Einstein’s Blunder Undone

Robert P. Kirshner
Harvard-Smithsonian Center for Astrophysics
The Milky Way

In 1917 = The Universe
Today = 1 in $10^{11}$
I think it must be static!
1917:

Einstein stuck in the cosmological constant to make a static Universe.

“Universe” = Milky Way Galaxy
Harvard “Computers” ~1900
Harvard Observatory
Director Pickering:

A great observatory should be as carefully organized and administered as a railroad...
A great savings may be effectuated by employing unskilled and therefore inexpensive labor, of course under careful supervision.
Henrietta Swann Leavitt:

“It is worthy of notice that the brighter variables have the longer periods.”

From George Johnson’s, “Miss Leavitt’s Stars”
The 100-inch Telescope at Mount Wilson
Edwin Hubble showed the Milky Way was not the whole Universe.

We live in a Universe of galaxies, each equivalent to the Milky Way.
Hubble used the apparent brightness of stars in galaxies to judge their distances.
The Milky Way is not unique: A Universe of $10^{11}$ Galaxies
Hubble showed we live in a big universe

$10^{11} = 100,000,000,000,000$ galaxies
Hubble showed we live in a big universe

10^{11} = 100,000,000,000,000 galaxies
Measure Motion from the spectrum:

The Redshift
Hubble’s Own 1929 Hubble Diagram

Redshift proportional to distance

4/14/07

KITP
Einstein visits Mt Wilson
1931
Einstein thinking about $\Lambda$ in Santa Barbara

$\Lambda$? Who needs it?
Gamow dubs a blunder
From *My World Line*
\[ \Lambda \] as the source of cosmic expansion: DeSitter in 1930

Thanks to Jim Peebles

"Who however blows up the ball? What makes the Universe expand or swell up? That is due to the Lambda. An other answer cannot be given." *A well known daily newspaper.
Einstein’s View on $\Lambda$

“An increase in the precision of data ...will enable us in the future to fix its sign and determine its value.” 1932

$\text{No } \Lambda!$
2005 Pinot Noir Estate "A" Sta. Rita Hills $27.95

1400 cases produced
Albert Einstein first proposed the idea of a cosmological constant as part of his general theory of relativity. Physicists today continue to denote this (now modified) concept with the Greek symbol lambda or \( \Lambda \). Peter and Rebecca Work have also proposed a lambda labeled constant in the form of an estate grown Pinot Noir. I must admit, theirs is much easier to digest – especially this '05 vintage. A blend of clones 113 (2/3) and Pommard (1/3) hand harvested from their

**Tasting Dates:**
**Saturday, March 10th 2007**
**Saturday, April 28th 2007**
Look up there, Willem!
Supernovae & Cosmology

Hubble (1929)

“a mysterious class of exceptional novae which attain luminosities that are respectable fractions of the total luminosities of the systems in which they appear.”
Exploding stars
\( \sim 4 \times 10^9 \) Suns

10^6 brighter than Miss Leavitt’s stars

\( \sim 1 \) SNIa/century in a galaxy

\( \sim 1 \) per second in the Universe!

4/14/07
In 1933, Fritz Zwicky speculated that supernovae come from the gravitational collapse of a star to a neutron star.
Tycho’s (1572)
Manufactured in supernovae!
CfA Supernova Group
2006
CfA:
Following up!
It is worth noting that the brightest supernovae have the slowest declines.
Hubble Diagram for Type Ia Supernovae

Expected to measure slowing down of cosmic expansion due to gravity.
$\Omega$: density
\[
\frac{\text{the critical density}}{
}
\]
Fritz Zwicky

Again!

Motion in Galaxy Clusters $\Rightarrow$

DARK MATTER!

$M \sim V^2 R / G$

Much bigger mass than inferred from light

4/14/07
Dark Matter at Work

$\Omega_{\text{matter}} \sim 0$
What is the history of cosmic expansion? We need to look deep into the past.
Giant Electronic Cameras Improve Searches
1/100 years \sim 1/5000 \text{ weeks} \Rightarrow 5000 \text{ galaxies}
Brian Schmidt explains how easy this will be
Searching by Subtraction
unskilled and therefore inexpensive labor
under careful supervision--computers!

Epoch 1  Epoch 2  Epoch 2 - Epoch 1
ESSENCE Results
An accelerating universe!
Big News in 1998!

High-Z Team

Riess et al. (1998)

Supernova Cosmology Project

Perlmutter et al. (1999)
WMAP view of fluctuations in the CMB => A "Flat" Universe
\[ \Omega < 1 \]

\[ \Omega = 1 \]

\[ \Omega > 1 \]
Not Your Father’s Universe!

- Dark Energy: 73%
- Cold Dark Matter: 23%
- Atoms: 4%
Although the universe is under no obligation to make sense, students in pursuit of the Ph.D. are.
Although the universe is under no obligation to make sense, students in pursuit of the Ph.D. are

Robert P. Kirshner
Dark Energy is Real...

SNe Ia

LSS

CMB (WMAP)

+ ISW, X-ray Clusters

But what is it?
Google ‘Dark Energy’!

“These specialized processes are also responsible for the very distinct odor of Dark Energy!”
Robert Kirshner
member in good standing

Real theorist!
Robert Kirshner
member in good standing
RENEWED

David Gross
president

Adam Burrows
shop steward

Real theorist!
Is the Dark Energy the Cosmological Constant?

Not good quantitative agreement!

“A bone in the throat.”-- S. Weinberg
Putting Λ on the Right Hand Side
Searching for Supernovae with HST

Back to the age of deceleration
HST Refurbishing
A New Camera on HST
The Rise and Fall of a Distant Supernova
Cosmic Deceleration from Dark Matter, then Acceleration from Dark Energy!
Evidence for a change in cosmic acceleration: ‘cosmic jerk’

Future: Acceleration without end? Big rip?

A ‘Cosmic Jerk’ That Reversed the Universe

By DENNIS OVERBYE

CLEVELAND, Oct. 10 — Astronomers said on Friday that they had determined the time in cosmic history when a mysterious force, “dark energy,” began to wrench the universe apart.

Five billion years ago, said Dr. Adam Riess, an astronomer at the Space Telescope Science Institute in Baltimore, the universe experienced a “cosmic jerk.” Before then, Dr. Riess said, the combined gravity of the galaxies and everything else in the cosmos was resisting the expansion, slowing it down. Since the jerk, though, the universe has been speeding up.

The results were based on observations by a multinational team of astronomers who used the Hubble Space Telescope to search exploding stars known as Type Ia supernovas, reaching back in time three-quarters of the way to the Big Bang, in which the universe was born. The results should help quell remaining doubts that the expansion of the universe is really accelerating, a strange-sounding notion that has become a pillar of a new and widely accepted model of the universe as being full of mysterious dark matter and even more mysterious dark energy.

“This gives great confidence that we’ve been on the right track,” said Dr. Riess, who announced his results at a meeting here on the Future of Cosmology sponsored by the Center for Education and Research in Cosmology and Astrophysics at Case Western Reserve University and the Kavli Institute.

Dr. Lawrence M. Krauss, an astrophysicist at Case Western, called the turnaround from slowing down to speeding up important confirmation.

The big surprise,” Dr. Krauss said, “would have been if it hadn’t happened.”

Dr. Joseph Lykken, a physicist at the Fermi National Accelerator Laboratory, known as Fermilab, in Batavia, Ill., said, “I could go home now and be happy.”

Knowing how and when the jerk occurred, astronomers said, was an important step in figuring out just what the dark energy is.

“He gave us information about when the universe hit the gas pedal,” said Dr. Michael S. Turner, a cosmologist at the University of Chicago who is director of mathematics and collaborators found Hubble observations of a supernova 10 billion years in the past. It proved to be anomalously bright, lending credence to the idea that a dark energy had taken over some time in between.

“But a single object is just not robust enough,” he said. For the last year, he and his colleagues have used the Hubble in collaboration with a large galaxy survey known as GOODS to find distant supernovae.

“We found lots of weapons of mass destruction,” he said, showing Hubble pictures of some exploding with the brilliance of small galaxies, $1 billion to 10 billion light-years away. More important, they were brighter than expected. When he plotted their velocities against distance, or time in the past, Dr. Riess found that the universe had to have changed direction, from slowing to speeding up, over a period of time five billion years ago, the so-called cosmic jerk, using the technical term for a change in acceleration.

“It’s great to see it,” Dr. Riess said.

In Dr. Lykken’s words, and as borne out by discussions at the meeting here, “theorists don’t have a clue” about the identity of the dark energy that is so important.
And some things just don’t fit, no matter how you turn the knobs.
Nothing more complicated than the cosmological constant is justified by the present data.
What next for HST?
DESTINY
Dark Energy Space Telescope
The Giant Magellan Telescope
The first mirror has already been cast!
Dark Energy puzzles-- a sign that we do not know how to combine gravity with quantum physics!

Modifications to General Relativity?

Effect of Extra Dimensions?
If you can’t get enough of these matters... I can’t recommend a better book
Science for...

Technology => Rich
Defense => Safe
Medicine => Immortal
Science for...

Technology => Rich
Defense => Safe
Medicine => Immortal
& Bored
Science for...

The joy of finding out how the world works
Figure 20

Inside-out universe. This surrealistic drawing represents a man walking on the surface of the Earth and looking up at the stars. The picture is transformed topologically according to the method indicated in Figure 19. Thus the Earth, sun, and stars are crowded in a comparatively narrow channel running through the body of the man, and surrounded by his internal organs.
Fritz Zwicky--
Supernova Visionary!
Einstein in 1917

Gravitation would make matter clump

Added in a “Cosmological Term” to make a static universe:

Λ
I feel sure that science will bring to this land both peace and a renewal of its youth, creating here the springs of a new spiritual and material life. And here I speak of science for its own sake and of applied science.

Chaim Weizmann 1946
Word of the day:
Lucubration: Earnest study at night

Saurabh Jha

2006 Harvard “computer”
Light Curve Shapes allow us to separate the bright ones from the dim bulbs
The Big Bang was here 14 billion years ago.
If the universe is closed, light rays from opposite sides of a hot spot bend toward each other ...

... and as a result, the hot spot appears to us to be larger than it actually is.

If the universe is flat, light rays from opposite sides of a hot spot do not bend at all ...

... and so the hot spot appears to us with its true size.

If the universe is open, light rays from opposite sides of a hot spot bend away from each other ...

... and as a result, the hot spot appears to us to be smaller than it actually is.
America: A Land of Scientific Culture
WHO'S PERFECT?

EXPANDING UNIVERSE ⇒

"AWAY WITH THE COSMOLOGICAL CONSTANT! "

4/14/07