lukas Bulla,1,2 Sebastian Ecker,1,2 Fabian Steinlechner,1,2 Rupert Ursin,1,2 Beili Hu,3 David Leon,4 Chris Benn,7 Adriano Ghedina,8 Massimo Cecconi,8 Alan H. Guth,5 David I. Kaiser,5,† Thomas Scheidl,1,2 and Anton Zeilinger1,2,‡


Let the Universe decide how to set up entanglement experiment!
COSMIC BELL TEAM

Prof. David Kaiser
Dr. Andrew Friedman
Prof. Alan Guth

Prof. Brian Keating
Prof. Anton Zeilinger
Prof. Jason Gallicchio

Other Collaborators
Johannes Handsteiner
Dominik Rauch
Dr. Thomas Scheidl
Dr. Johannes Kofler
Dr. Hien Nguyen
Calvin Leung
David Leon et al.

1: MIT Physics/CTP
2: Vienna IQOQI
3: Harvey Mudd
4: Max Planck MPQ
5: UCSD CASS
6: NASA JPL/Caltech
Bright, distant galaxies powered by supermassive black holes

Visible all the way to the edge of the universe!

COSMIC BELL TEST: LA PALMA

Image Credit: Jason Gallicchio (Harvey Mudd)
COSMIC BELL TEST WITH QUASARS

William Herschel Telescope (WHT)

Nordic Optical Telescope (NOT)

Entangled Particle Source

Telescope Nazionale Galileo (TNG)

Image ©2018 DigitalGlobe (Google Earth)
CHOOSING THE BEST QUASARS

Image Credit: Andrew Friedman (UCSD)
REMOTE ASSISTANCE

Image Credit: Andrew Friedman (UCSD)
NO PRESSURE!

Image Credit: Andrew Friedman (UCSD)
Nordic Optical Telescope (NOT)

Cosmic Bell Test
Entangled Particle Source
(Shipping Container)

Image Credit: Dominik Rauch (Vienna)
NEAR DISASTER!

Cosmic Bell Test Shipping Container

Image Credit: Dominik Rauch (Vienna)

Nordic Optical Telescope (NOT)
NEAR DISASTER!

Image Credit: Dominik Rauch (Vienna)
NEAR DISASTER!

Image Credit: Dominik Rauch (Vienna)
Cosmic Bell Test Shipping Container

DISASTER AVERTED
Entangled photon source fixed, reinstalled in now secured shipping container control room.
ADVENTURES IN LA PALMA

Chris Benn, Head of Astronomy, Isaac Newton Group of Telescopes, La Palma

Thomas Scheidl (Vienna)

Armin Hochrainer (Vienna)

Dominik Rauch (Vienna)

Anton Zeilinger (Vienna)

Image Credit: David Kaiser (MIT)
COSMIC BELL ON TV!

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Greenberger+1990, American Journal of Physics, Volume 58, Issue 12, pp. 1131-1143
Hall 2011, Phys. Rev. A, vol. 84, 2, id. 022102
Mermin 1990, American Journal of Physics, Volume 58, Issue 8, pp. 731-734
Scheidl+2010, PNAS, 107, 46, p. 19708-19713