Dark Matter Science:

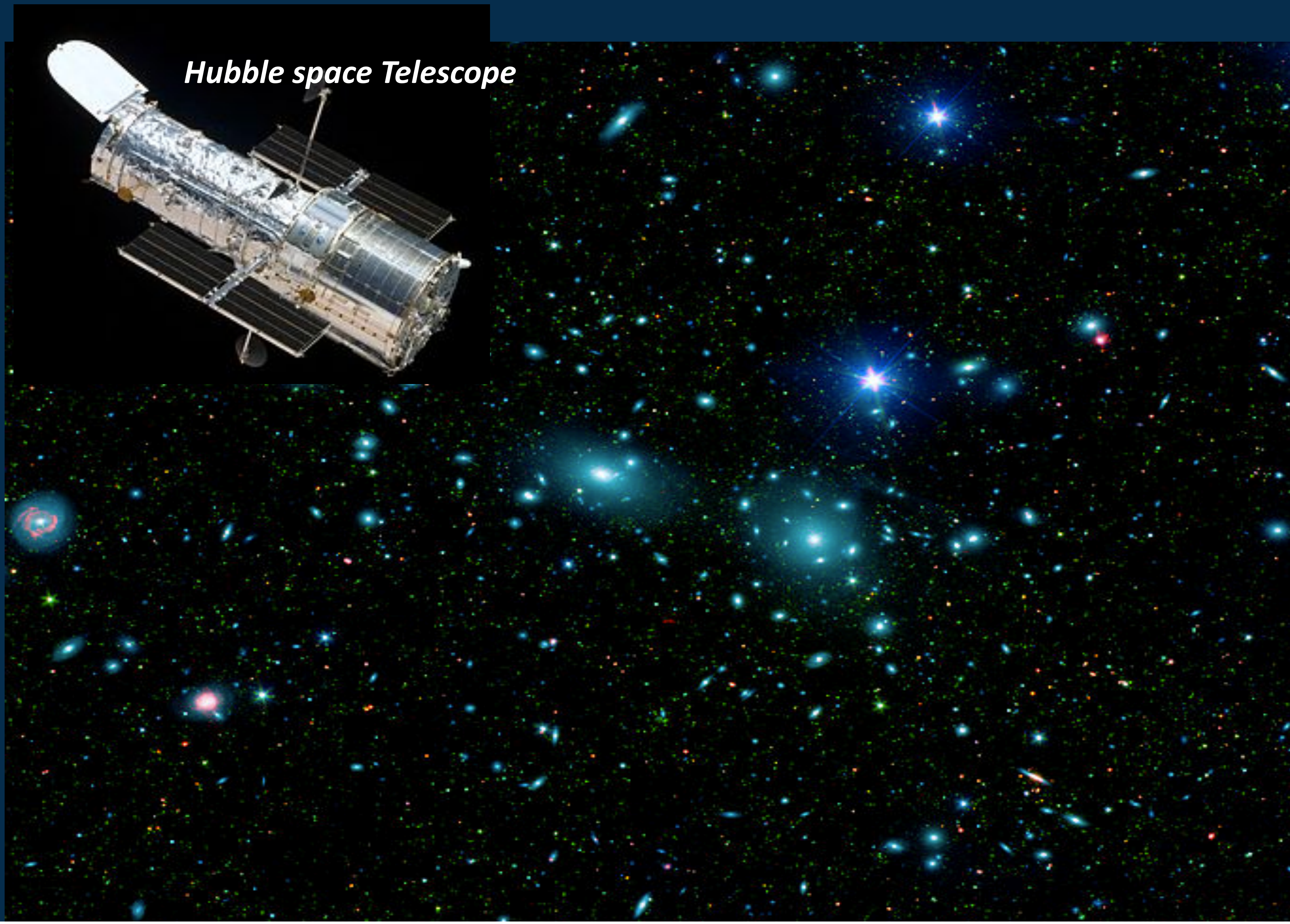
Early experiments and the role of Ron L. Brodzinski at PNNL

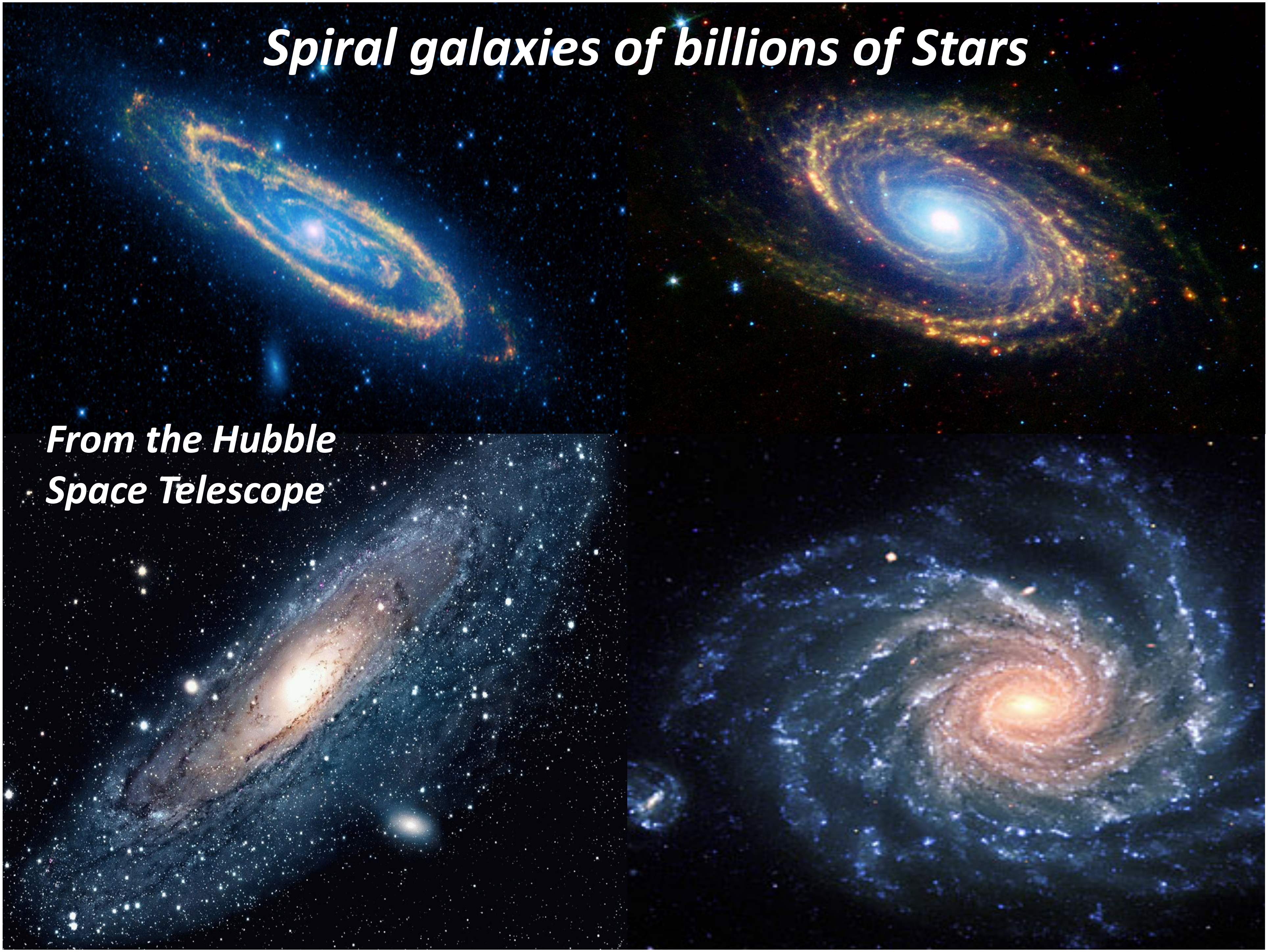
Monday, June 18, 2012 | 4:00 pm
Battelle Auditorium

Frank Avignone, University of South Carolina

In memory of Ron L. Brodzinski

What do you imagine when you look into the night sky?




Spiral galaxies of billions of Stars
From the Hubble
Space Telescope

Astronomers have observed that the dynamic behavior of clusters of galaxies, and that of stars in spiral galaxies, imply that there must be an an enormous amount invisible material with mass that permeates all space.

Now we call it Dark Matter.

Dark Matter In The Universe

Where did the notion come from?

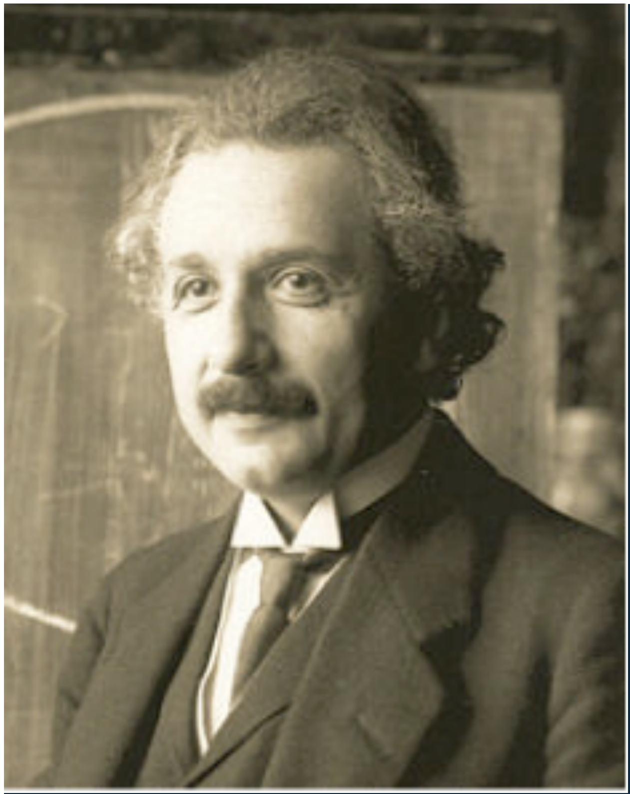
What evidence do we have that it exists?

How do we search for it?

What is this thing called Dark Energy?

What evidence do we have that it exists?

First we should briefly visit some history of astronomy and cosmology starting in the 1920s

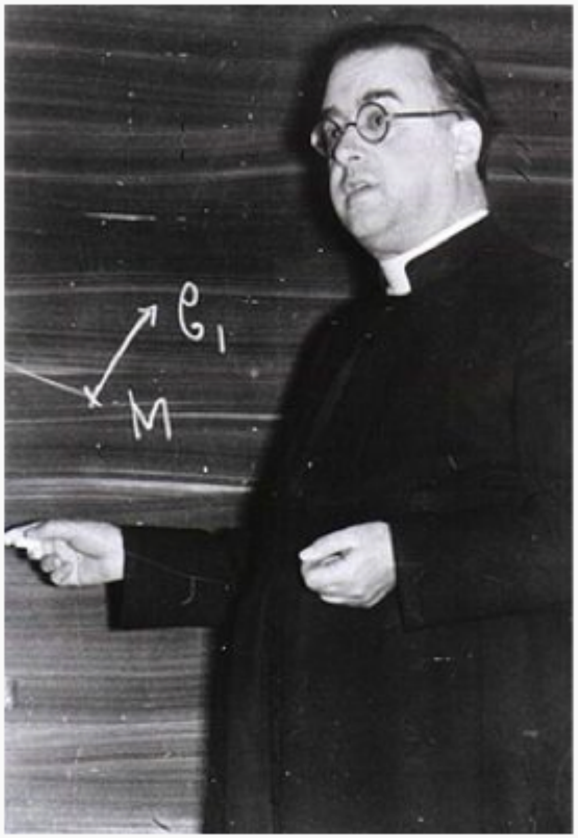


In 1920 Albert Einstein was convinced from all of the astronomical data that the Universe was neither expanding nor contracting.

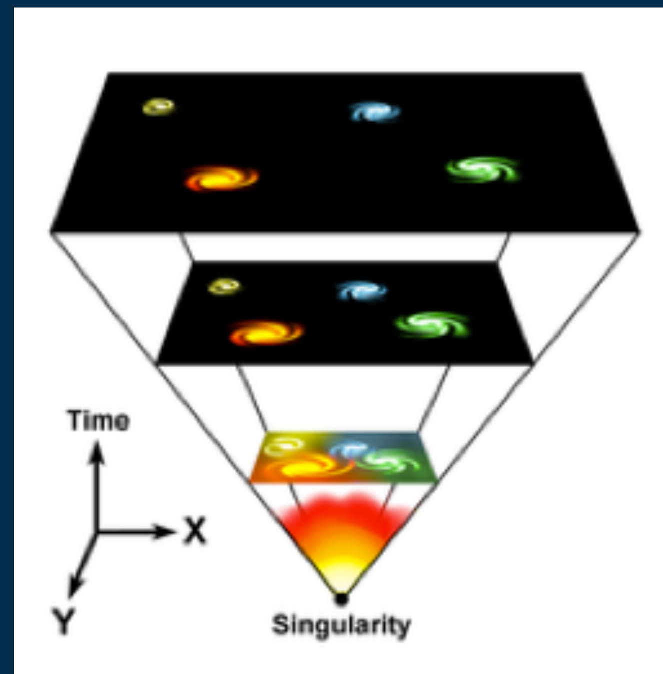
Accordingly he fixed his General Theory of Relativity to describe a "Static Universe."

Monseigneur Georges Lemaître was the first to propose that the universe was expanding. In a paper in 1927 he predicted the linear expansion which Hubble actually discovered in 1929.

Albert Carin



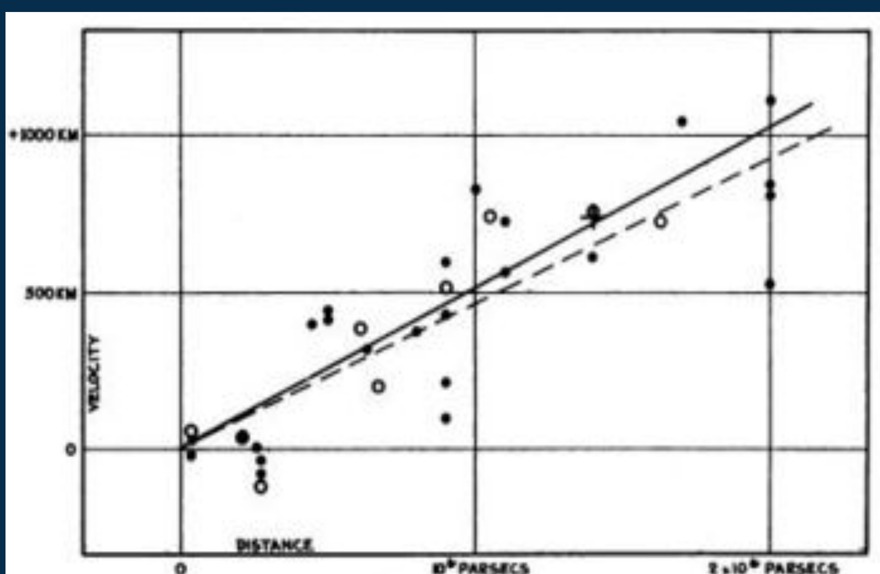
Monseigneur Georges Lemaître, priest and scientist



Einstein Remarked: " Vos calculs son corrects, mais votre physique est abominable!"

Edwin Hubble in 1929

This WW-I veteran and ex-lawyer made significant astronomical observations that showed that galaxies are receding from one another in a systematic way.



H_0=velocity/distance

Hubble's Low

Age of the Universe: *6 Billion Years*

COSMIC TIMES

Size of the Universe: *4 Billion Light Years*

1955

'Yardsticks' in Neighbor Galaxy Double Universe's Size

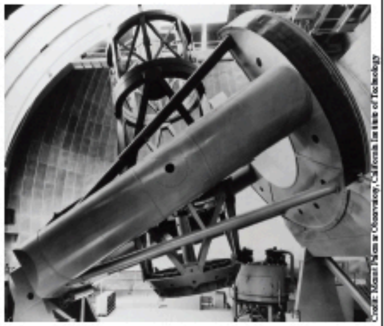
The universe is twice as large as we thought says Caltech astronomer Walter Baade, who has now employed the giant 200-inch glass reflecting telescope at Mount Palomar to confirm the scale of the cosmos.

Baade's discovery hasn't come from simply reading mile markers in space, of course. To properly divine the distance of stars and the scale of the universe first he had to discover that Nature has created more than one kind of mile marker, or yardstick, if you will. Until a few years ago, there was just one cosmic yardstick known to astronomers, and it was being used incorrectly. Oddly enough, it took the wartime blackouts in Los Angeles to begin setting things straight.

That first universal yardstick was discovered around the turn of the century. It is a type of pulsating, variable star called a Cepheid. Henrietta S. Leavitt of the Harvard Observatory was surveying the Magellanic Clouds, those junior galaxies outside of the Milky Way, when she noticed that brighter Cepheids pulsed slower than dimmer Cepheids. This was intriguing, since for all practical purposes the stars in the Magellanic Clouds can be considered the same distance from Earth. It suggested that those Cepheids were offering up a handy relationship between their real (not just apparent) luminosity and their pulsation rate.

If, for example, an astronomer observes a fast-pulsating Cepheid in our own Milky Way galaxy which appears dim from Earth, he can use Miss Leavitt's brightness/pulsation relationship to surmise that the star is actually very bright, just very distant. Likewise, a slowly pulsing Cepheid which appears bright in our sky is probably a relatively dim star that only appears bright because it's closer.

The same relationship seemed to hold with Cepheids found in dense star clusters, in our own Galaxy, as was discovered by astronomer Solon Bailey. Finally, astronomer, Harlow Shapley standardized the yardstick so he could map the distance of both fast-period and slow period Cepheids both inside and outside globular clusters in the Milky Way.



The telescope that confirmed the scale of the cosmos: Mount Palomar's 200-inch Hale Telescope was completed in 1949.

As chance would have it, the solution came during the wartime blackouts of 1943 in California. Doctor Baade took advantage of the darkened skies and the power of the 100-inch Hooker telescope at the Mount Wilson Observatory near Los Angeles to re-examine Andromeda's globular clusters. Using special red-sensitive photographic plates Dr. Baade discovered two populations of stars: redder, fainter "Type II" stars near Andromeda's center and in its outlying halo (the same arrangement as in the Milky Way) and bluer, brighter "Type I" variable stars located in the outer spiral arms as well as in abundance in the Magellanic Clouds. So, Dr. Baade realized that there must be two populations of Cepheids – those Type I Cepheids more common in the disk of a galaxy and those Type II Cepheids more common in the globular clusters.

Each type of Cepheid, it turns out, has a different way of encoding its actual brightness into its pulsing light. It was as if the measuring stick for one type of Cepheid was measured in feet, i.e., a good old American yardstick, and the other was in cubits. The problem was Shapley had treated them both as regular 36-inch yardsticks.

"…[U]nknowingly Shapley had made a fatal step when he linked the cluster-type variables to

Origin of Everything: Hot Bang or Ageless Universe?

It's difficult to imagine a deeper mystery than the one being addressed recently at the meeting of the National Academy of Sciences in Pasadena, California: Is the universe eternal or does it have a beginning, middle and an end?

The case for an ageless, steady-state universe which forever looks much as it does today was presented at the conference by astrophysicists Jesse L. Greenstein and physicist William A. Fowler of the California Institute of Technology. The steady state theory rivals the "evolutionary" theory of the universe which calls on an initial brew of hot particles exploding at the dawn of time and making all the universe's hydrogen and perhaps helium on one fell swoop.

Both theories explain – in entirely different ways – the inescapable fact that the universe is expanding. This cosmic expansion was first detected in 1914, when American astronomer Vesto Melvin Slipher surveyed some galaxies and noticed the light from most of them was "red-shifted." This is essentially the broadening and reddening of the visible light waves caused by the retreat of the galaxies. It's the electromagnetic equivalent of how the wail of a retreating locomotive drops in tone as it passes by a train watcher's ear.

In the steady-state theory the expansion comes from the continuous bubbling up of the most basic element, hydrogen, from empty space at a rate of one particle every cubic meter every 300,000 years or so. This hydrogen eventually gathers and condenses into stars which, through nuclear fusions in their cores, manufacture all the heavier elements. As stars age and die, they disperse the heavier elements around the galaxies, giving rise to new stars with rocky planets around them – like our own Solar System. As evidence of that process, Greenstein and Fowler referred to the heavy-element-making red giant stars which can be seen today in our Galaxy.

An important aspect of the steady-state is that it's anything but static, as the champion of this theory British cosmologist Fred Hoyle, likes to point out. Hoyle compares the deathless universe to a river. It may appear unchanging, but there is plenty of movement and change un-

again in an gigantic collapse that rebounds and starts the universe all over – the endlessly exploding and collapsing universe described by the late Caltech physicist Richard Tolman.

Which theory will prevail? Only more research with bigger and better telescopes will tell.

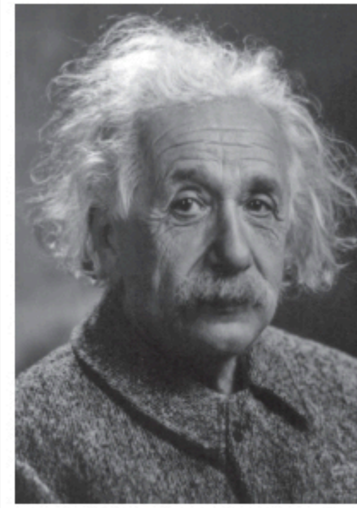
Fred Hoyle and William Fowler in Fowler's office in the W. K. Kellogg Lab at Caltech.

Hoyle Scoffs at "Big Bang" Universe Theory

British cosmologist Fred Hoyle has thrown down the gauntlet with regards to where and when all the universe's elements were created. In a recent radio broadcast he panned a rival theory, championed by Ukrainian-born American physicist George Gamow, labeling it a ridiculous "big bang."

Gamow's Evolutionary Theory of the universe calls on an initial stew of super-hot nuclear fusions of basic particles to create all the hydrogen in the cosmos in one explosive moment. The same blast then caused space to expand. The ongoing expansion from that

Death of a Genius

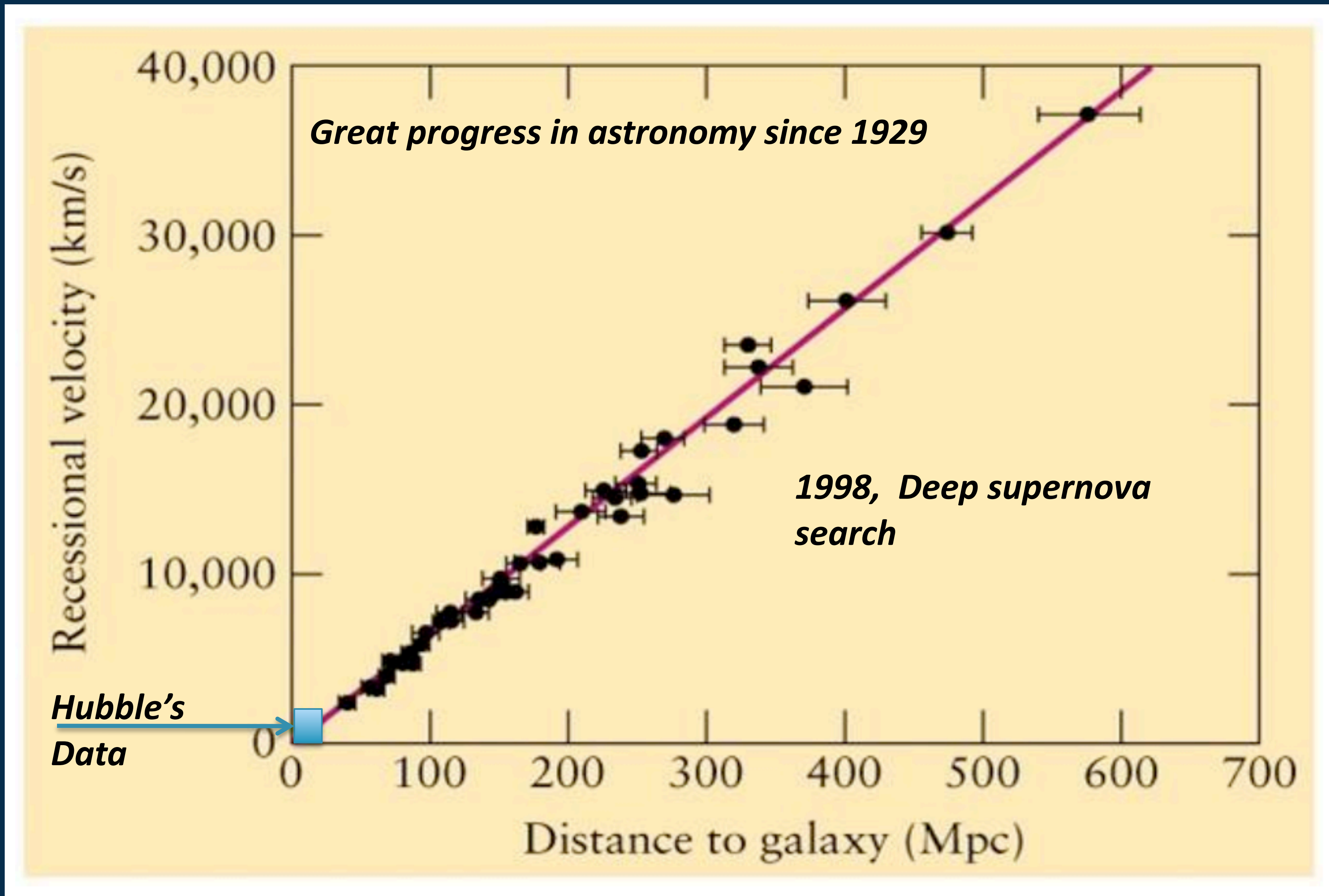


Albert Einstein in 1947.

The world has just lost its greatest scientific mind. Albert Einstein died in his sleep on April 18th from complications of a lingering gall bladder infection. He was 76. There is no doubt that this rumpled, white-haired, pipe-smoking professor peered deeper into the nature of the universe than any other man. In death he joins a select few – such as Newton, Copernicus, Archimedes and Pythagoras – as a giant in science whose genius changed the course of history.

The immediate outpouring of tributes to the German-born scientist begins to convey his place in history. President Eisenhower said "No other man contributed so much to the vast expansion of 20th century knowledge." Moshe Sharett, the Prime Minister of Israel observed "The world has lost its foremost genius." There were even eulogies behind the Iron Curtain. Pravda described him as "A great transformer of natural science."

The true nature of Einstein's achievements are better known to his colleagues and scientific progeny, who still labor to understand, test and apply his theories. There is his revolutionary rethinking of light as not just waves but particles.



H_0 =71 ± 3 km/sec/ mega-parsec

What in the world is a parsec and a mega-parsec ?

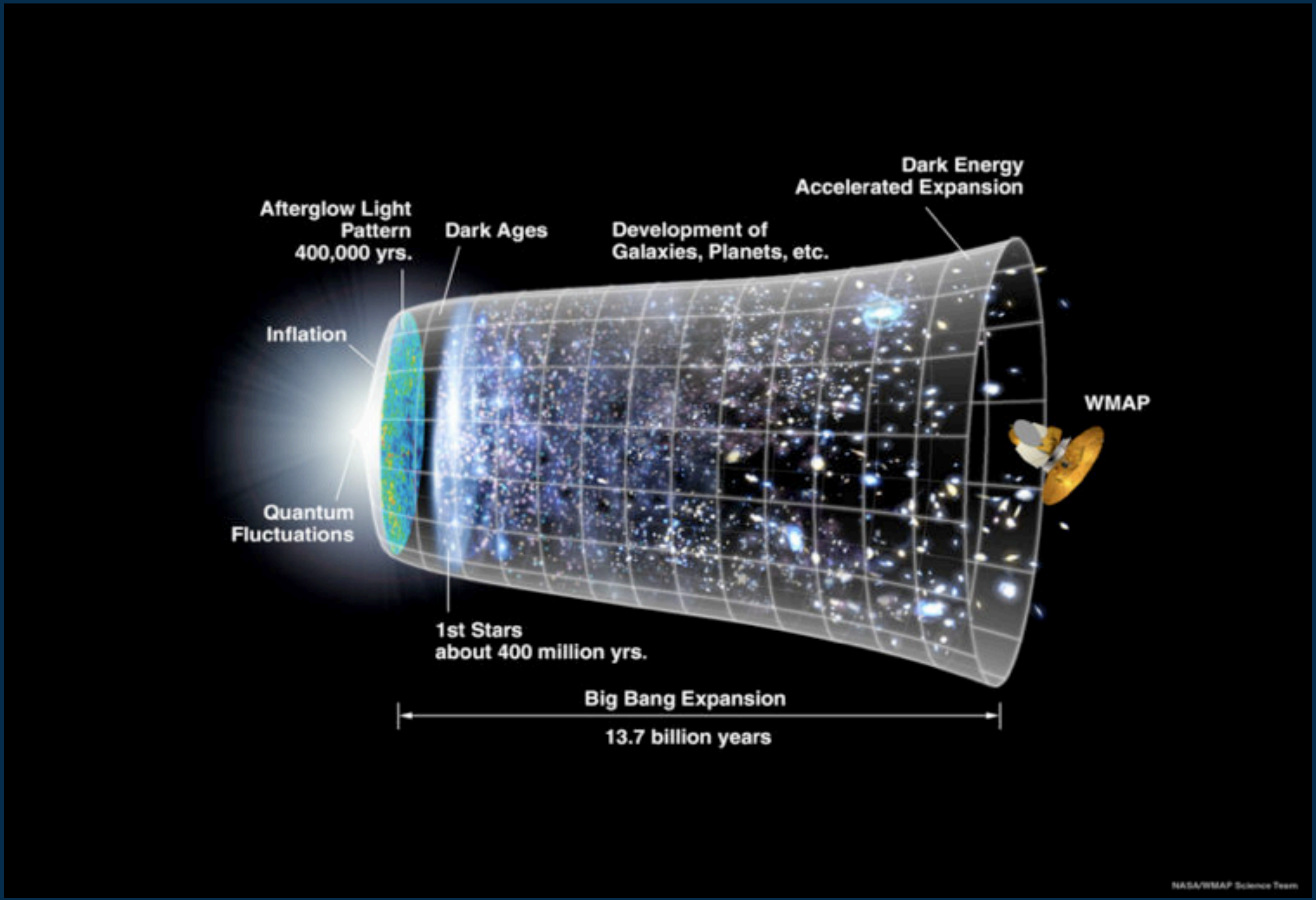
1pc = 3.26 light-years

1Mpc = 1 Mega Parsec = 3.26 million light-years

1Mpc ~ 30-billion billion kilometers or

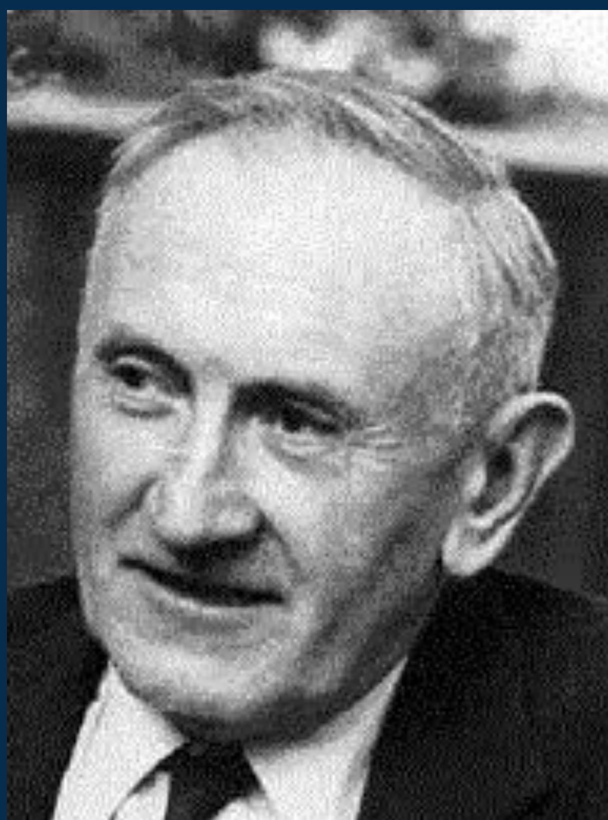
1Mpc ~ 18-billion billion miles

From this it was concluded that the universe was born in a BIG BANG.



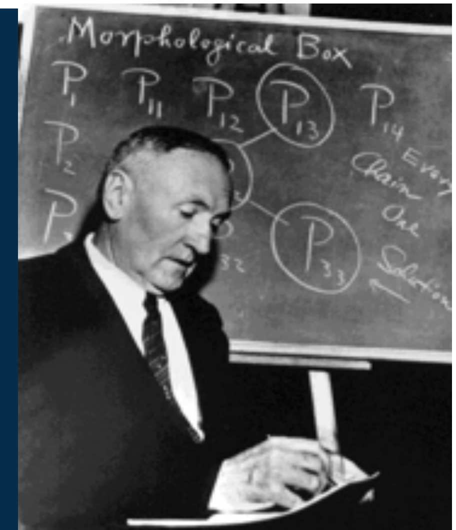
Alright, all that is interesting, but where did the notion of Dark Matter come from?

In 1933, Enter stage left Cal Tech Professor Fritz Zwicky



Zwicky at the 18-inch Schmidt

Fritz Zwicky



- *Professor of Astronomy, Cal. Tech. (1942-1968*
- *R&D Dir. Aerojet Engineering & "father of the modern jet Engine"*
- *First to discover evidence of Dark Matter (1933)*
- *Hypothesized and named "supernovae" & "neutron stars" (1934)*
- *Proposed that galaxies and galaxy clusters act as gravitational lenses (1937)*

In 1933 Zwicky examined the motions of galaxies in the Coma Cluster.

He concluded that the mass in stars and ordinary matter could not account for the most of the mass needed to explain their motions.

A Sloan Digital Sky Survey/Spitzer Space Telescope

The Coma Cluster has more than 1000 galaxies.

The measured red shift corresponds to a recession speed of almost 70,000 km/s

Zwicky concluded that the overwhelming majority of the mass in the Coma Cluster was some dark material.

What other evidence is there for dark material we now call dark matter?

More evidence is seen in "Galaxy Rotation Curves."

Following Zwicky's pioneering work in 1933, the American astronomer Vera Rubin and her colleagues began a series of analyses of the rotational behavior of spiral galaxies.

They measured the peripheral velocities of stars far from the galactic center as a function of their distance from the center.

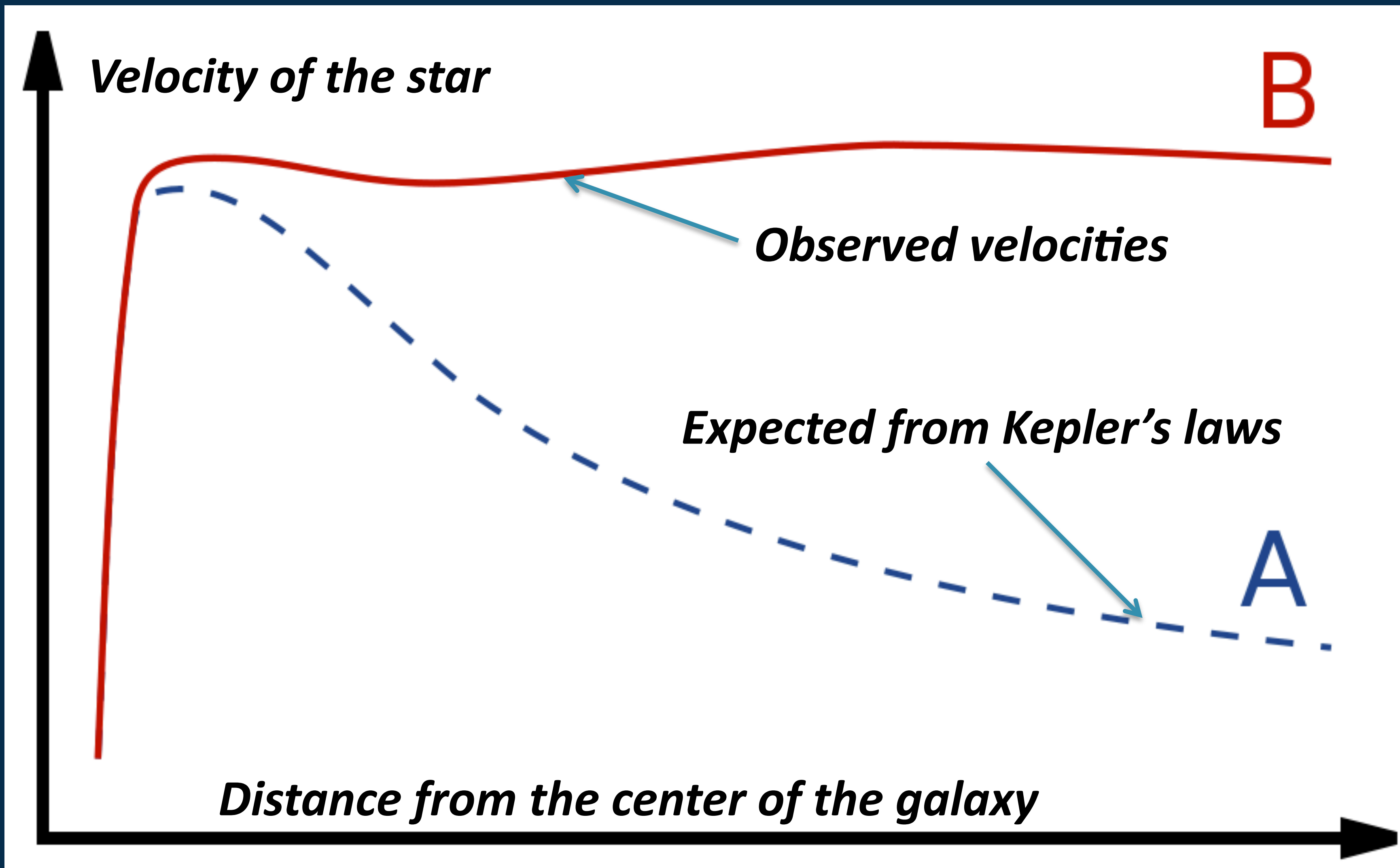
Measuring Rotation Curves in Spiral Galaxies

Red shifted
Wavelength lengthened

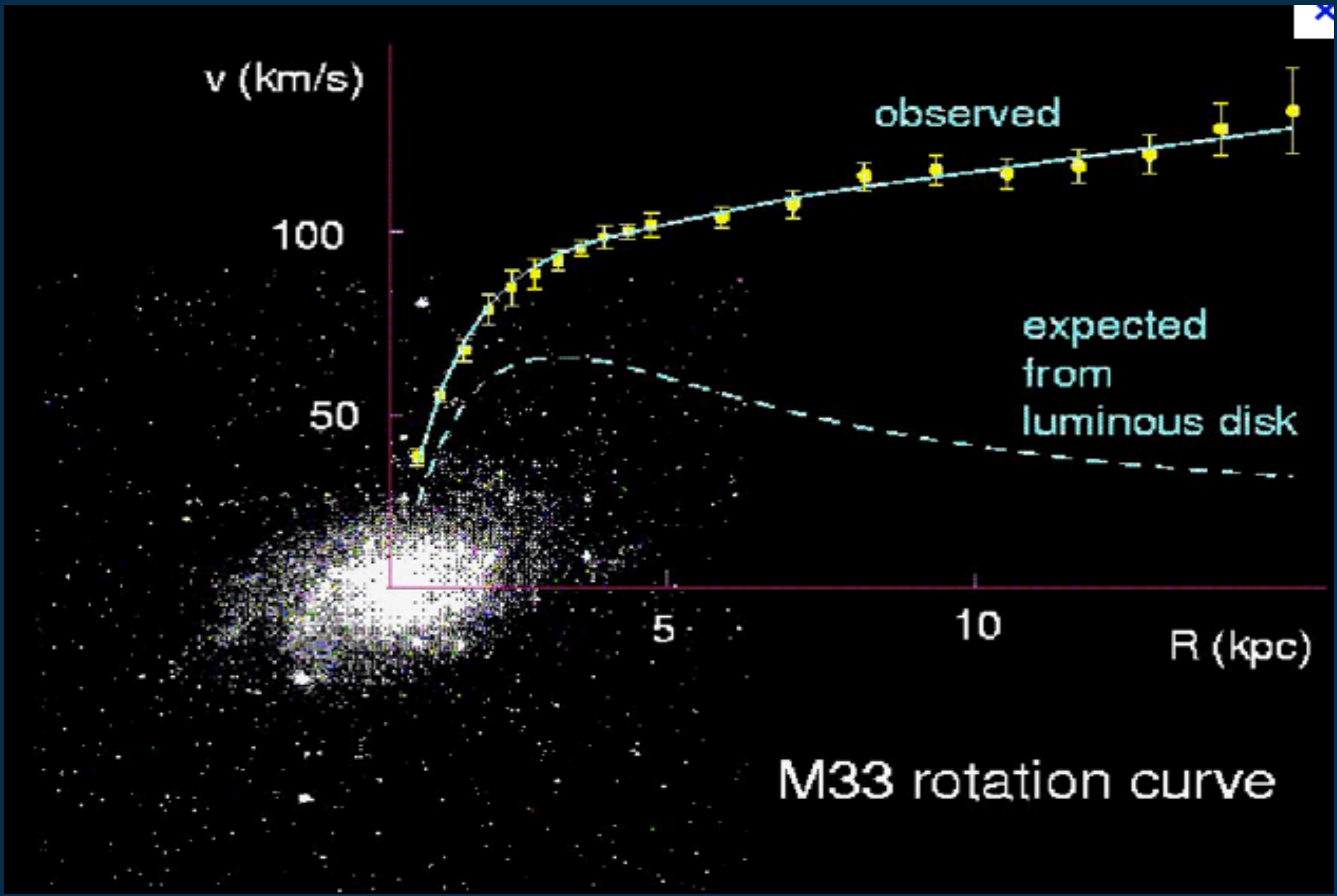
Blue shifted
Wavelength shortened

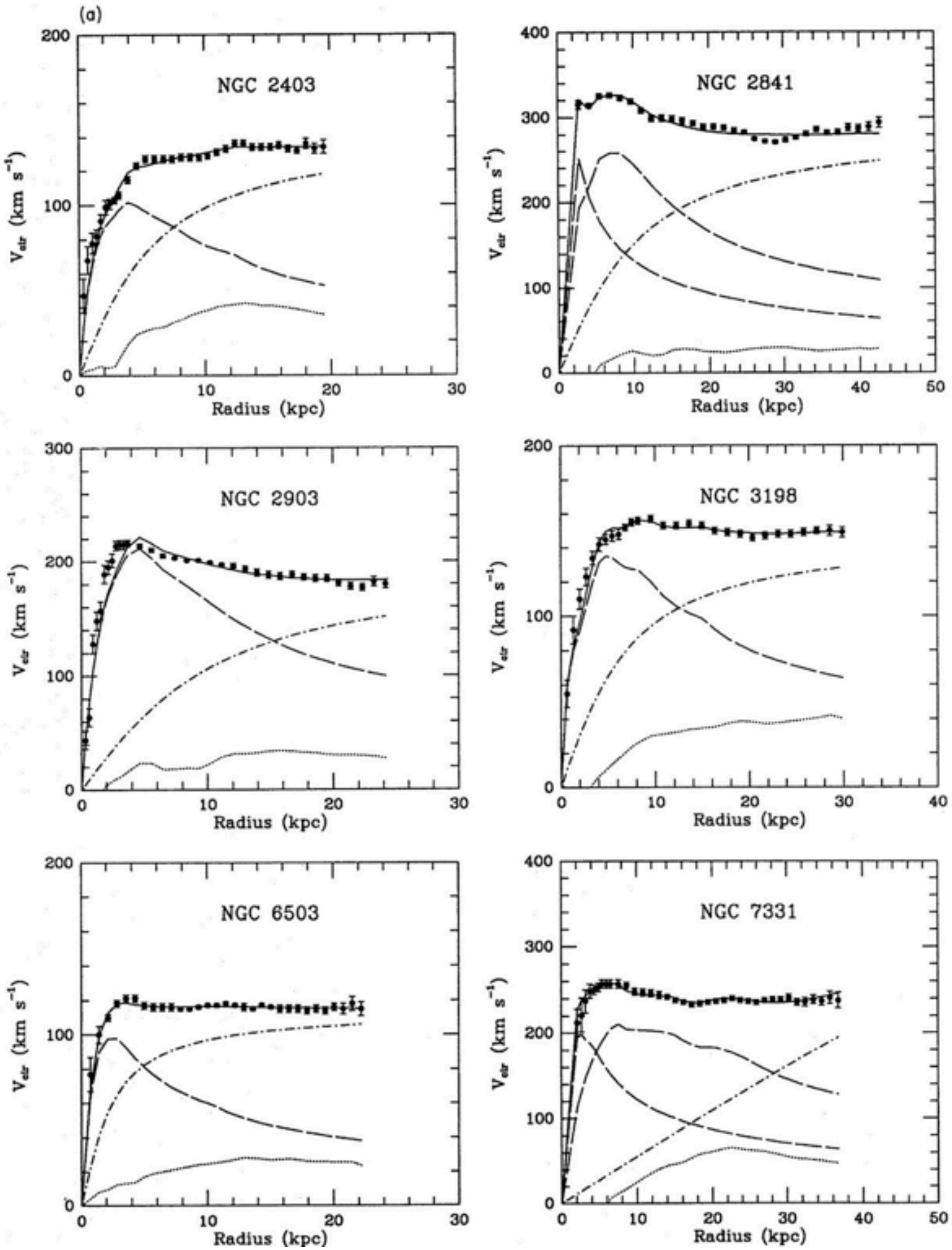
Redshift $Z=\Delta\lambda/\lambda$

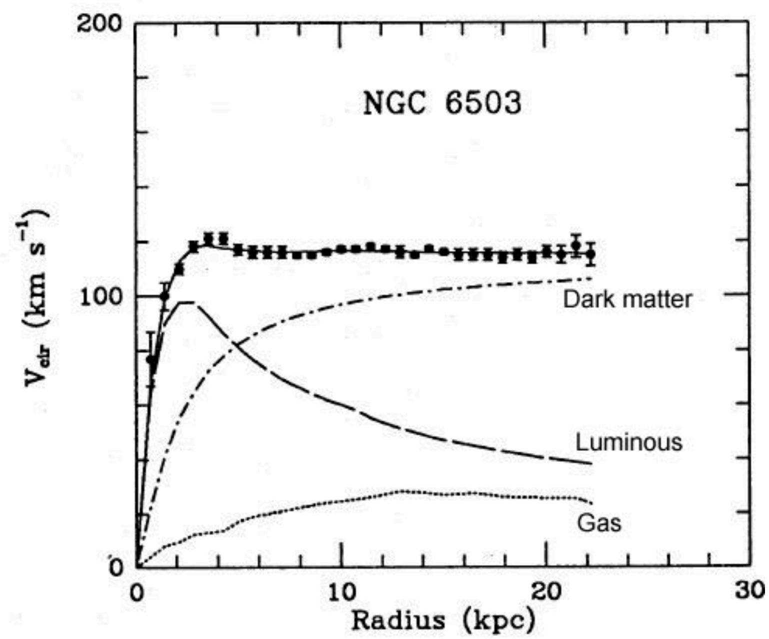
Stellar Rotation Curves and the early puzzle



An actual rotation curve of the M33 Galaxy




(a)
NGC 2403
NGC 2841
NGC 2903
NGC 3198
NGC 6503
NGC 7331
V_cir (km s^-1)
Radius (kpc)

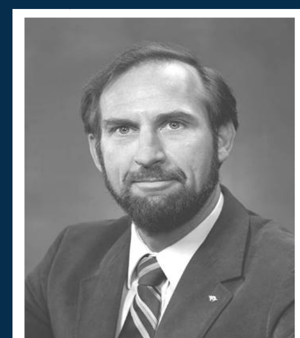

NGC 6503
V_cir (km s^-1)
Radius (kpc)
Dark matter
Luminous
Gas

By this time, the case for dark matter was well established

1980 was the beginning of the Battelle-Carolina Experiments

These experiments were originally intended to search for the hypothesized nuclear double-beta decay without neutrino emission. They could also detect dark matter in certain circumstances.

In 1980 Frank Avignone joined Ron Brodzinski and Ned Wogman and formed the Battelle-Carolina Collaboration

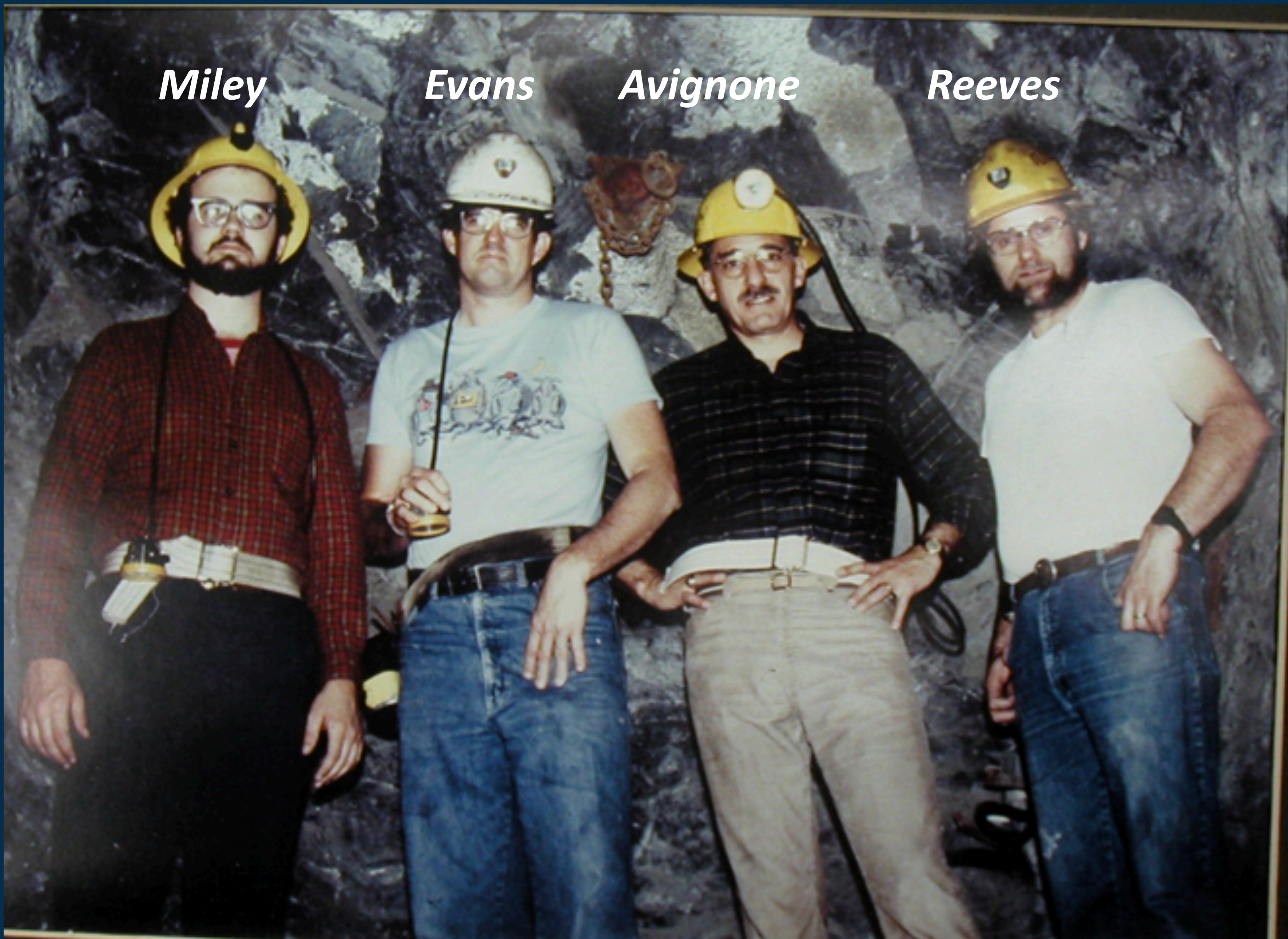


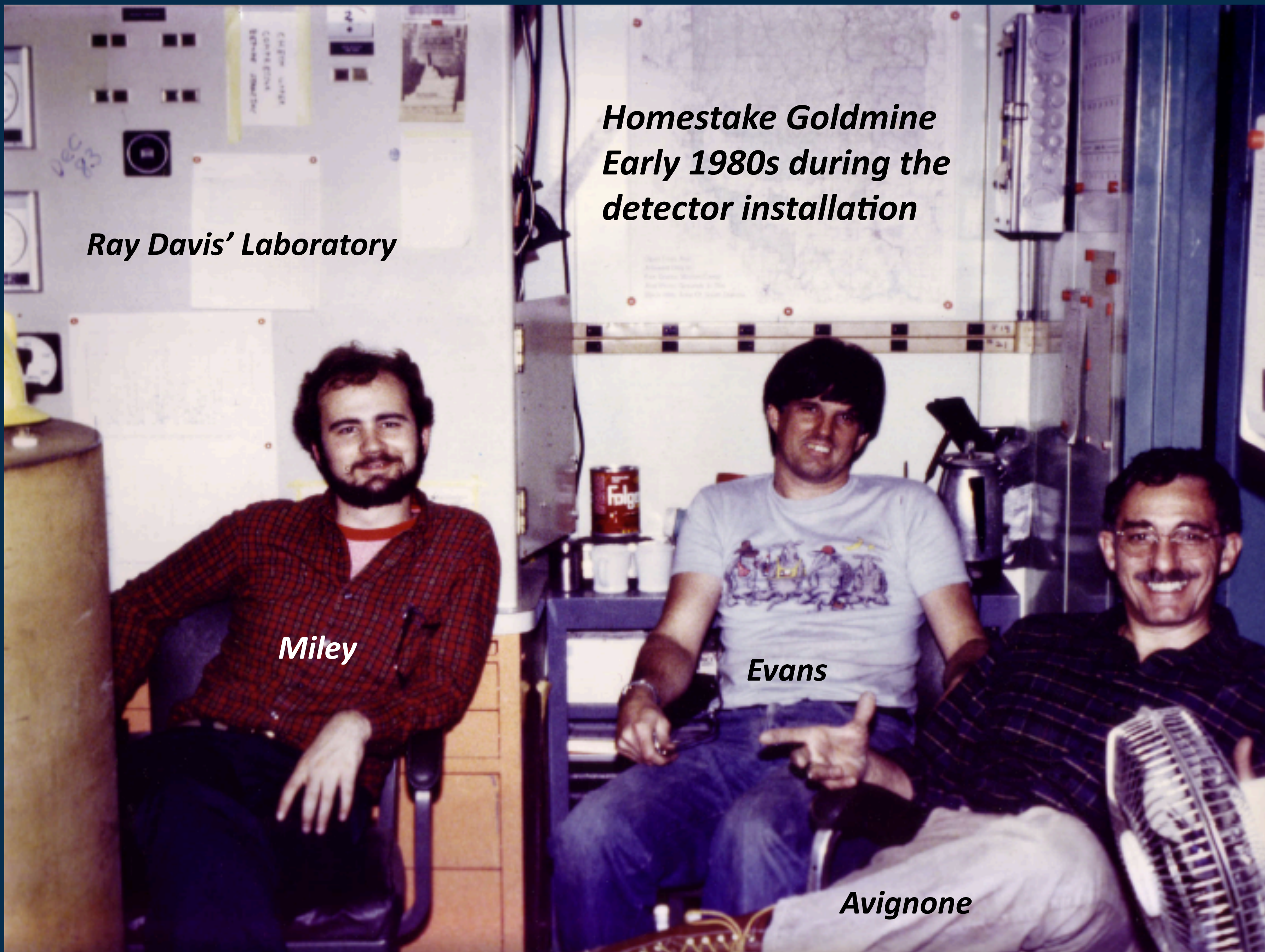
The goal was to apply PNL low background technology to search for rare events: Double-Beta Decay and later Dark Matter, after inspiration from Stodolsky and Drukier.

An early Battelle-Carolina germanium detector in a copper cryostat

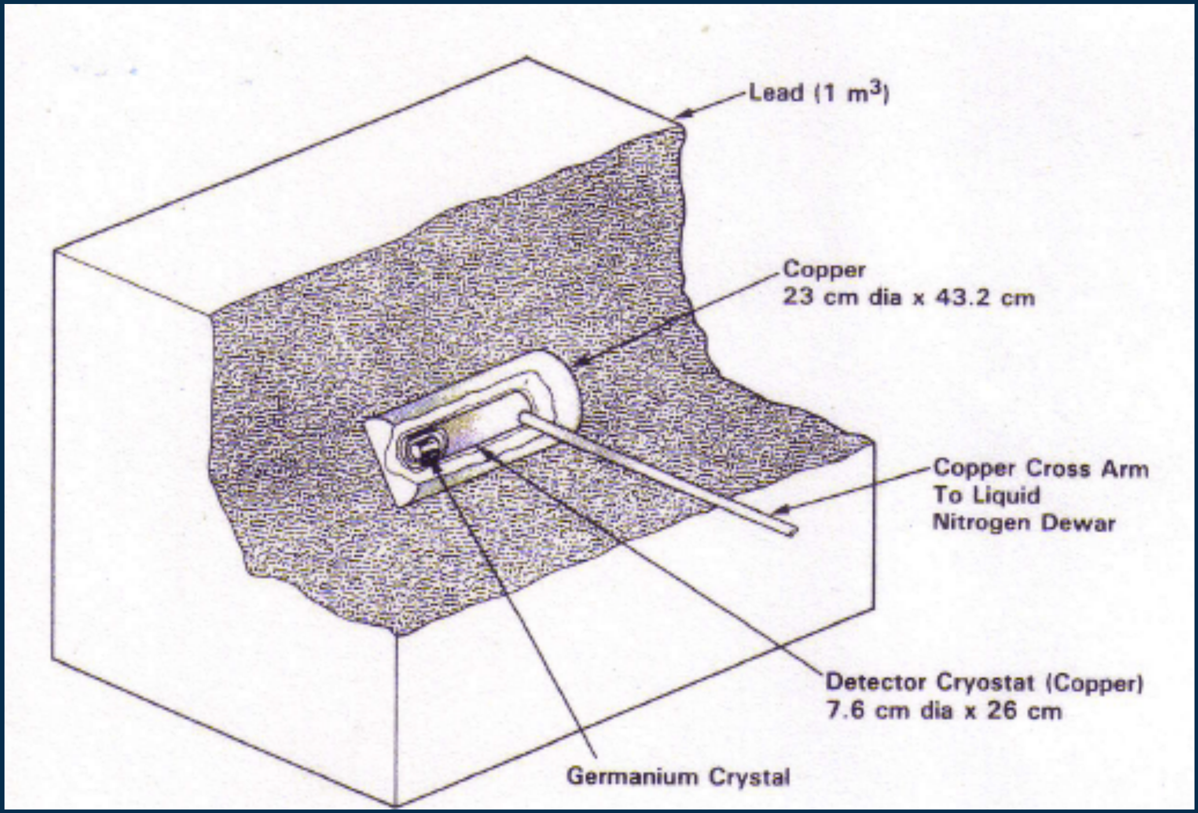
Ok, now we that had an ultralow background germanium detector, we needed to move it deep underground to operate it in an environment free from cosmic rays. The Homestake Goldmine in Lead, South Dakota was the choice.

Early 1980s at the site in the Homestake Goldmine setting up




Homestake Goldmine
Early 1980s during the
detector installation
Ray Davis' Laboratory
Miley
Evans
Avignone

The Battelle-Carolina Low-Background Ge Detector in the lead Bulk Shield at the 4850-ft Level in the Homestake Goldmine



The original intent was a search for the exotic double-beta decay without the emission of neutrinos.

In 1985 FTA was invited to Max Planck Munich To give a talk on low background work with PNL.

Stodolsky

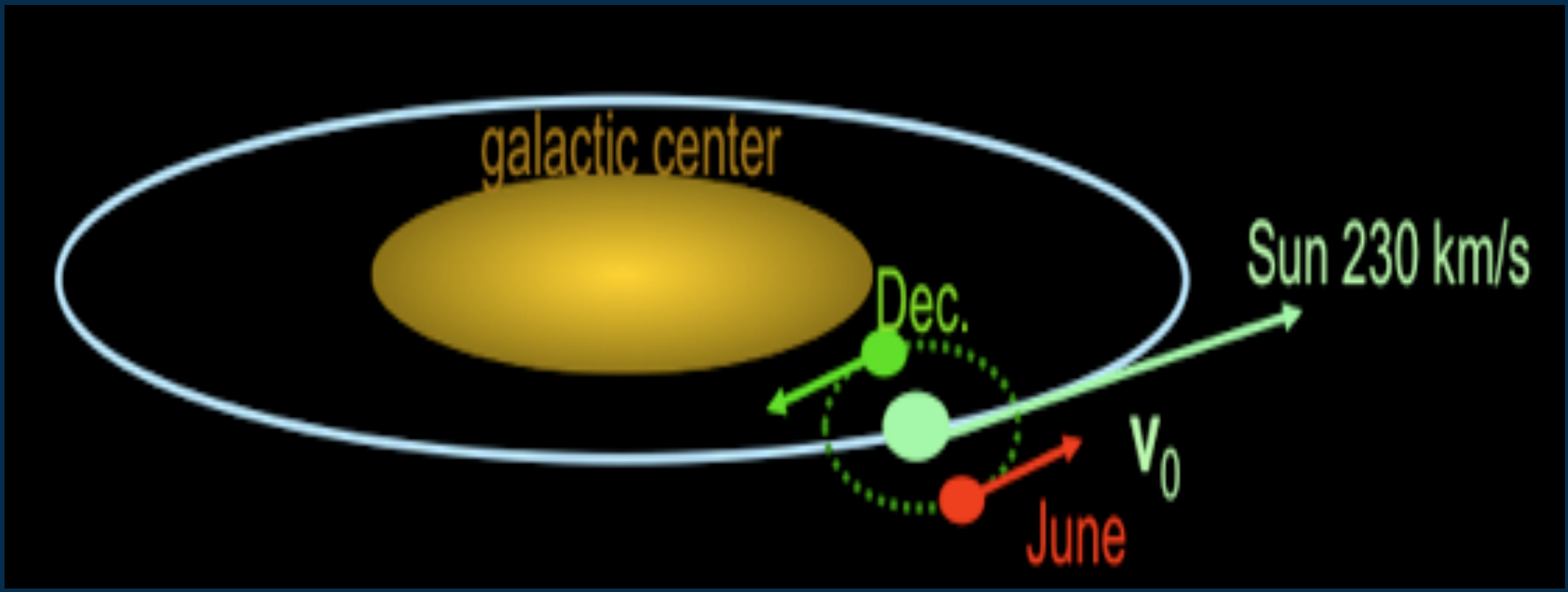
Drukier

Avignone

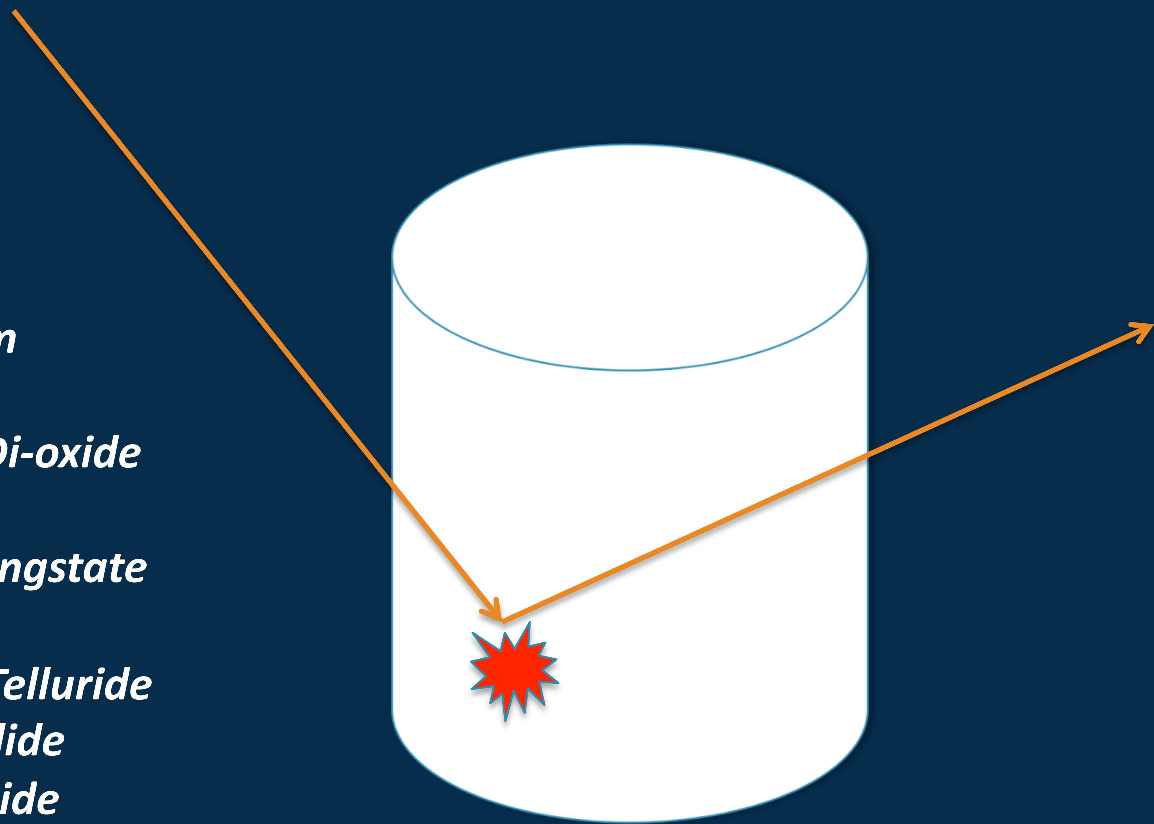
Brodzinski

Ron and I went to work getting low energy data.

The solar system moves through the galactic halo at about 230-kilometers per second. That creates a wind of dark matter particles impinging on detectors on earth!



Weakly Interacting Massive Particle (WIMP) interacting in the bulk material of a detector



Germanium
Saphire
Tellurium Di-oxide
Xenon
Calcium Tungstate
Argon
Cadmium Telluride
Sodium Iodide
Cesium Iodide
And more

The interaction produces ionization and/or phonons or and/or Scintillation light, even noise pulses.

LIMITS ON COLD DARK MATTER CANDIDATES FROM AN ULTRALOW BACKGROUND GERMANIUM SPECTROMETER

S.P. AHLEN [a], F.T. AVIGNONE III [b], R.L. BRODZINSKI [c], A.K. DRUKIER [d,e], G. GELMINI [f,g,1] and D.N. SPERGEL [d,h]

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Received 5 May 1987

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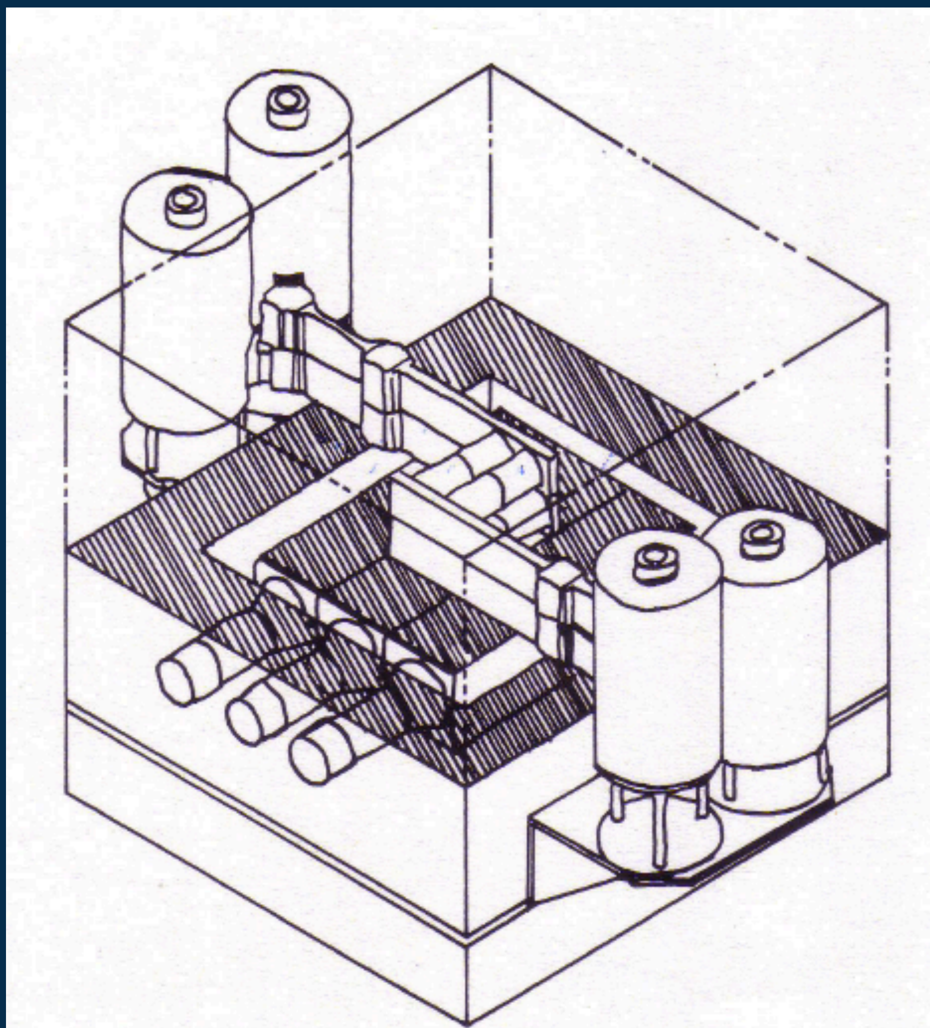
Received 5 May 1987

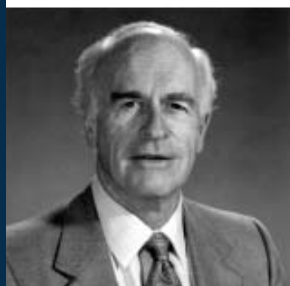
An ultralow background spectrometer is used as a detector of cold dark matter candidates from the halo of our galaxy Using a realistic model for the galactic halo, large regions of the mass–cross section space are excluded for important halo component particles. In particular, a halo dominated by heavy standard Dirac neutrinos (taken as an example of particles with spin-independent Z^0 exchange interactions) with masses between 20 GeV and 1 TeV is excluded. The local density of heavy standard Dirac neutrinos is <0.4 GeV/cm^3 for masses between 17.5 GeV and 2 5 TeV, at the 68% confidence level.

The Santa Barbara Berkley Collaboration multi-Ge Detector



During the same period There was another similar experiment running 200-meters in the Powerhouse of the Oroville Dam in California.

VOLUME 61, NUMBER 5 PHYSICAL REVIEW LETTERS 1 AUGUST 1988



Laboratory Limits on Galactic Cold Dark Matter

D. O. Caldwell, R. M. Eisberg, D. M. Grumm, and M. S. Witherell
Department of Physics, University of California, Santa Barbara, California 93106

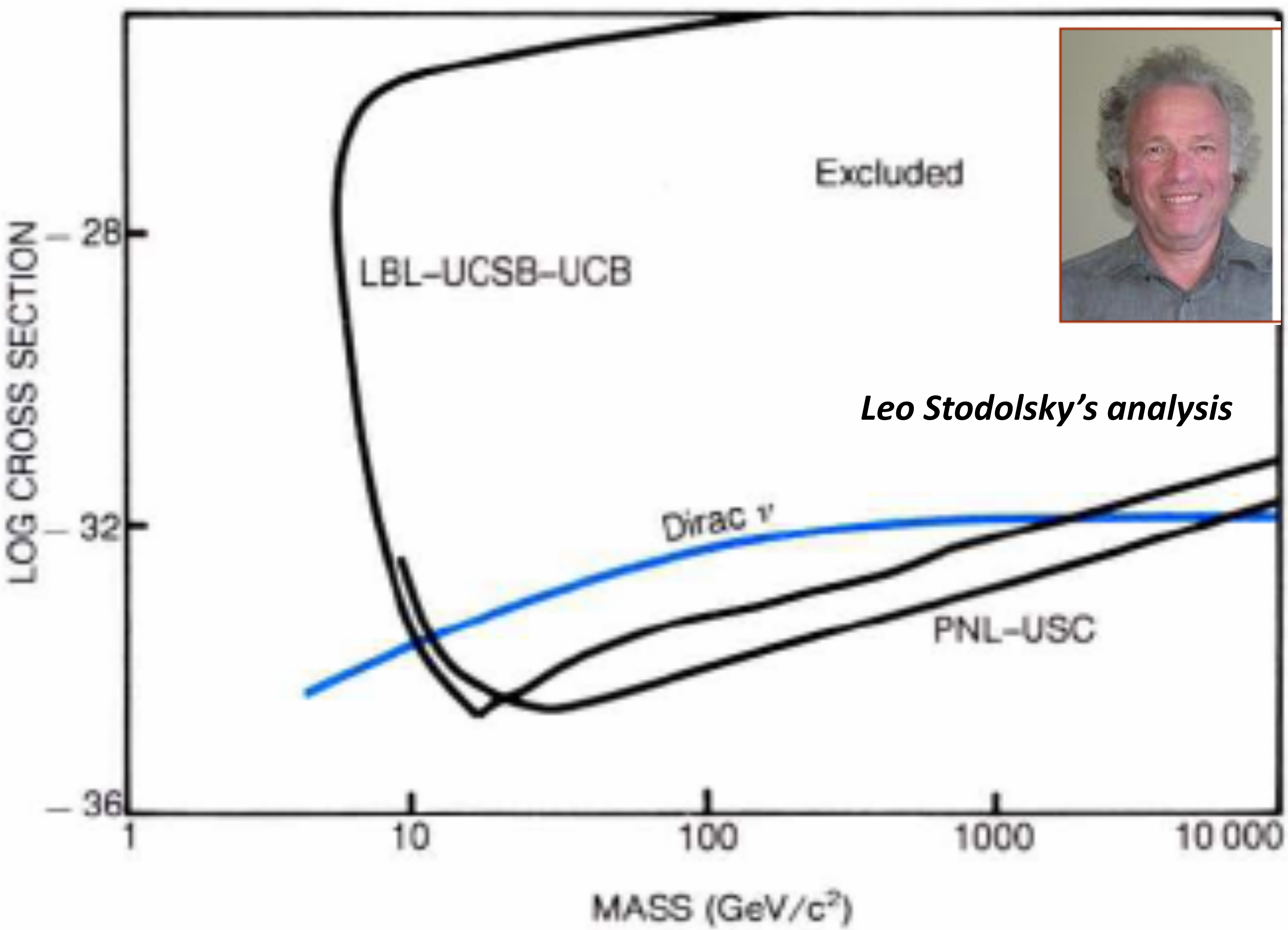
B. Sadoulet
Physics Department, University of California, Berkeley, California 94720

and

F. S. Goulding and A. R. Smith
Lawrence Berkeley Laboratory, Berkeley, California 94720
(Received 13 November 1987; revised manuscript received 16 May 1988)

Interesting limits are set on candidates for cold-dark-matter particles in the halo of our Galaxy from their interaction with a very-low-background Ge detector used to search for double-β decay. Dirac neutrinos constituting all of dark matter are excluded for masses between 12 GeV/c^2 and 1.4 TeV/c^2. There are slightly better limits on magninos and cosmions, proposed massive particles which also explain the solar-neutrino problem but which interact more strongly with Ge. In addition, millicharged shadow matter is ruled out as the main form of dark matter.

PACS numbers: 98.60.Ln, 14.60.Gh, 14.80.Pb, 96.60.Kx

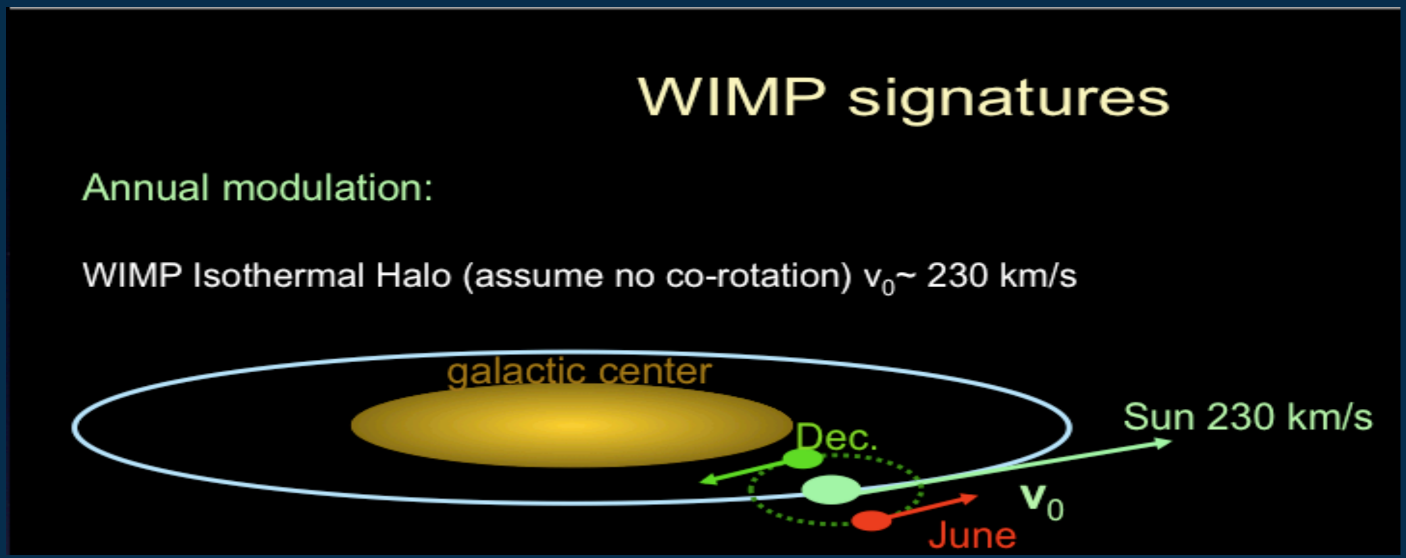


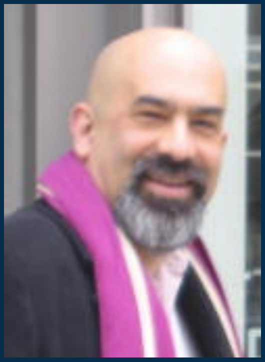
Leo Stodolsky's analysis

QUESTION:

If you see a signal, how do you know it is due to dark Matter?

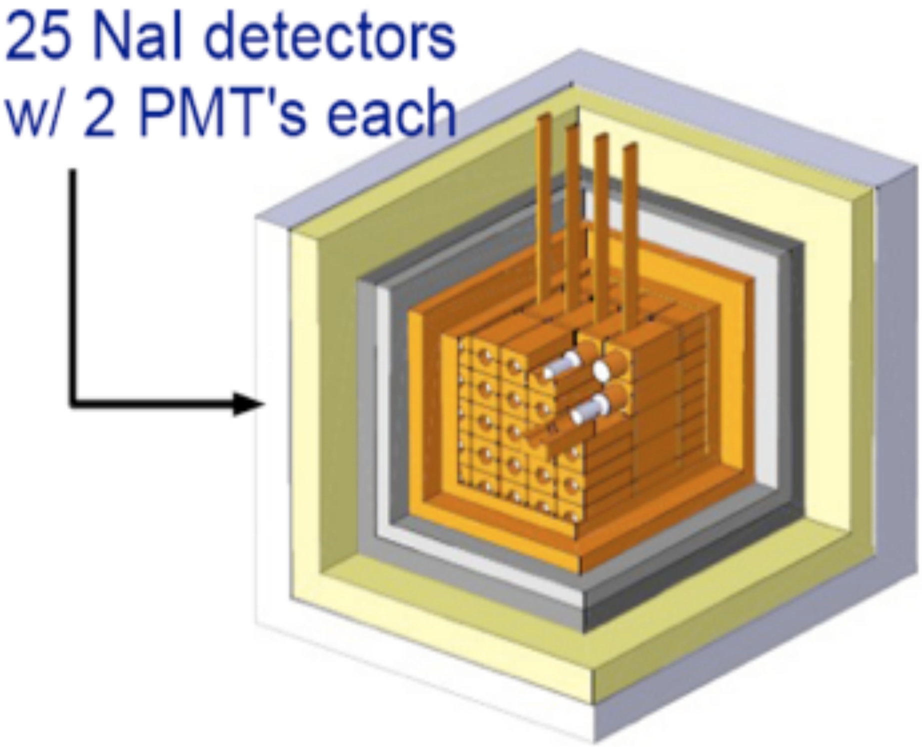
How do you tell a signal from background ?
By Annual Modulation of course !
Physical Review D 33, 3495 (1986)

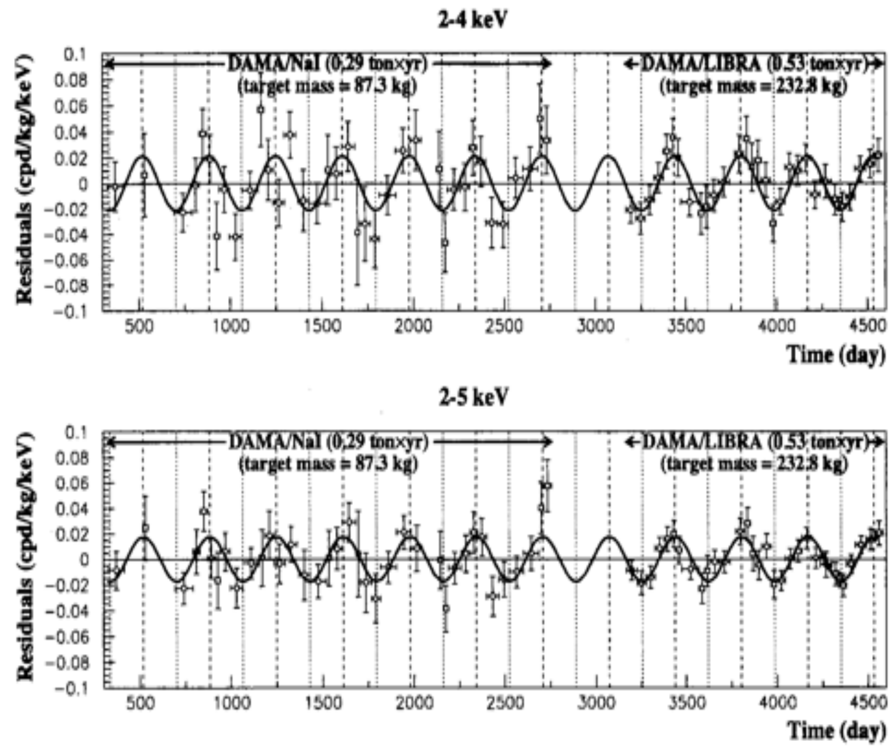




Andrzej Drukier ***Kattie Freese*** ***David Spergel***

The DAMA and DAMA/LIBRA Collaboration has reported direct observation of annual modulation signals at a confidence level of more that 8 standard deviations. Other experiments imply that the signal is not due to Dark Matter, but to something else.

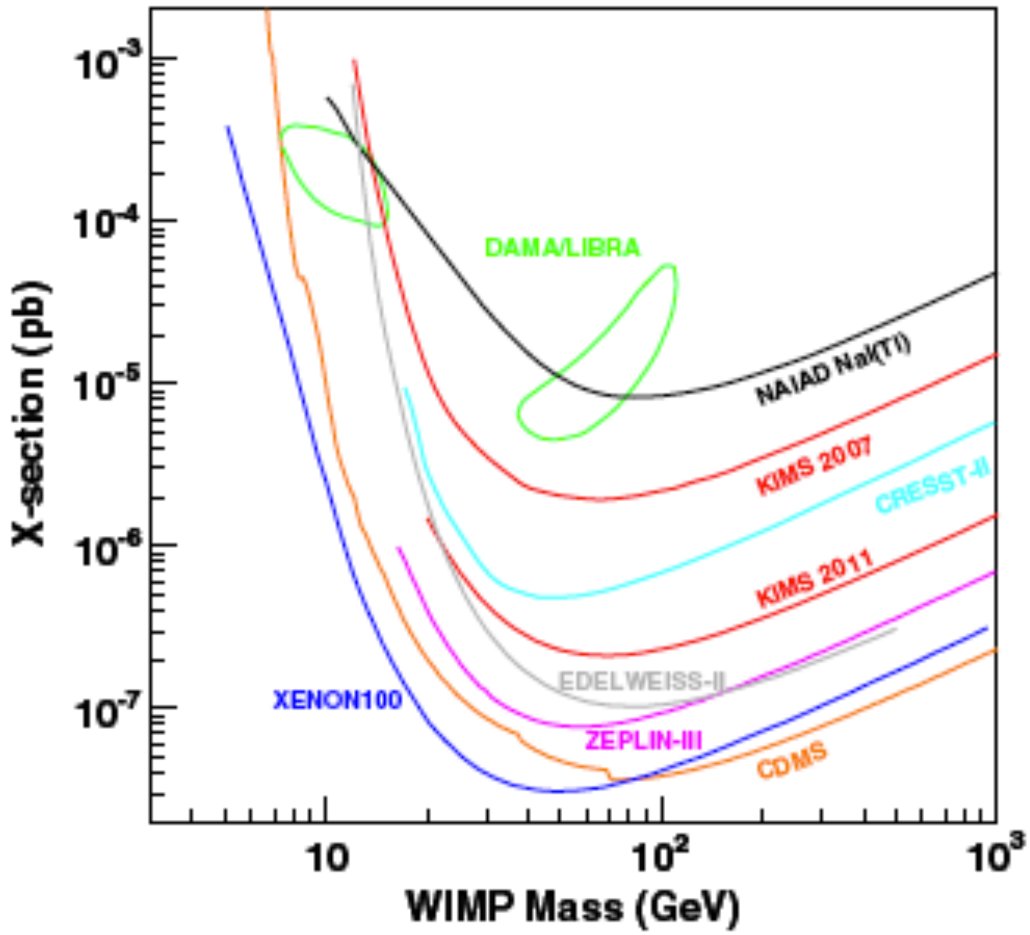




Very recently, KIMS, a similar experiments seems to disagree

PRL **108,** 181301 (2012) PHYSICAL REVIEW LETTERS week ending 4 MAY 2012

New Limits on Interactions between Weakly Interacting Massive Particles and Nucleons Obtained with CsI(Tl) Crystal Detectors

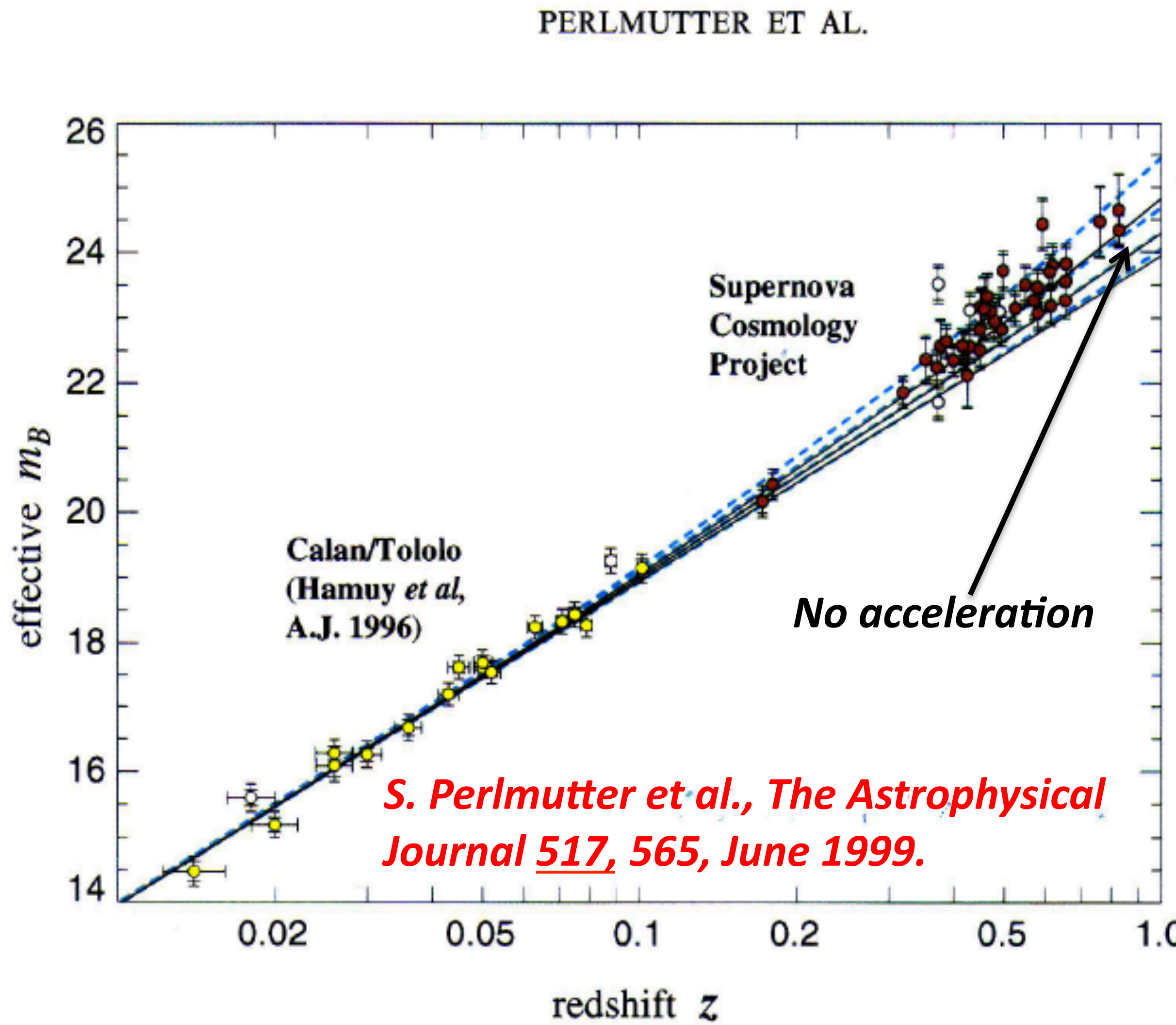


So what is all this talk about Dark Energy?

What is Dark Energy?

What is the motivation to believe there is such a thing?

There is no simple way to explain how one deduces from this plot that the expansion of the universe is accelerating, but it was concluded from this plot that it is to greater than 99.7% confidence.



This discovery resulted in the Nobel Prize for Sol Perlmutter, Adam Riess And Brian Schmidt

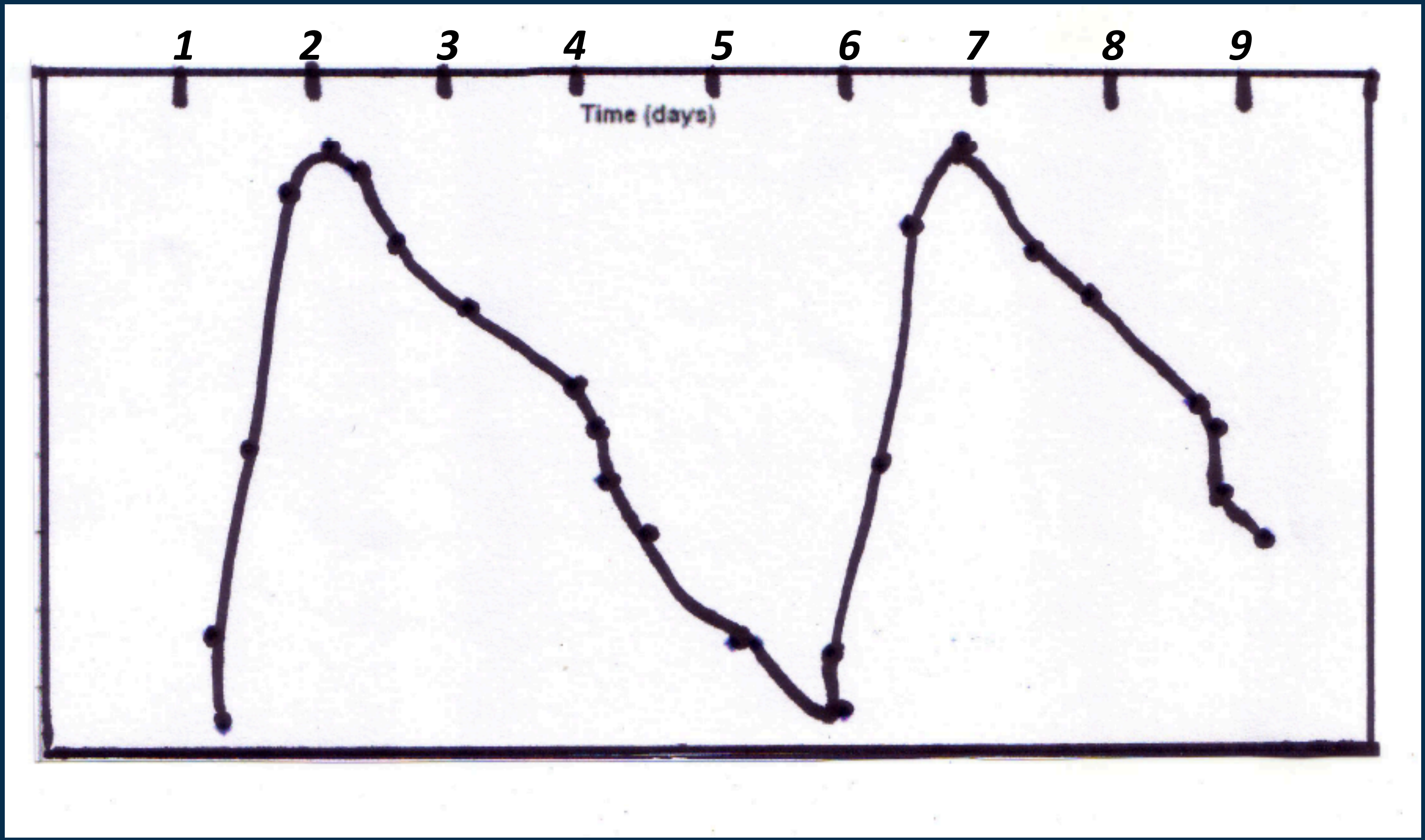
This observation was not straight forward at all ! How were they able to measure distances with sufficient accuracy ?

Astronomers use standard candles-stars whose brightness is measurable, and then observed luminosity tells the distance.

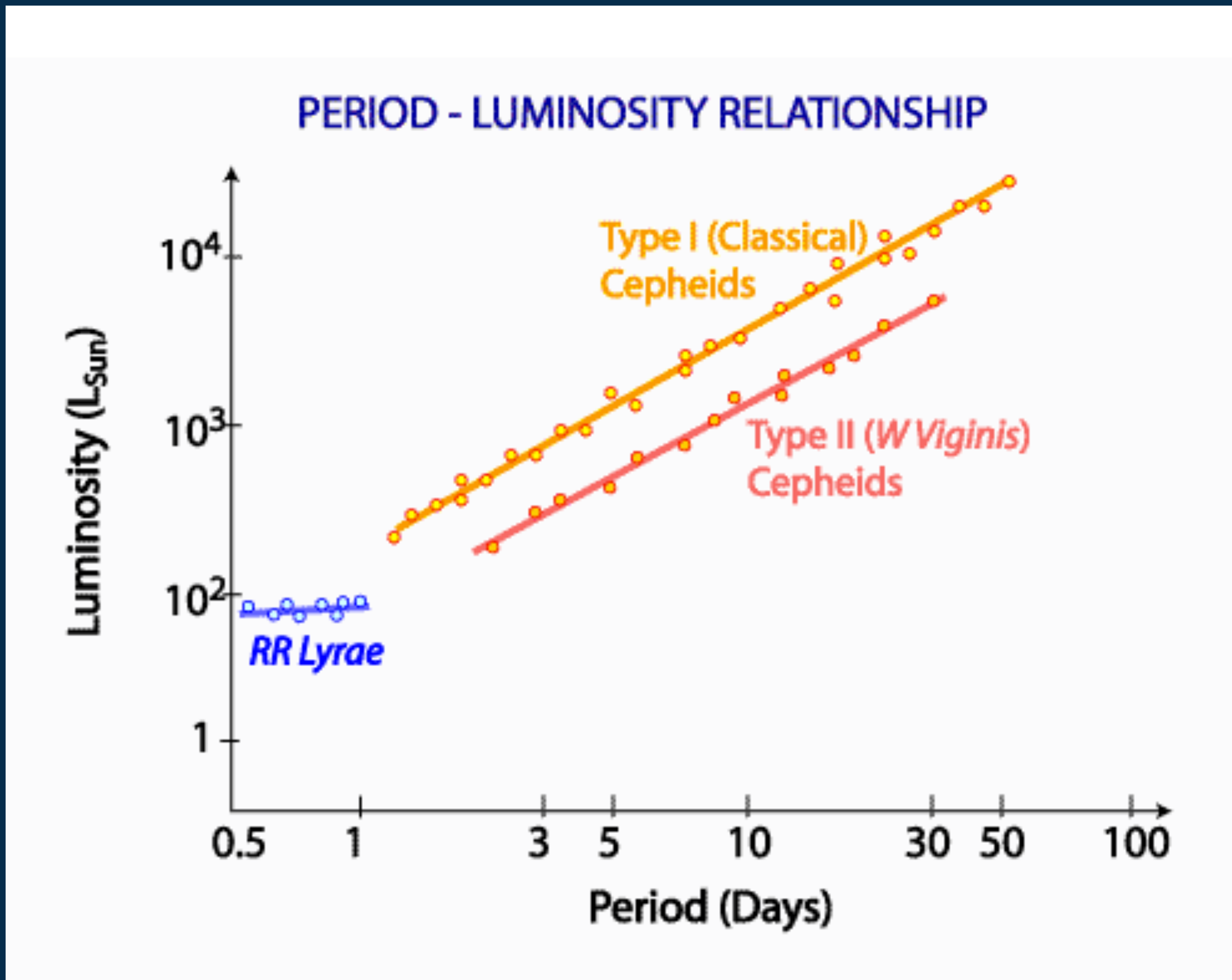
How do they measure the brightness to use as a standard?

The trick was by extending the old trick with Cepheid variable stars whose luminosity varied in a systematic way with the period of variation.

Cepheid variable stars were first classified in the early 1900s by Henrietta Leavitt at the Harvard College Observatory



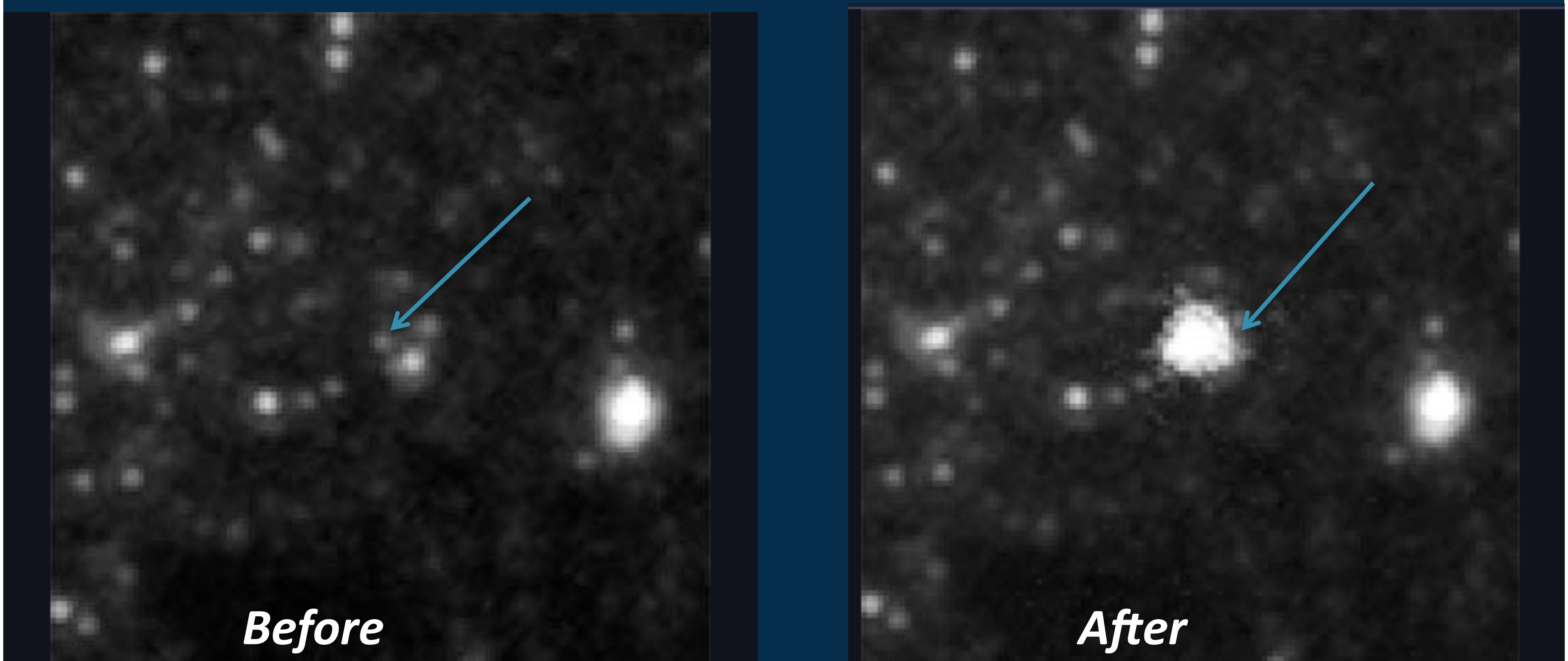
Australia Telescope
Outreach and Education



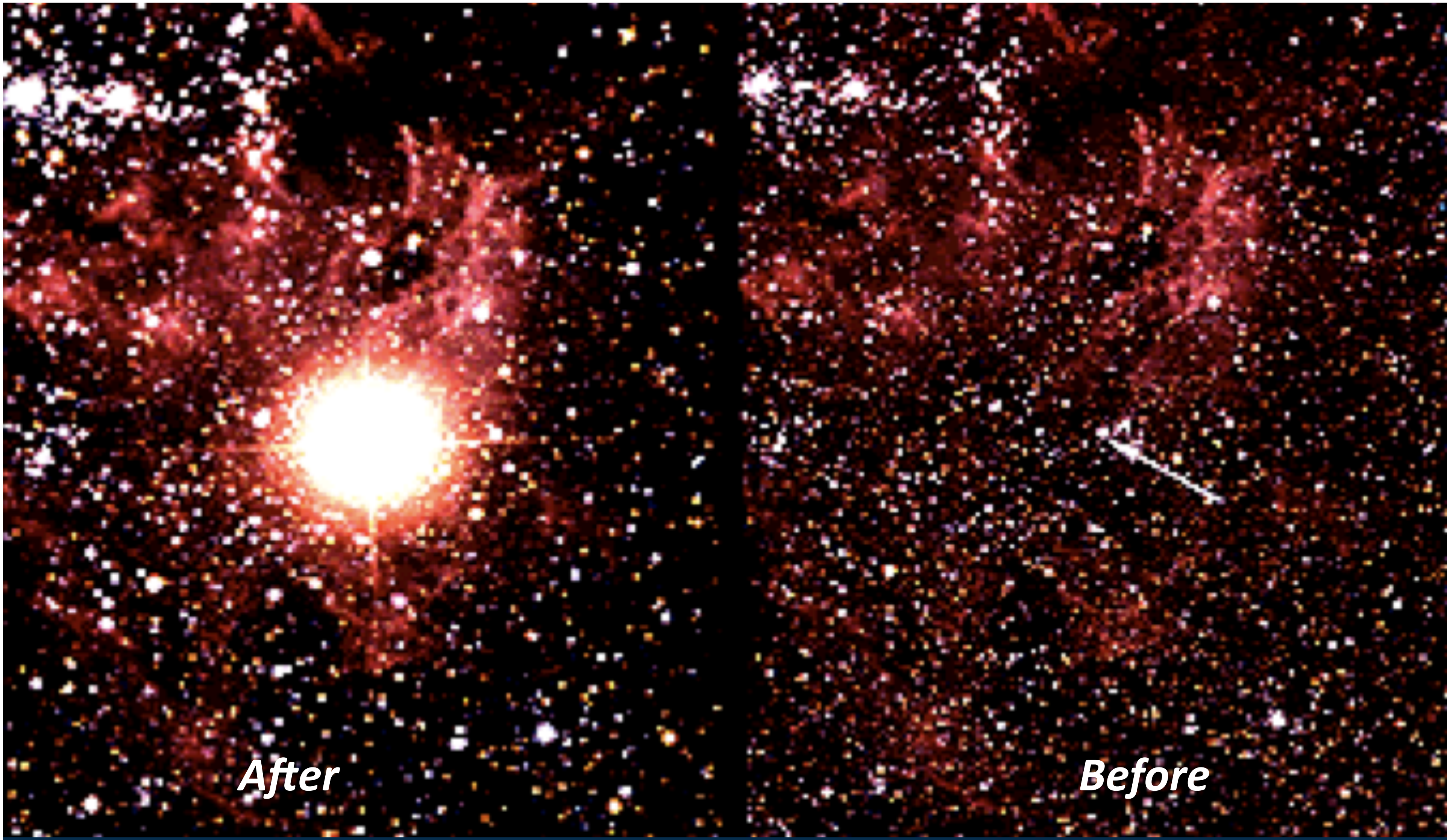
Cepheid variable stars are excellent standard candles for out to the Andromeda galaxy at almost one million light years but to observe much further one needs brighter candles i.e., Type 1A supernova.

Astronomers have telescopes observing large regions of the sky, and before and after images can show evidence of a supernova explosion.

Supernova SN2005cs in the galaxy M51 Before and after



From the Hubble Space Telescope, Alex Fillippenko et al.



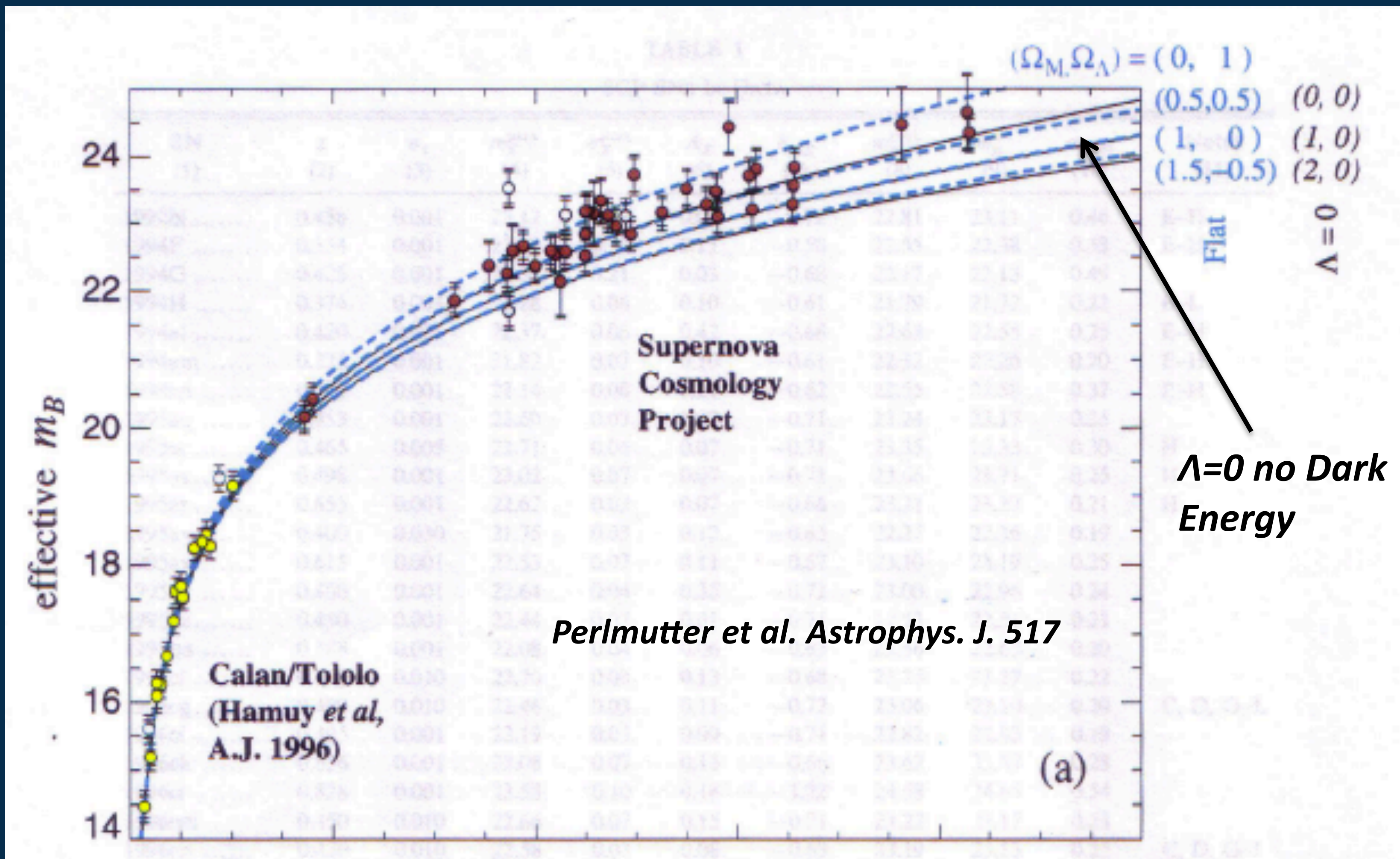
Feb. 23, 1987, right before, left, after: SN-1987 A

Perlmutter et al., and Reiss et al., calibrated the nearby Type 1A supernovae with well measured Cepheid variable stars.

Then they used the fact that these supernovae had very uniform magnitudes or luminosities.

Now they had standard candles that can determine distances about 1000 Mega Parsecs out, much farther than one could with Cepheid variables.

This was the trick used to observe these far out Supernovae.

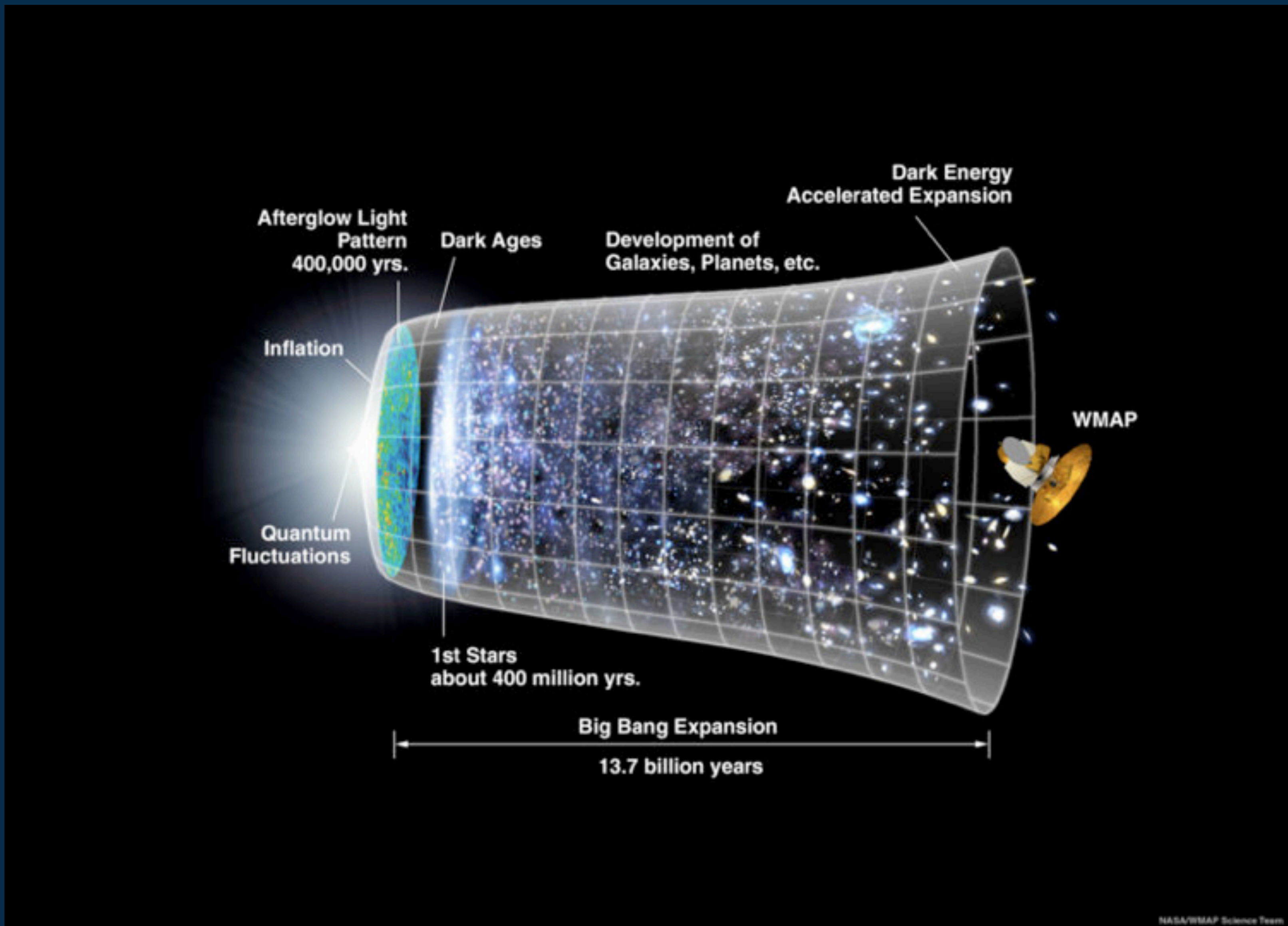


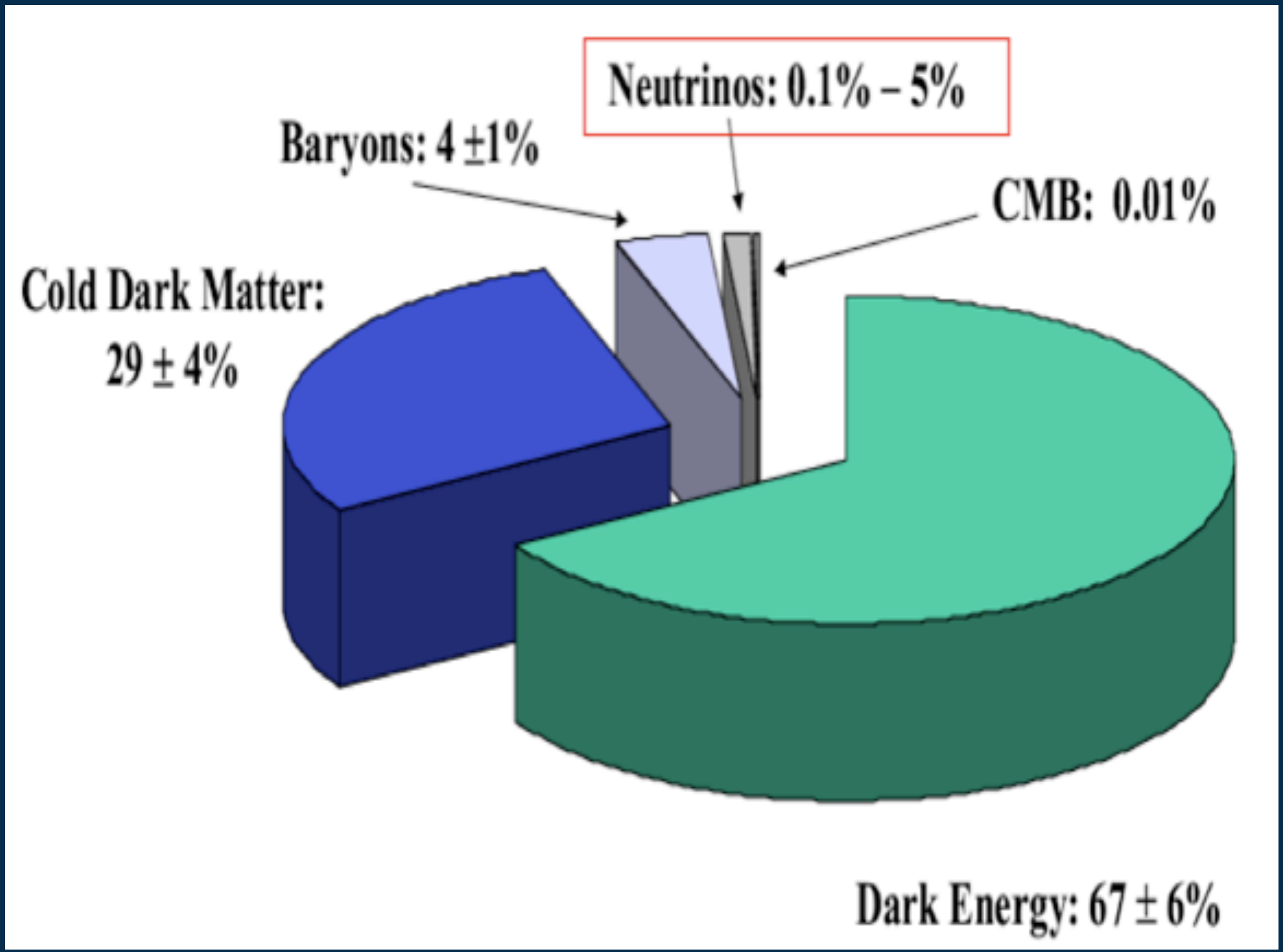
The data points fall above the $\Lambda=0$ curve for very distant supernovae.

Ω_Λ denotes Dark Energy, Ω_m denotes total mass, dark matter and ordinary mass.

It requires a non-zero value for Λ to explain the observed velocities of distant supernova.

The conclusion: The universe is expanding more rapidly now than in the early universe.


Dark Energy
Accelerated Expansion
Afterglow Light
Pattern
400,000 yrs.
Dark Ages
Development of
Galaxies, Planets, etc.
Inflation
WMAP
Quantum
Fluctuations
1st Stars
about 400 million yrs.
Big Bang Expansion
13.7 billion years
NASA/WMAP Science Team


Neutrinos: 0.1% – 5%
Baryons: 4 ±1%
CMB: 0.01%
Cold Dark Matter:
29 ± 4%
Dark Energy: 67 ± 6%

Dark Matter Silver Jubilee Symposium

June 19-21, 2012
Pacific Northwest National Laboratory
Richland, WA

In memory of Ron L. Brodzinski

Ron Brodzinski played a crucially important role in the creation of the first ultra-low background germanium detectors that were necessary to do the first Dark Matter search as well as a dozen other experiments the group did later. I could never forget that !

1991, Toledo, Spain, the Organization Meeting of IGEX

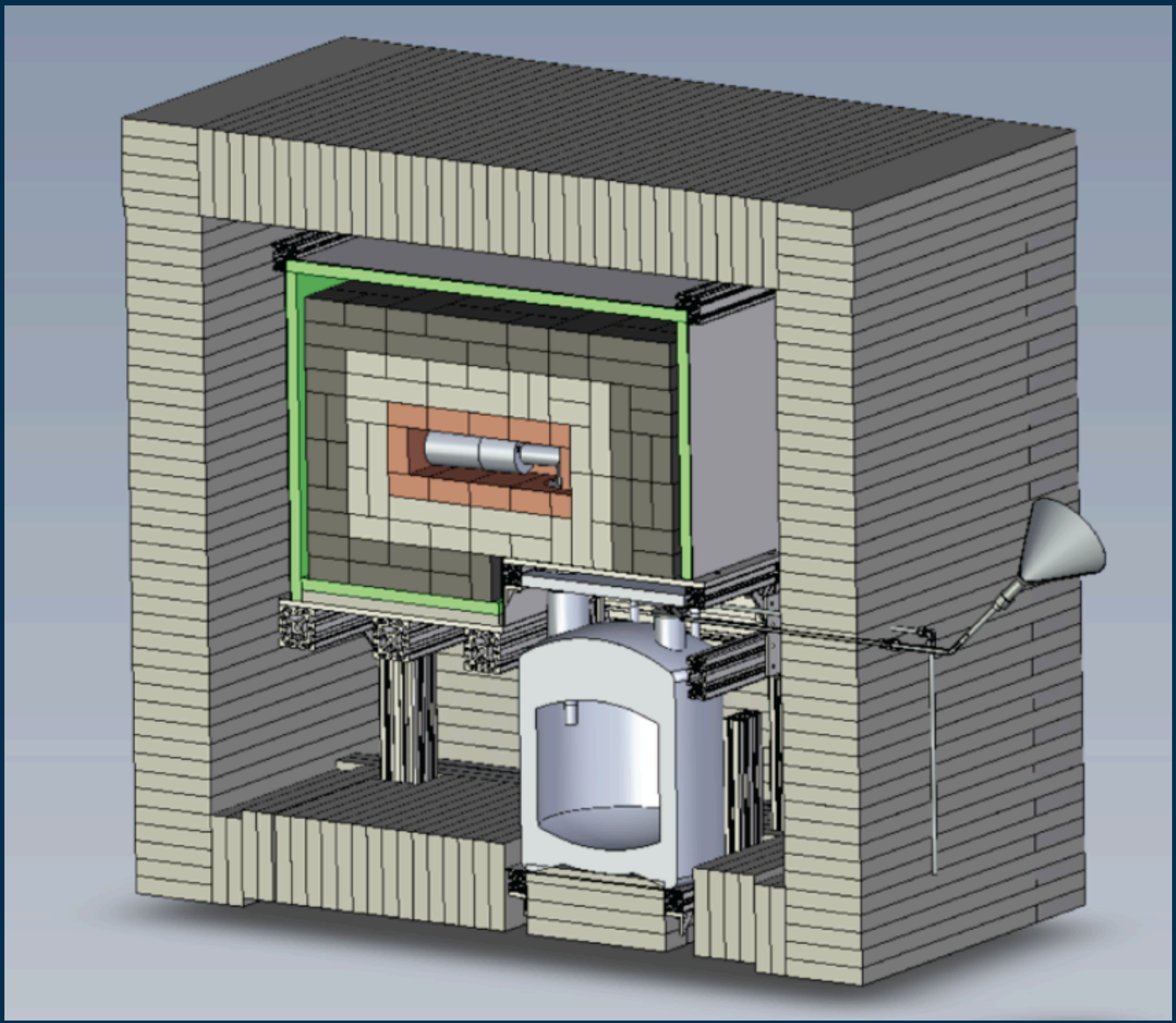
Colleagues at Neutrino-92, 7-12 June, 1992, Granada Spain

PNNL is now involved in at least two new searches for Cold Dark Matter. One is an extension of the COGENT experiment led by Juan Collar of the University of Chicago, and the other is the MAJORANA DENONSTRATOR Project.

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

The COGENT-II CDM Experiment

U.S. DEPARTMENT OF ENERGY



Juan Collar
University of Chicago

Dark Matter Silver Jubilee Symposium

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Tomorrow we will begin a three-day international symposium on the theory and experimental status of dark matter and many efforts to search for it. There will be speakers representing a number of theoretical and experimental groups.

The key-note speaker will be Professor Edward (Rocky) Kolb of the University Chicago.