Linfield University

presents the

2023 Oregon Nobel Laureate Symposium

Keynote speech:

"Time, Einstein and the Coolest Stuff in the Universe" by Nobel laureate William D. Phillips

Richard and Lucille Ice Auditorium
McMinnville Campus

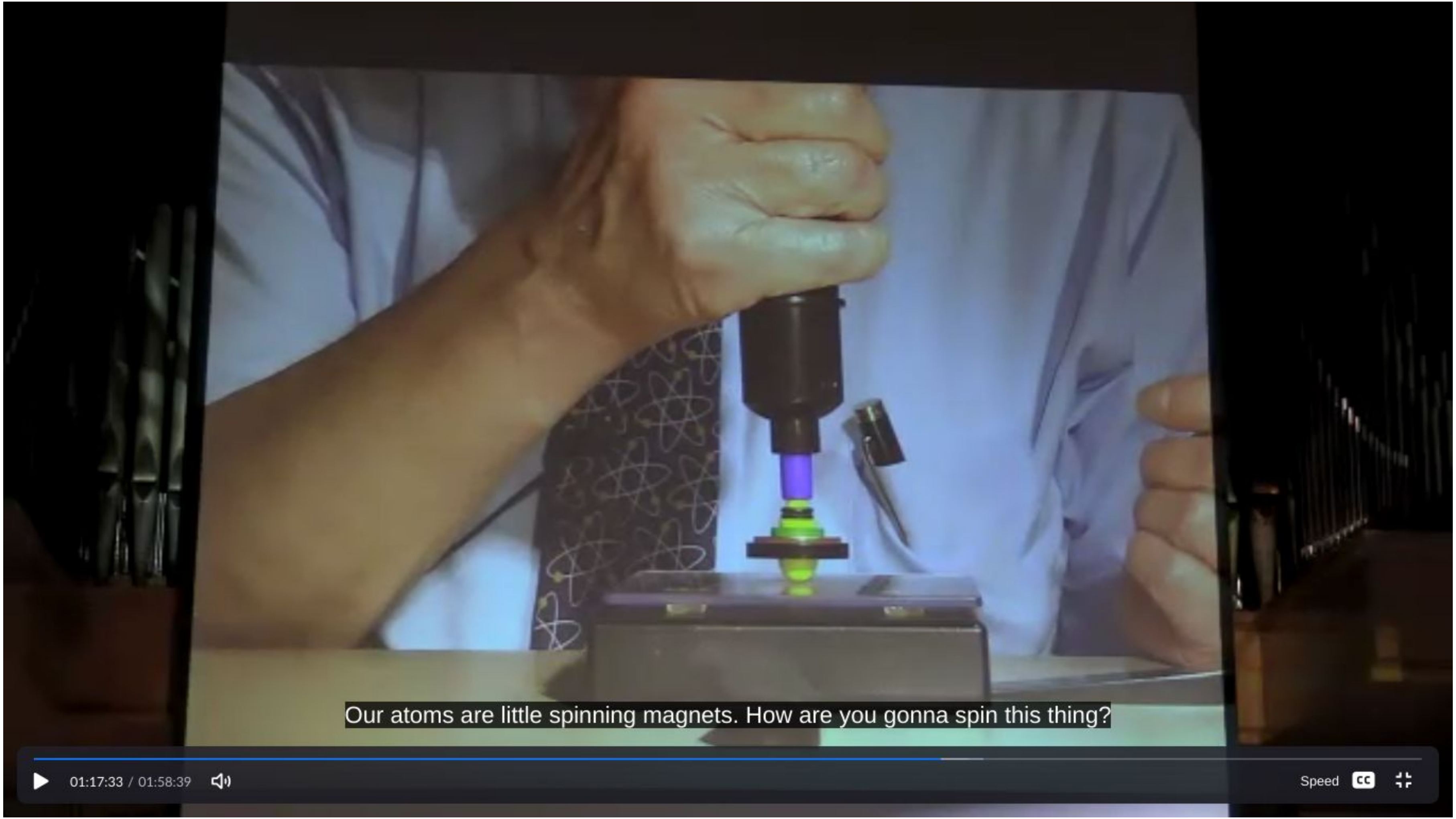
https://linfielduniversity.zoom.us/rec/play/OifvYmvD5wfTJ1ps_FKcq8VUwv4li_DOSwdaaLvAVbglhiUIUGvALn3gB-K6t1_sYOgyKpc6euM9oXiD.8E0gTAnQ6YSgaWXU?continueMode=true&tk=z79UU4mOQp4FNEnSvr8z3vw1trlBh3jQ-UKPLhN9HYw.DQMAAAAWmNcdthZHNFM0SF96X1JkMjVRX0VnVVoyejV3AAAAAAAAAAAAAAAAAAAAAAAAAAAAA&uuid=WN_SdlgSRIRtKS3wG6UfZ4lw&_x_zm_rtaid=8H7X3R_wR3ebSflrPMrssg.1677380323653.a87bac4445d38ec7f2b6504f3614cc6e&_x_zm_rhtaid=36

Lecture recording link

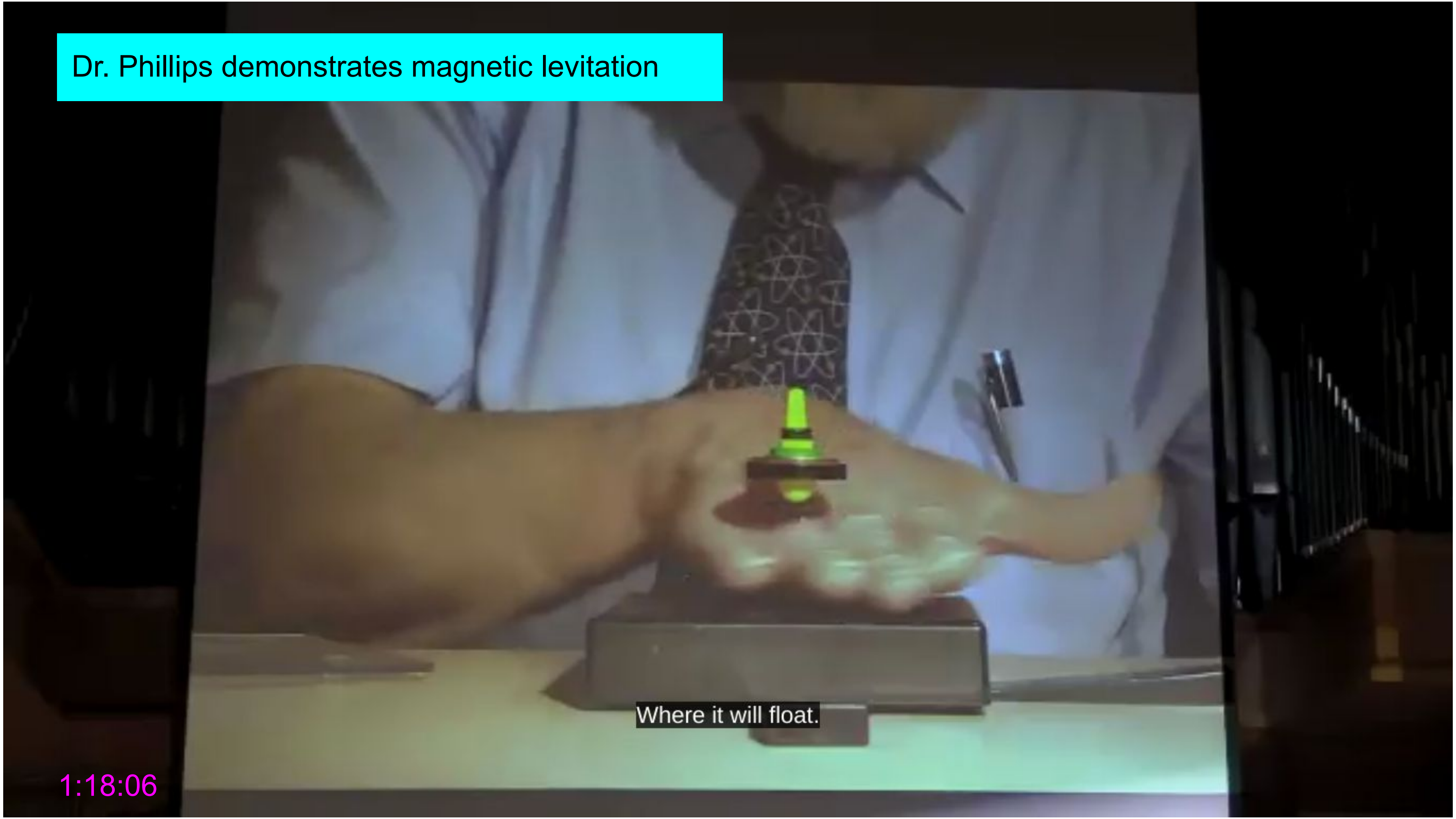
https://linfielduniversity.zoom.us/rec/play/OifvYmvD5wfTJ1ps_FKcq8VUwv4li_DOSwdaaLvAVbglhiUIUGvALn3gB-K6t1_sYOgyKpc6euM9oXiD.8E0gTAnQ6YSgaWXU?continueMode=true&tk=z79UU4mOQp4FNEnSvr8z3vw1trlBh3jQ-UKPLhN9HYw.DQMAAAAWmNcdthZHNFM0SF96X1JkMjVRX0VnVVoyejV3AAAAAAAAAAAAAAAAAAAAAAAAAAAAAA&uuid=WN_SdlgSNRIRtKS3wG6UfZ4lw&_x_zm_rtaid=8H7X3R_wR3ebSflrPMrssg.1677380323653.a87bac4445d38ec7f2b6504f3614cc6e&_x_zm_rhtaid=369

The Linfield University Nobel lecture happened in the middle of a historic snow storm

Miles Davis, president of Linfield University, introduces Nobel laureate Dr. William Philllips.


Our atoms are little spinning magnets. How are you gonna spin this thing?
01:17:33 / 01:58:39
Speed

Dr. Phillips demonstrates magnetic levitation



Comets show light exerts force on a gas.

The comet tail comes before the head as it heads away from the sun.

Live Transcription (Closed Captioning) has been enabled | Who can see this transcript? ×

A little model that Adam up here

Audio Setting ^ | Q&A | Chat ^ | CC Hide Captions ^ | Lower Hand | ••• More | Leave

Transcript

Search

But when it gets out of sync that causes people's problems.

19:24:16
So we always keep it within 1 s, and when it gets out of sync we introduce a leap second, and that's what they're talking about.

19:24:24
Here it was just a few years ago that we had our last leap.

19:24:27
Second. It's always done on New Year's Eve.

19:24:31
So I think New Year's Eve. Was it 2,016?

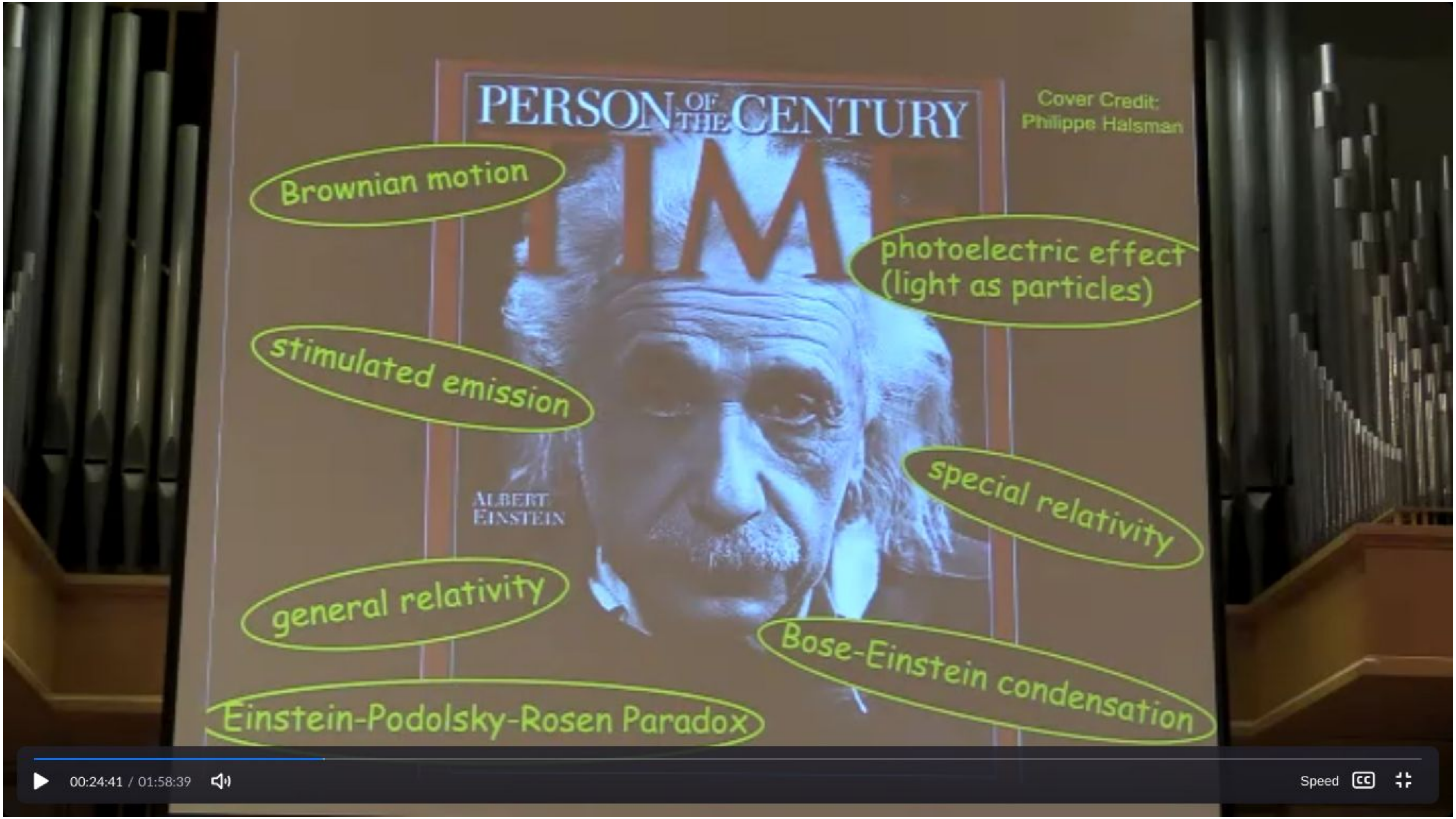
19:24:33
We had a leap second, and so that that New Year's Eve was 1 s longer than normal.

19:24:40
I hope you all use that 1 s. Why is that? But I didn't really show you this picture in order to tell you about leave seconds as fantastic as they are.

19:24:50
The reason I showed this was to assure you that the instrument in front of which these 2 Dorks are standing looks nothing like an atomic cost.

19:25:01
I'm isn't this marvelous?

19:25:03
A little model that Adam up here

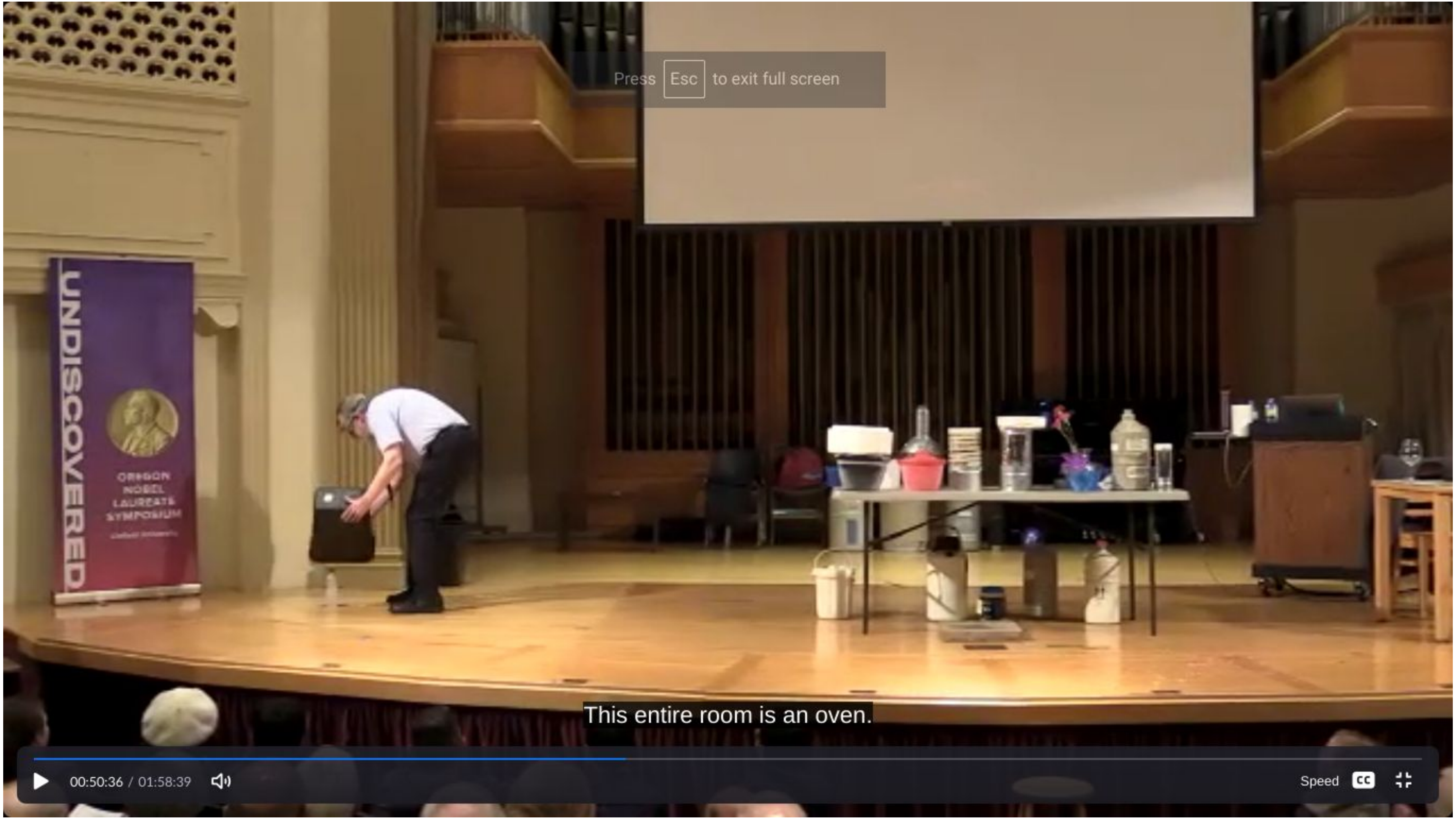

PERSON OF THE CENTURY
TIME
Cover Credit:
Philippe Halsman
Brownian motion
photoelectric effect
(light as particles)
stimulated emission
special relativity
ALBERT
EINSTEIN
general relativity
Bose-Einstein condensation
Einstein-Podolsky-Rosen Paradox
00:24:41 / 01:58:39
Speed


Play
00:54:00 / 01:58:39
Speed

Dr Phillips blasts a waste basket into the air using liquid nitrogen!


So this stuff at 77 degrees above absolute 0. The coldest stuff you've ever seen.
01:09:45 / 01:58:39
Speed
CC


4LD
Let's pour some in.
00:50:04 / 01:58:39
Speed


Press Esc to exit full screen
UNDISCOVERED
OREGON
NOBEL
LAUREATE
SYMPOSIUM
This entire room is an oven.
00:50:36 / 01:58:39
Speed
CC

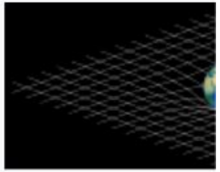

0:42:15
00:55:33 / 01:58:39
Speed


0:42:15
00:55:43 / 01:58:39
Speed

In physics and general relativity, **gravitational redshift** (known as **Einstein shift** in older literature)[1][2] is the phenomenon that electromagnetic waves or photons travelling out of a gravitational well (seem to) lose energy. This loss of energy corresponds to a decrease in the wave frequency and increase in the wavelength, known more generally as a *redshift*. The opposite effect, in which photons (seem to) gain energy when travelling into a gravitational well, is known as a **gravitational blueshift** (a type of *blueshift*). The effect was first described by Einstein in 1907,[3] eight years before his publication of the full theory of relativity.

Gravitational redshift can be interpreted as a consequence of the equivalence principle (that gravity and acceleration are equivalent and the redshift is caused by the Doppler effect)[4] or as a consequence of the mass-energy equivalence and conservation of energy ('falling' photons gain energy),[5][6] though there are numerous subtleties that complicate a rigorous derivation.[4][7] A gravitational redshift can also equivalently be interpreted as gravitational time dilation at the source of the radiation:[7][2] if two oscillators (attached to transmitters producing electromagnetic radiation) are operating at different gravitational potentials, the oscillator at the higher gravitational potential (farther from the attracting body) will seem to 'tick' faster; that is, when observed from the same location, it will have a higher measured frequency than the oscillator at the lower gravitational potential (closer to the attracting body).

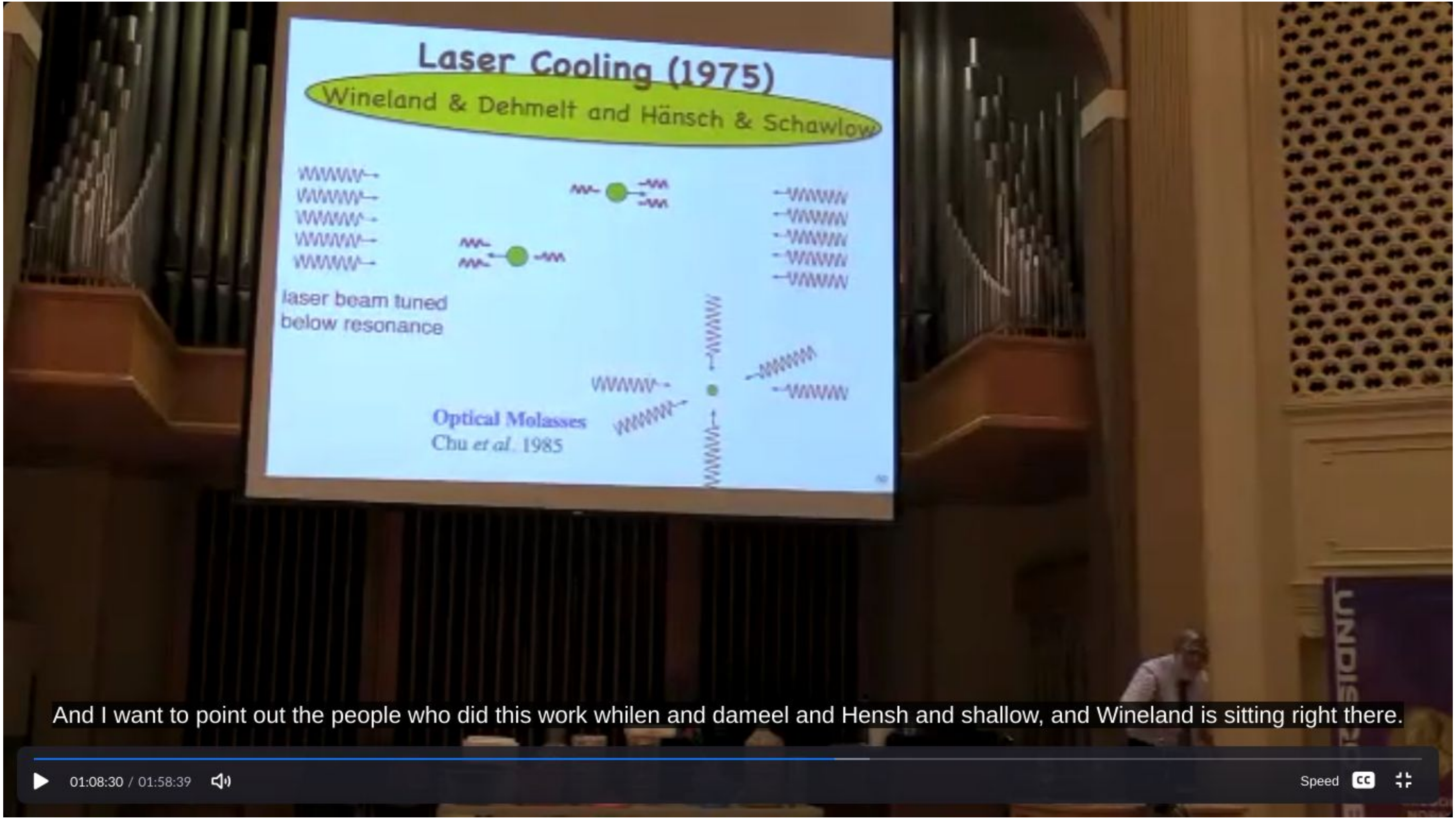
General



$G_{\mu\nu} + \Lambda$

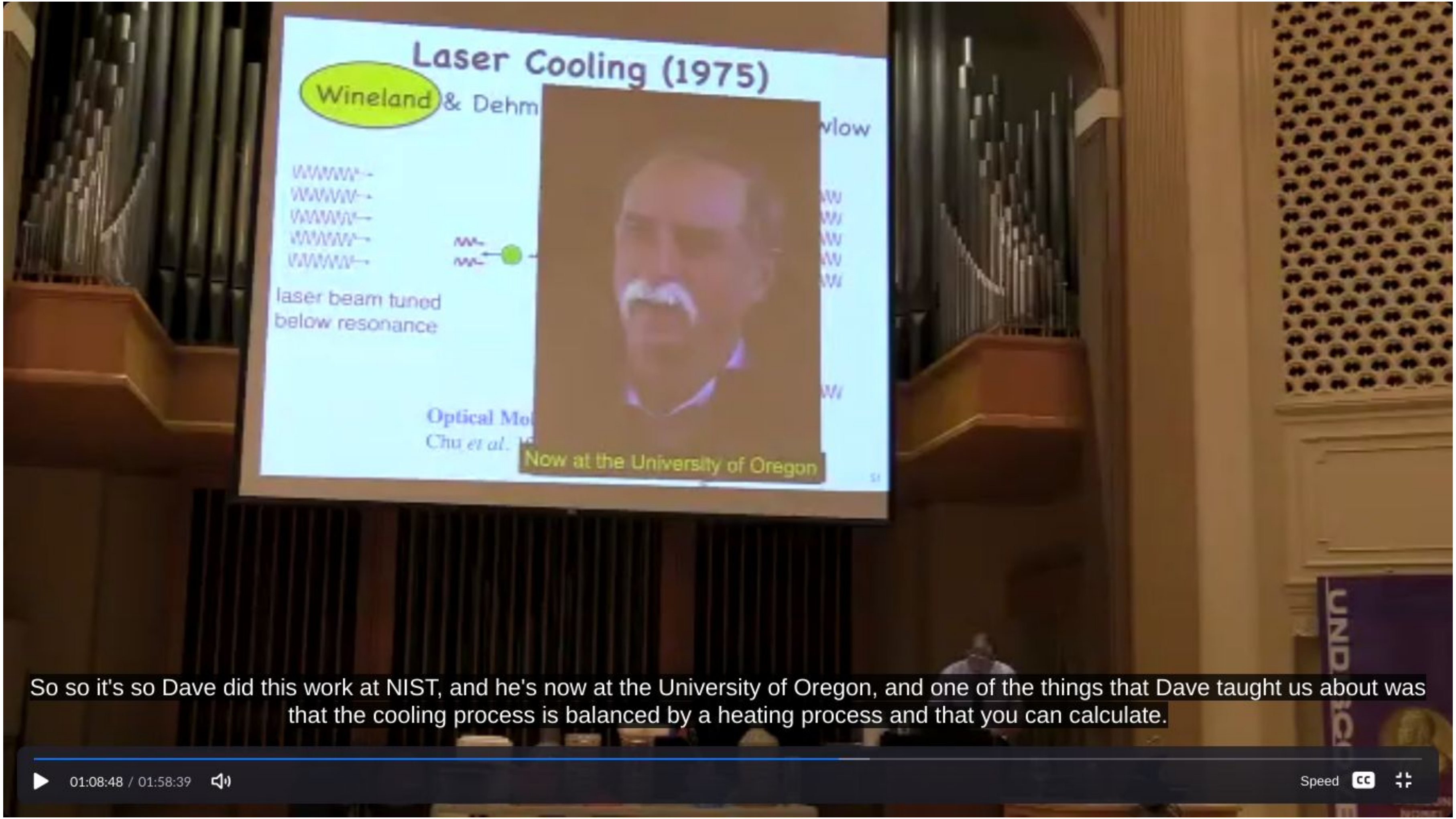
Intro
History
Mathematic
Te

Fundamental
Phenom
Equations · F
Solutio
Scienti
Physics por

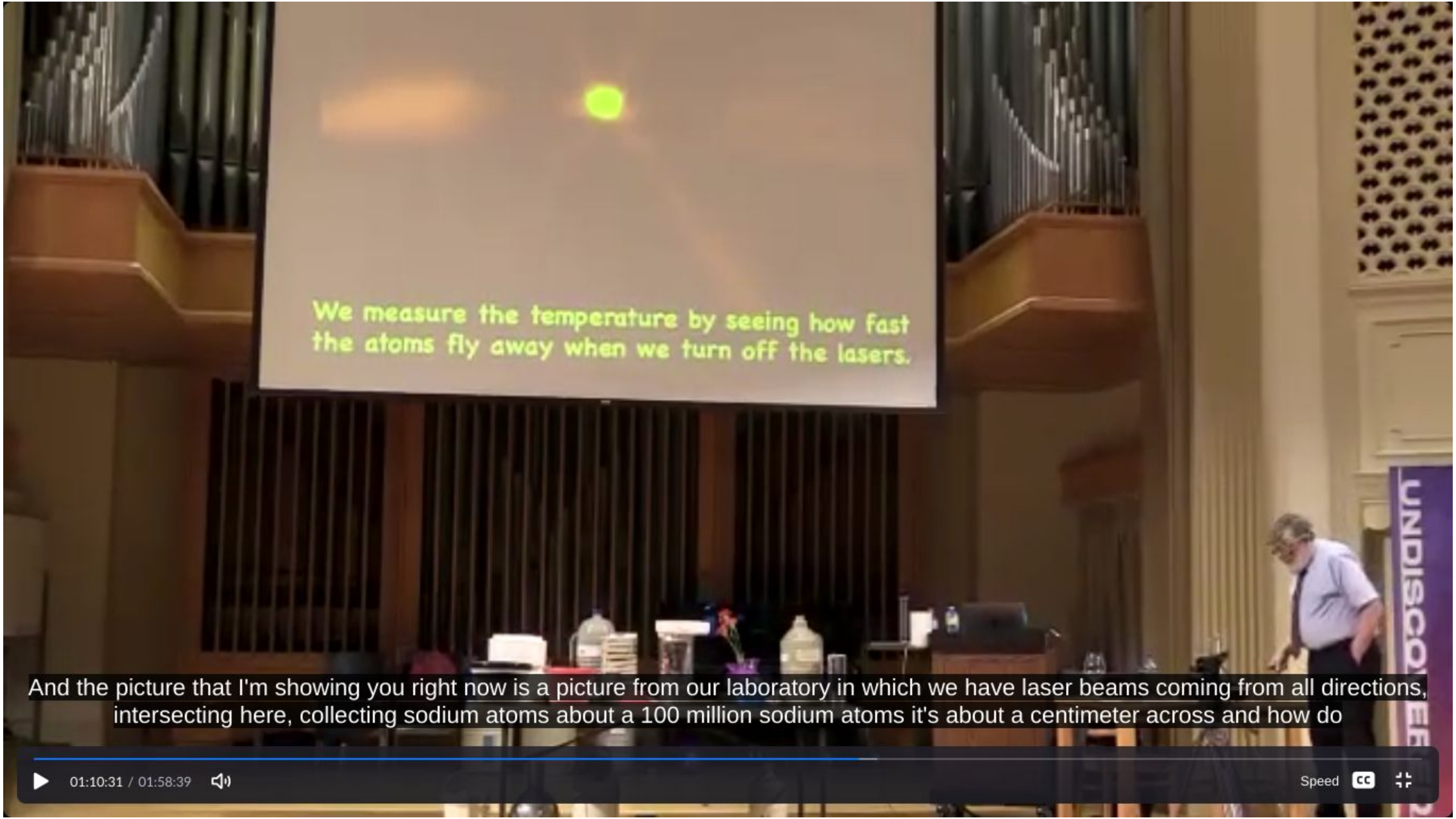

Laser Cooling (1975)
Wineland & Dehmelt and Hänsch & Schawlow
laser beam tuned
below resonance
Optical Molasses
Chu et al. 1985
And I want to point out the people who did this work whilen and dameel and Hensh and shallow, and Wineland is sitting right there.
01:08:30 / 01:58:39
Speed

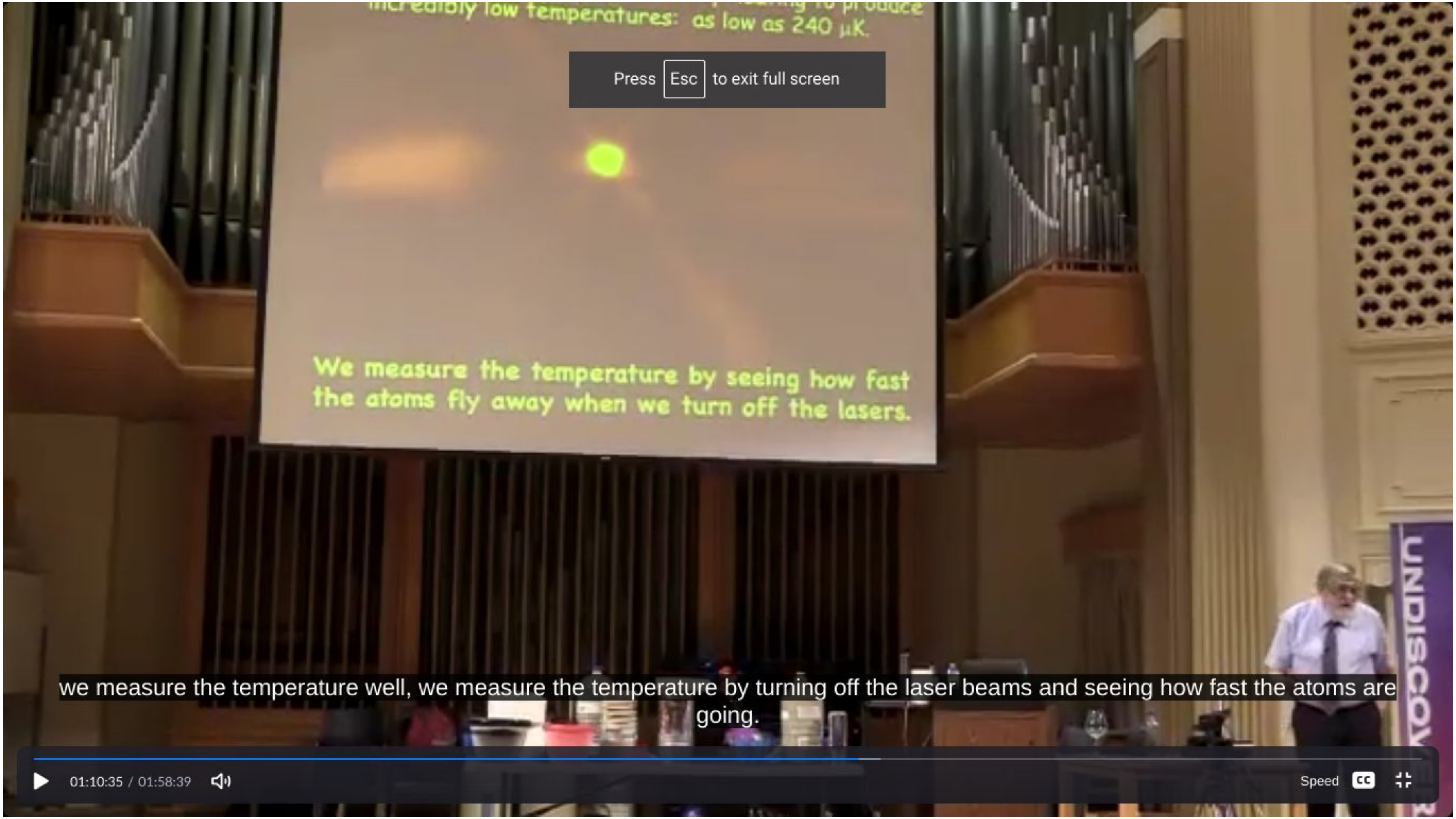
- numerical value: $8.854\ 187\ 8128 \times 10^{-12}$ F/m^{-1}
- standard uncertainty: $0.000\ 000\ 0013 \times 10^{-12}$ F/m^{-1}
- relative standard uncertainty: 1.5×10^{-10}
- concise form: $8.854\ 187\ 8128(13) \times 10^{-12}$ F/m^{-1}

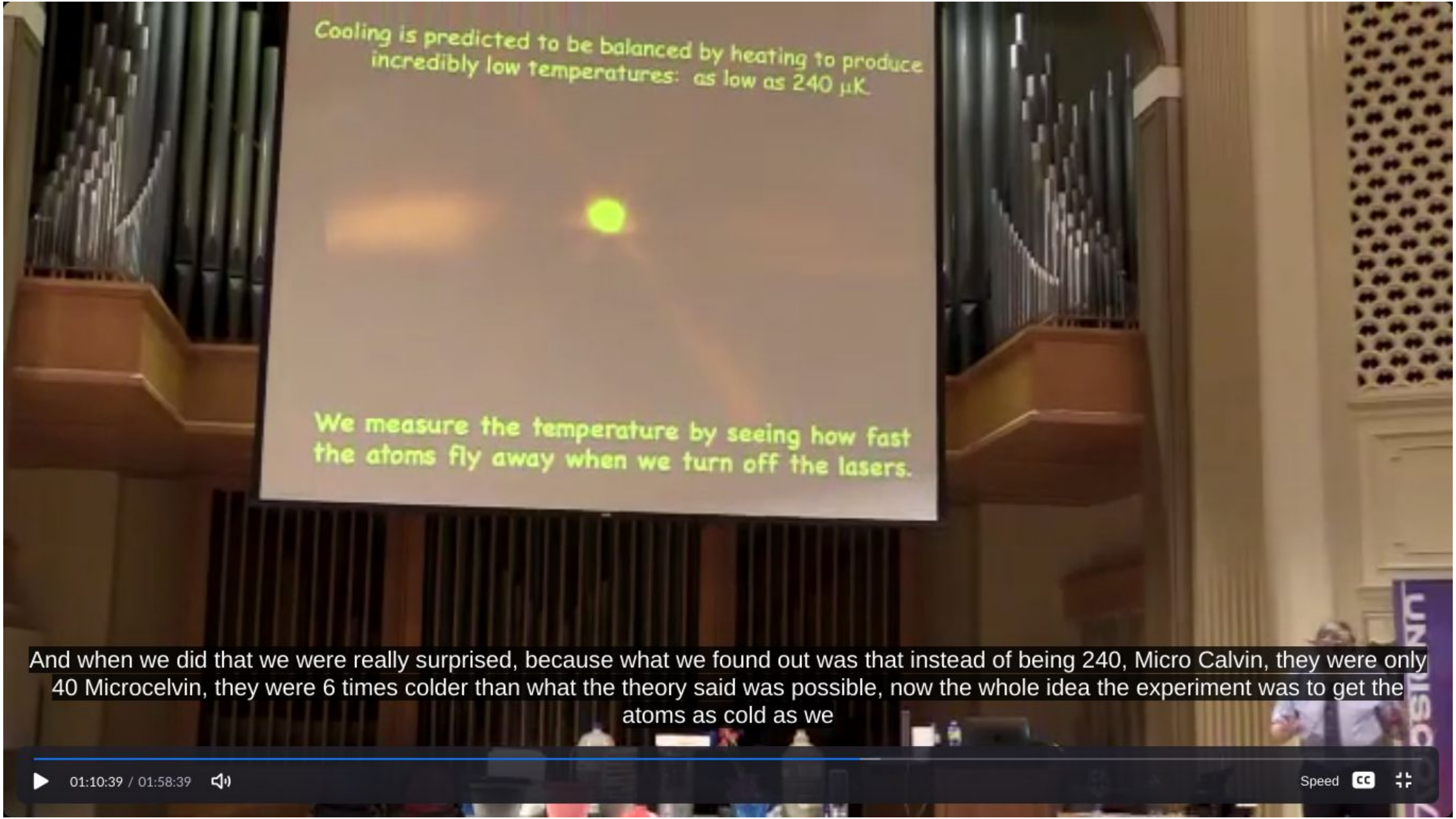
The value's uncertainty is a result of changes made in 2019 to the International System of Units. At the time, base unit definitions such as kilogram, ampere, kelvin and mole were updated. The ampere update affected the value of vacuum permeability (μ_0), which now comes with a relative standard uncertainty. According to the National Institute of Standards and Technology, the μ_0 value must now be "determined experimentally" because of this uncertainty. And as a result, this uncertainty passes to the ε_0 equation because it incorporates the μ_0 value.

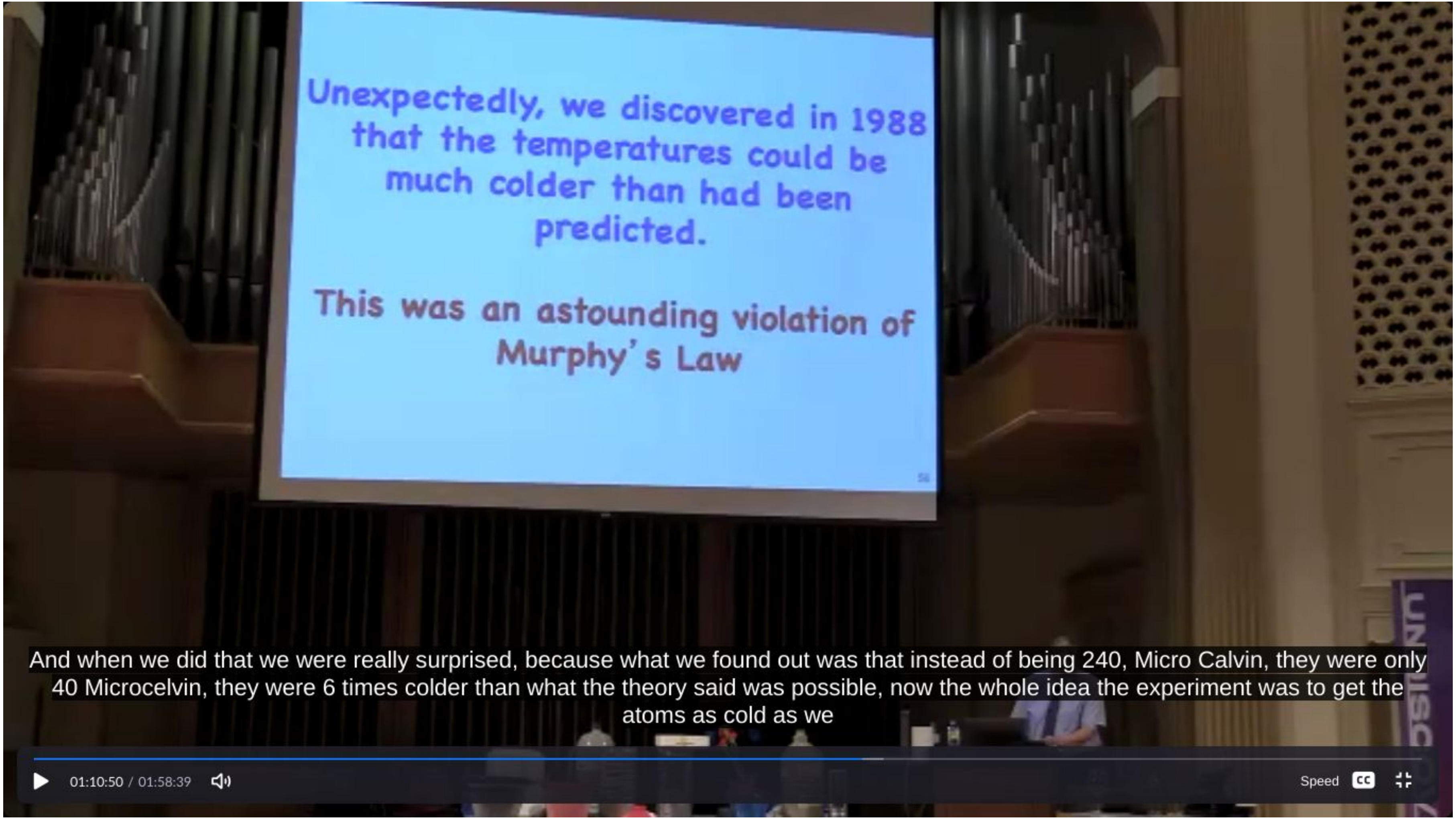

Laser Cooling (1975)
Wineland & Dehm
laser beam tuned
below resonance
Optical Mo
Chu et al.
Now at the University of Oregon
So so it's so Dave did this work at NIST, and he's now at the University of Oregon, and one of the things that Dave taught us about was that the cooling process is balanced by a heating process and that you can calculate.
01:08:48 / 01:58:39
Speed


We're talking about getting to temperatures that are 300,000 times colder than liquid nitrogen.
01:09:55 / 01:58:39
Speed


We measure the temperature by seeing how fast the atoms fly away when we turn off the lasers.
And the picture that I'm showing you right now is a picture from our laboratory in which we have laser beams coming from all directions, intersecting here, collecting sodium atoms about a 100 million sodium atoms it's about a centimeter across and how do
01:10:31 / 01:58:39
Speed
CC

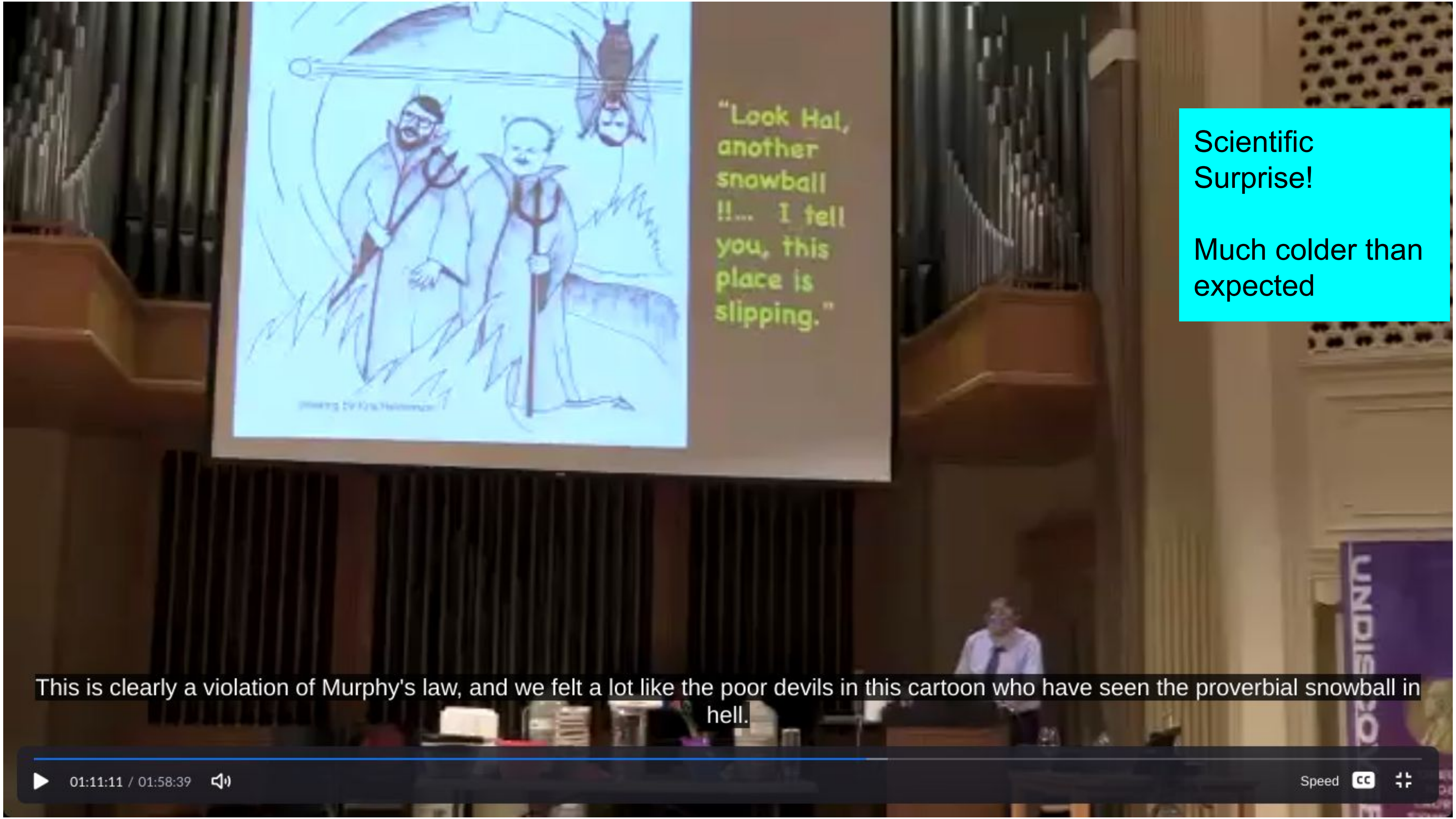

low temperatures: as low as 240 μK.
Press Esc to exit full screen
We measure the temperature by seeing how fast the atoms fly away when we turn off the lasers.
we measure the temperature well, we measure the temperature by turning off the laser beams and seeing how fast the atoms are going.
01:10:35 / 01:58:39
Speed
CC

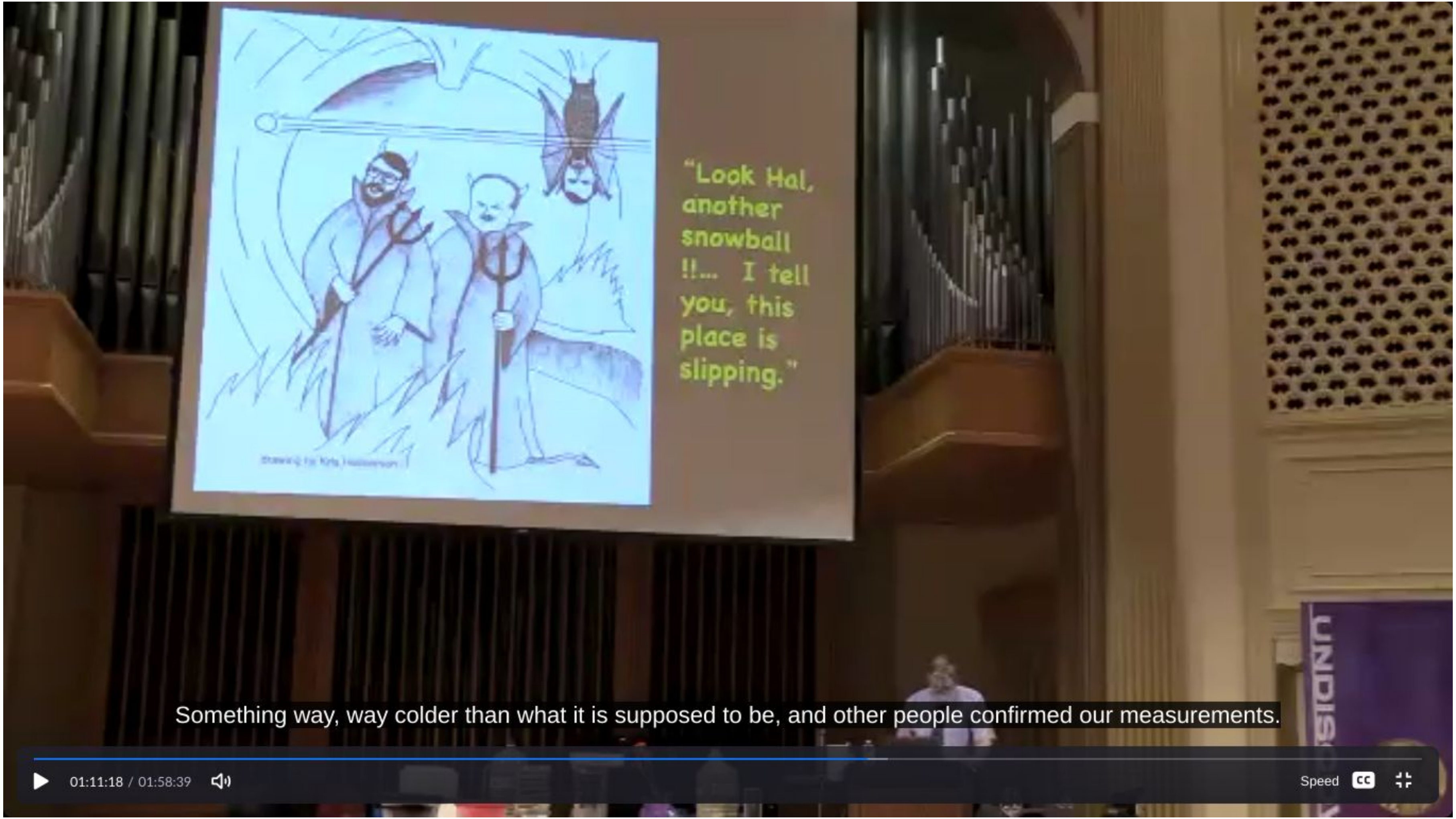

Cooling is predicted to be balanced by heating to produce incredibly low temperatures: as low as 240 μK.
We measure the temperature by seeing how fast the atoms fly away when we turn off the lasers.
And when we did that we were really surprised, because what we found out was that instead of being 240, Micro Calvin, they were only 40 Microcelvin, they were 6 times colder than what the theory said was possible, now the whole idea the experiment was to get the atoms as cold as we
01:10:39 / 01:58:39
Speed
CC


Unexpectedly, we discovered in 1988 that the temperatures could be much colder than had been predicted.
This was an astounding violation of Murphy's Law
And when we did that we were really surprised, because what we found out was that instead of being 240, Micro Calvin, they were only 40 Microcelvin, they were 6 times colder than what the theory said was possible, now the whole idea the experiment was to get the atoms as cold as we
01:10:50 / 01:58:39
Speed

Scientific Surprise!

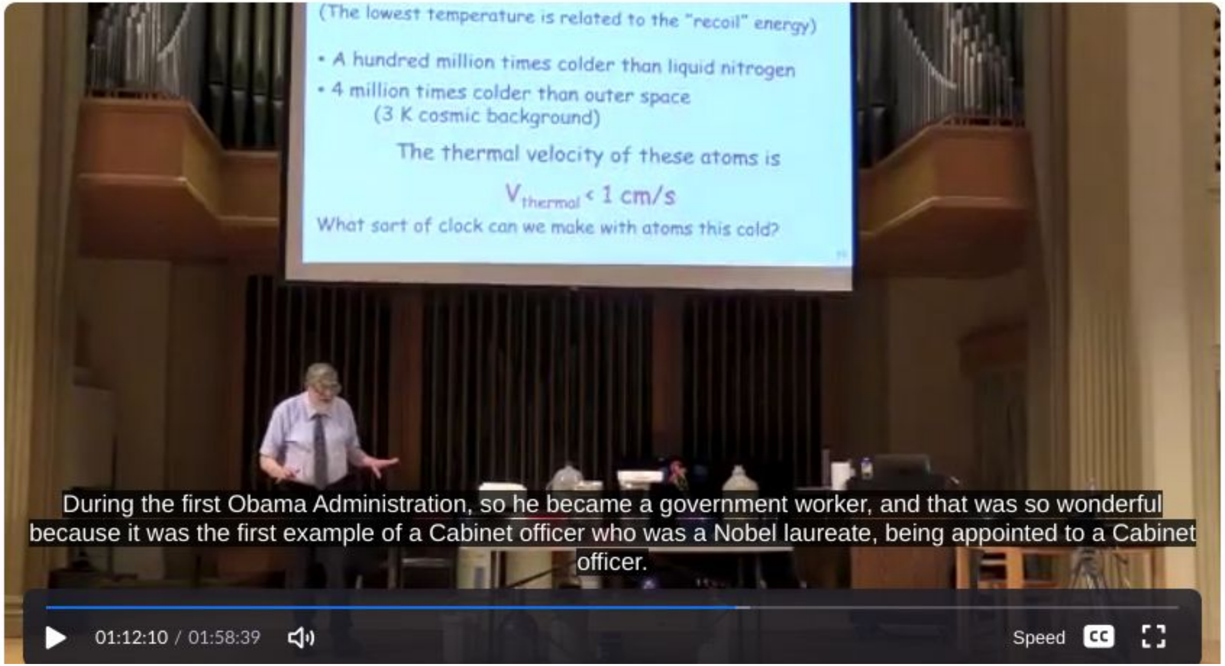
Much colder than expected





“Look Hal, another snowball !!... I tell you, this place is slipping.”
Something way, way colder than what it is supposed to be, and other people confirmed our measurements.
01:11:18 / 01:58:39
Speed
CC


Heated discussions about
cooling ensued. Eventually
Press Esc to exit full screen
And then people realized we needed a better understanding of laser cooling, and there were lots of discussions about how Laser cooling should be changed.
01:11:30 / 01:58:39
Speed
CC



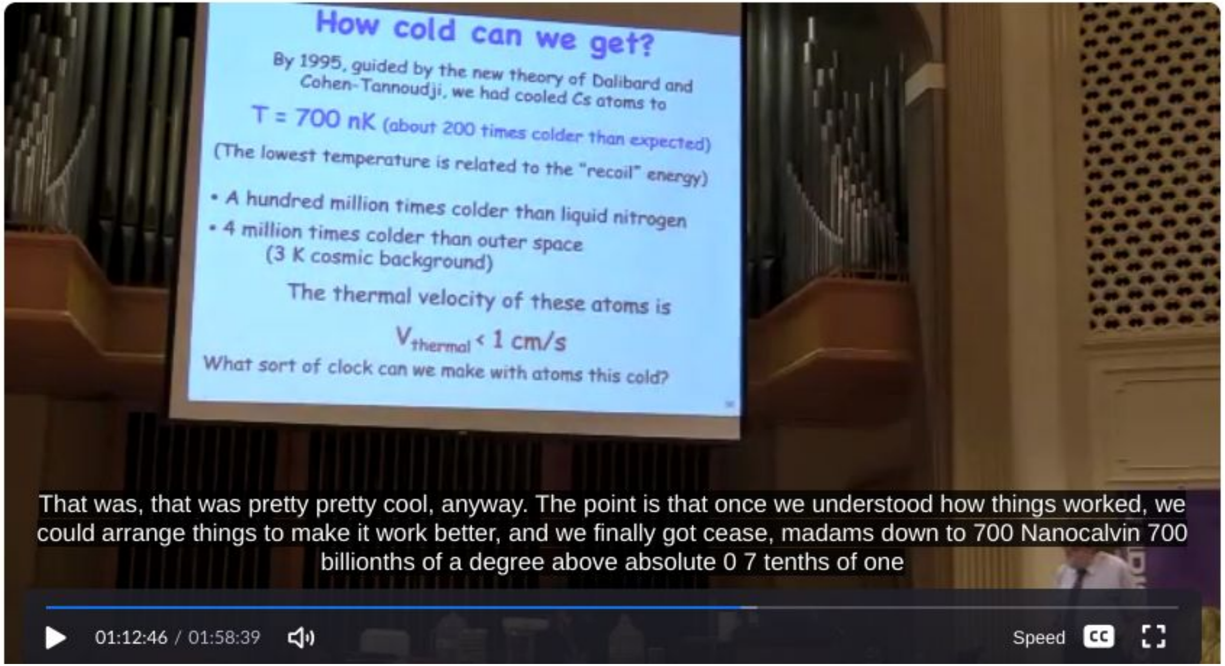
Audio Transcript

Search transcript

you about. It is such a great story. But by 1,995, guided by a new understanding of laser cooling, which came from our our friends in in Paris, John Dali, Bar, and Claude Cantanuji, as well as from Steve Chu, who by this time had moved to Stanford.

Unknown Speaker 01:11:53

He had been at Bell Labs before. Oh, and we were talking about government workers getting a Nobel prize. Well, Steve Chu wasn't a government worker when he got the Nobel Prize, but later



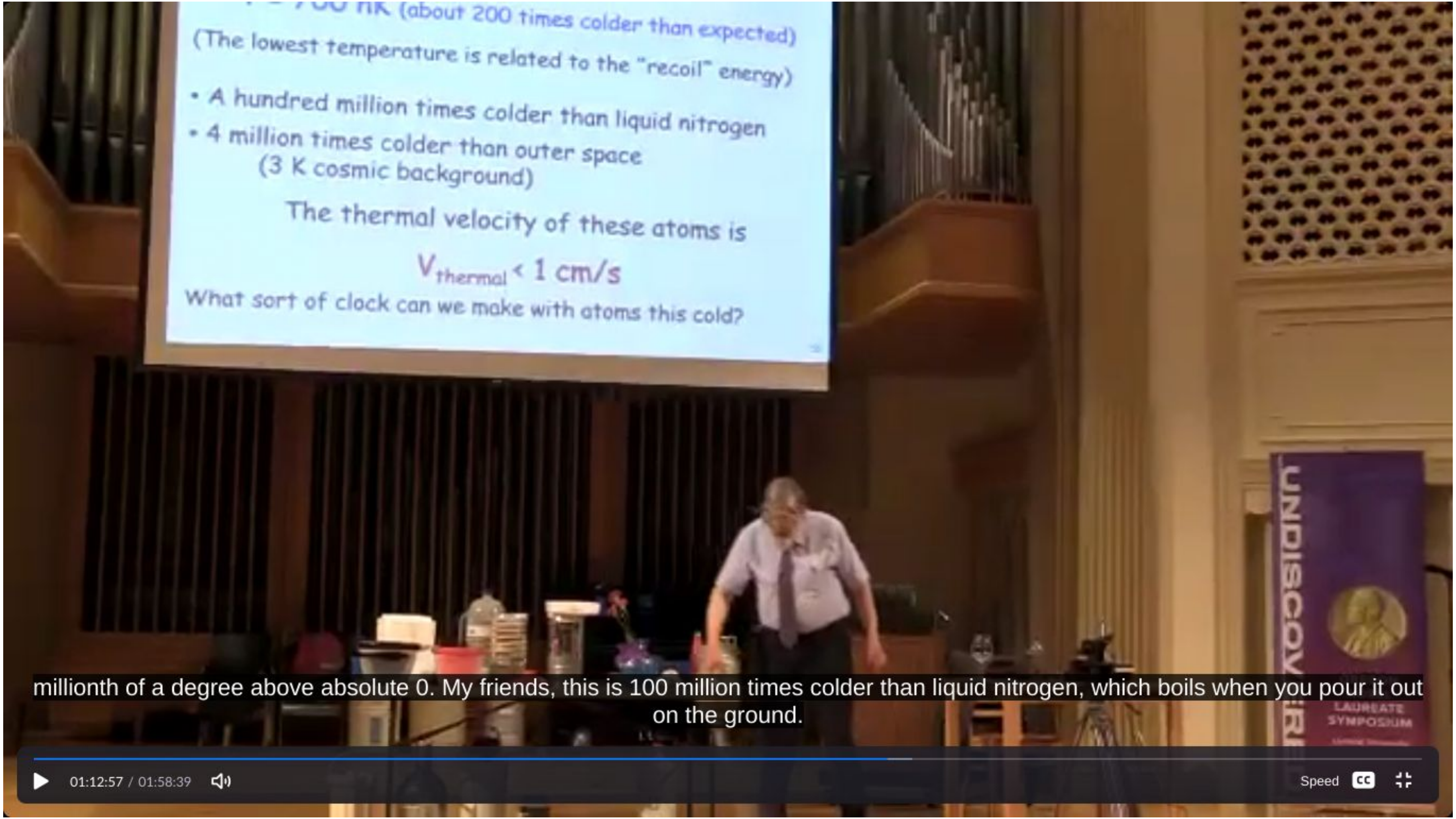
Audio Transcript

Search transcript

being appointed to a Cabinet officer. Now Henry Kissinger want a Nobel prize while he was a Cabinet officer, but but Steve Chu was was was appointed as a Nova warrior. That was. That was pretty pretty cool, anyway. The point is that Once we understood how things worked

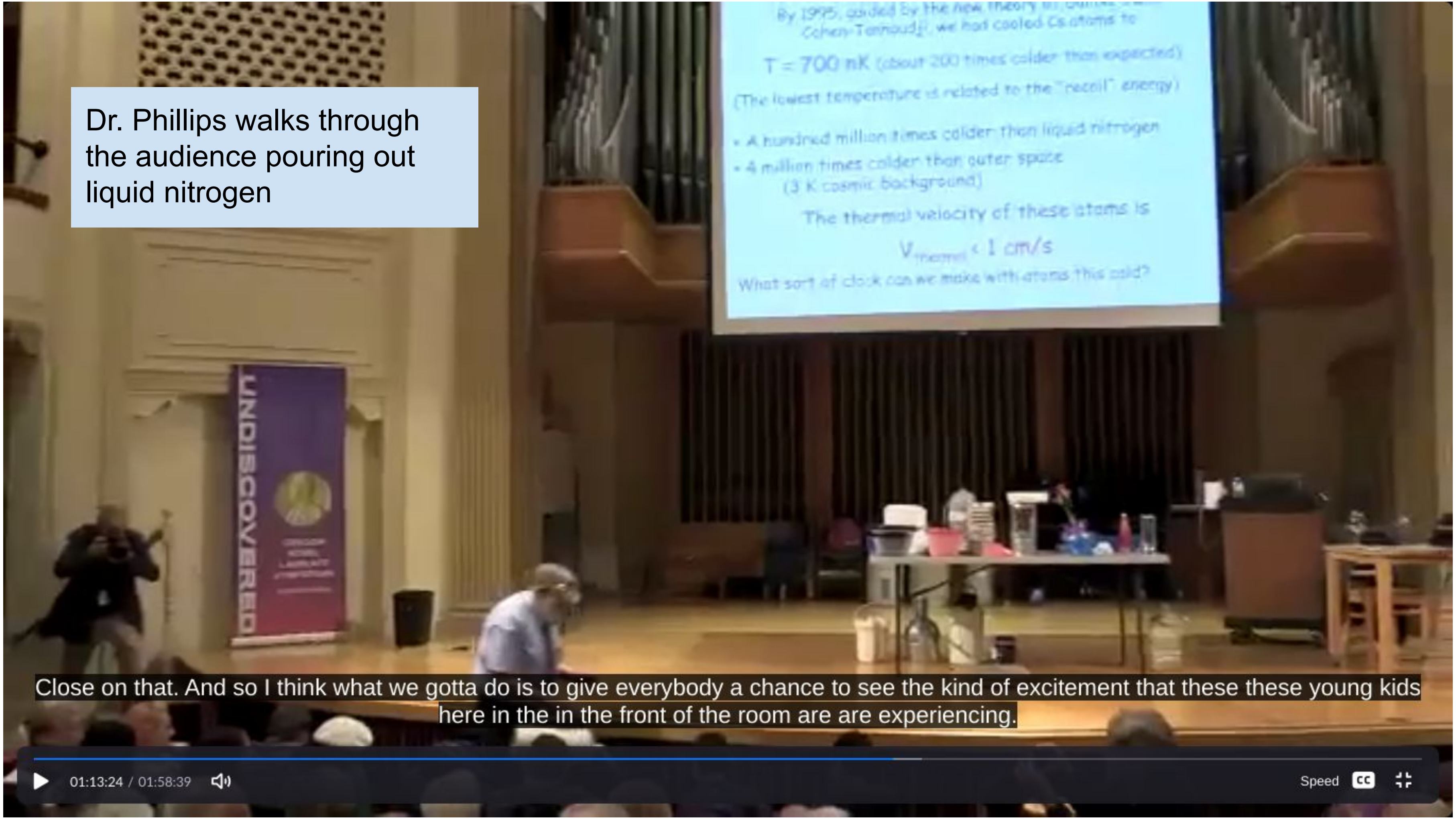
we could arrange things to make it work better. and we finally got Caesium Adams down t0 700 Nano Kelvin. 700 billionth of a degree above absolute 0 7 tenth of one millionth of a degree above absolute 0.

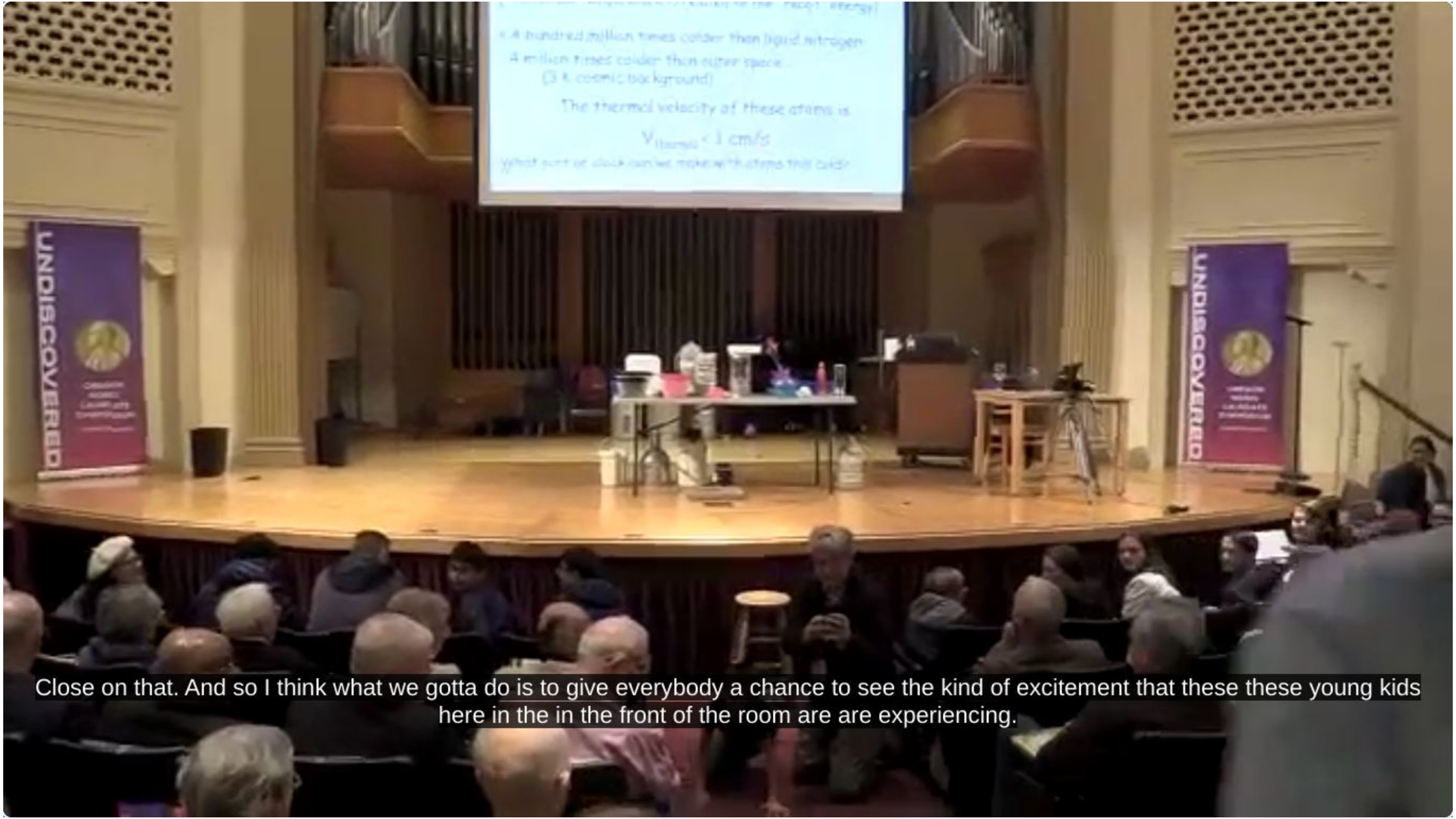
Got Caesium to 700 nano kelvin

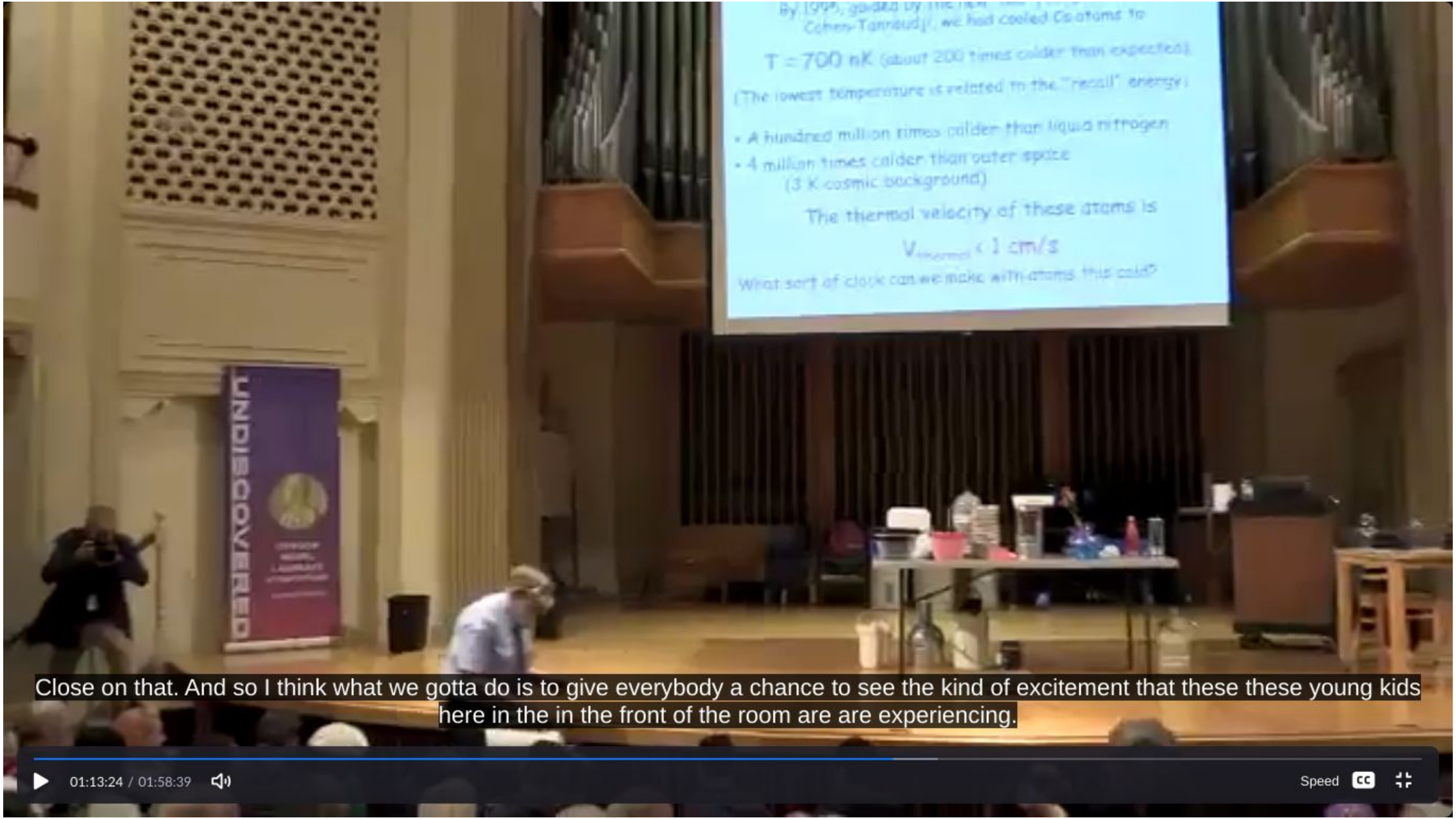


(about 200 times colder than expected)
(The lowest temperature is related to the "recoil" energy)
• A hundred million times colder than liquid nitrogen
• 4 million times colder than outer space
(3 K cosmic background)
The thermal velocity of these atoms is
$V_{thermal} < 1$ cm/s
What sort of clock can we make with atoms this cold?
LAUREATE
SYMPOSIUM
millionth of a degree above absolute 0. My friends, this is 100 million times colder than liquid nitrogen, which boils when you pour it out on the ground.
01:12:57 / 01:58:39
Speed
CC

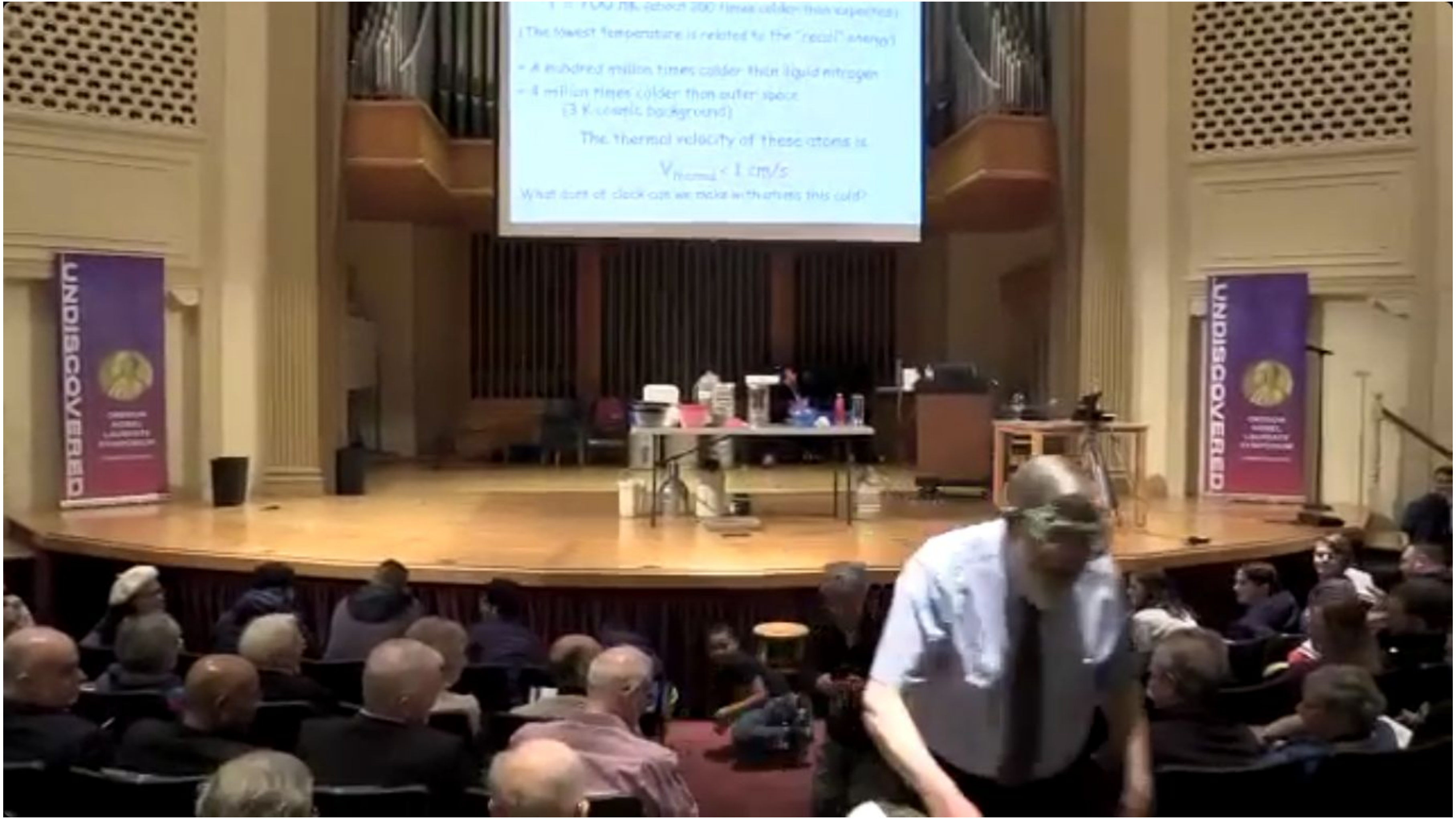
Dr. Phillips walks through the audience pouring out liquid nitrogen

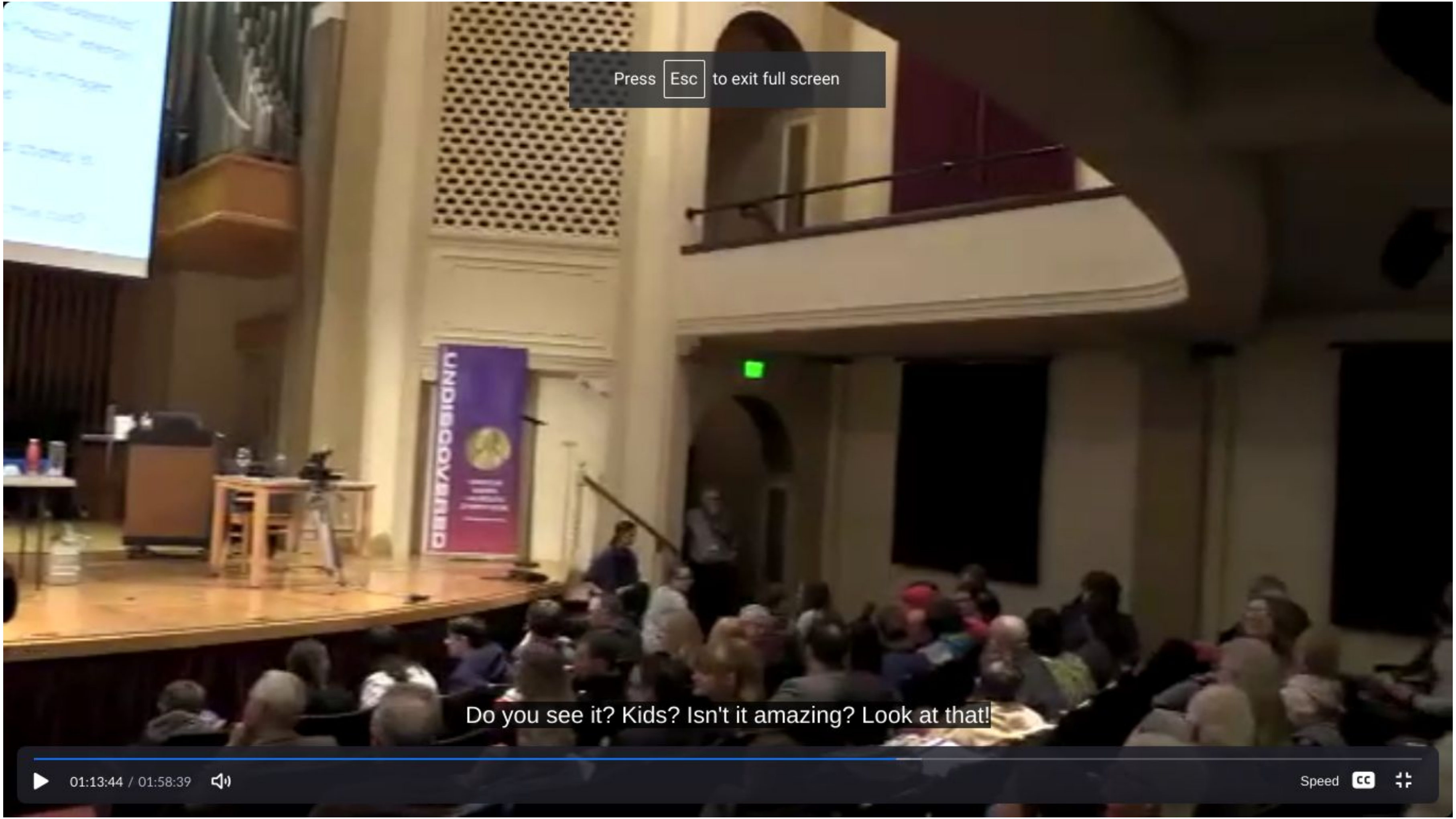



A hundred million times colder than liquid nitrogen
A million times colder than outer space
(3 K cosmic background)
The thermal velocity of these atoms is
UNDISCOVERED
UNDISCOVERED
Close on that. And so I think what we gotta do is to give everybody a chance to see the kind of excitement that these these young kids here in the in the front of the room are are experiencing.


Cohen-Tannoudji, we had cooled Cs atoms to
T = 700 nK (about 200 times colder than expected)
(The lowest temperature is related to the "recoil" energy)
• A hundred million times colder than liquid nitrogen
• 4 million times colder than outer space
(3 K cosmic background)
The thermal velocity of these atoms is
$V_{thermal} < 1$ cm/s
What sort of clock can we make with atoms this cold?
UNDISCOVERED
Close on that. And so I think what we gotta do is to give everybody a chance to see the kind of excitement that these these young kids here in the in the front of the room are are experiencing.
01:13:24 / 01:58:39
Speed
CC


• 4 hundred million times colder than liquid nitrogen
• 4 million times colder than outer space
(3 K cosmic background)
The thermal velocity of these atoms is
$V_{thermal} < 1$ cm/s
What sort of clock can we make with atoms this cold?
UNDISCOVERED
UNDISCOVERED


(The lowest temperature is related to the "recoil" energy)
• A hundred million times colder than liquid nitrogen
• 4 million times colder than outer space
(3 K cosmic background)
The thermal velocity of these atoms is
V thermal < 1 cm/s
UNDISCOVERED
UNDISCOVERED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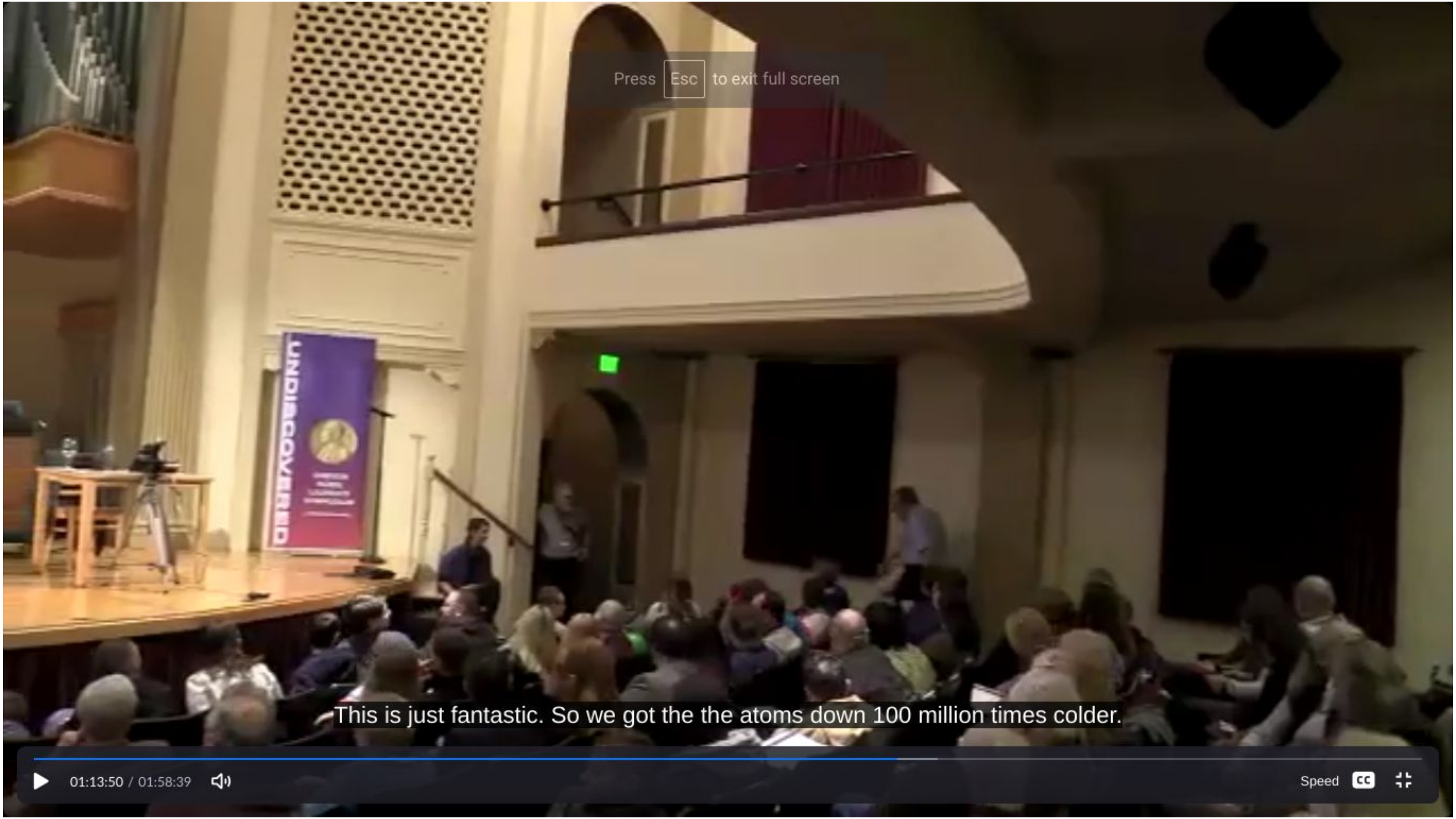
UNDISCOVERED
Do you see it? Kids? Isn't it amazing? Look at that!
01:13:44 / 01:58:39
Speed
CC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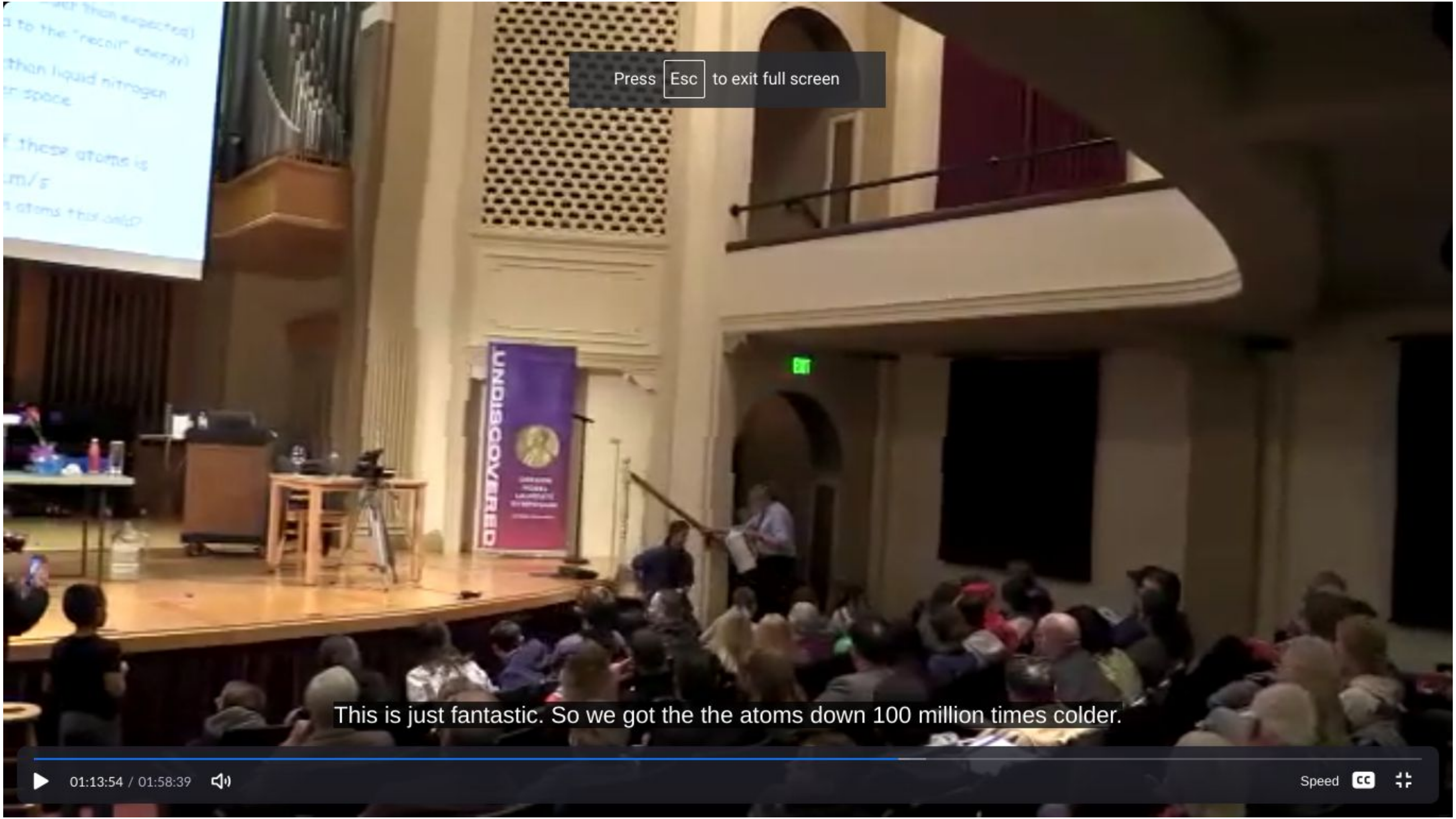
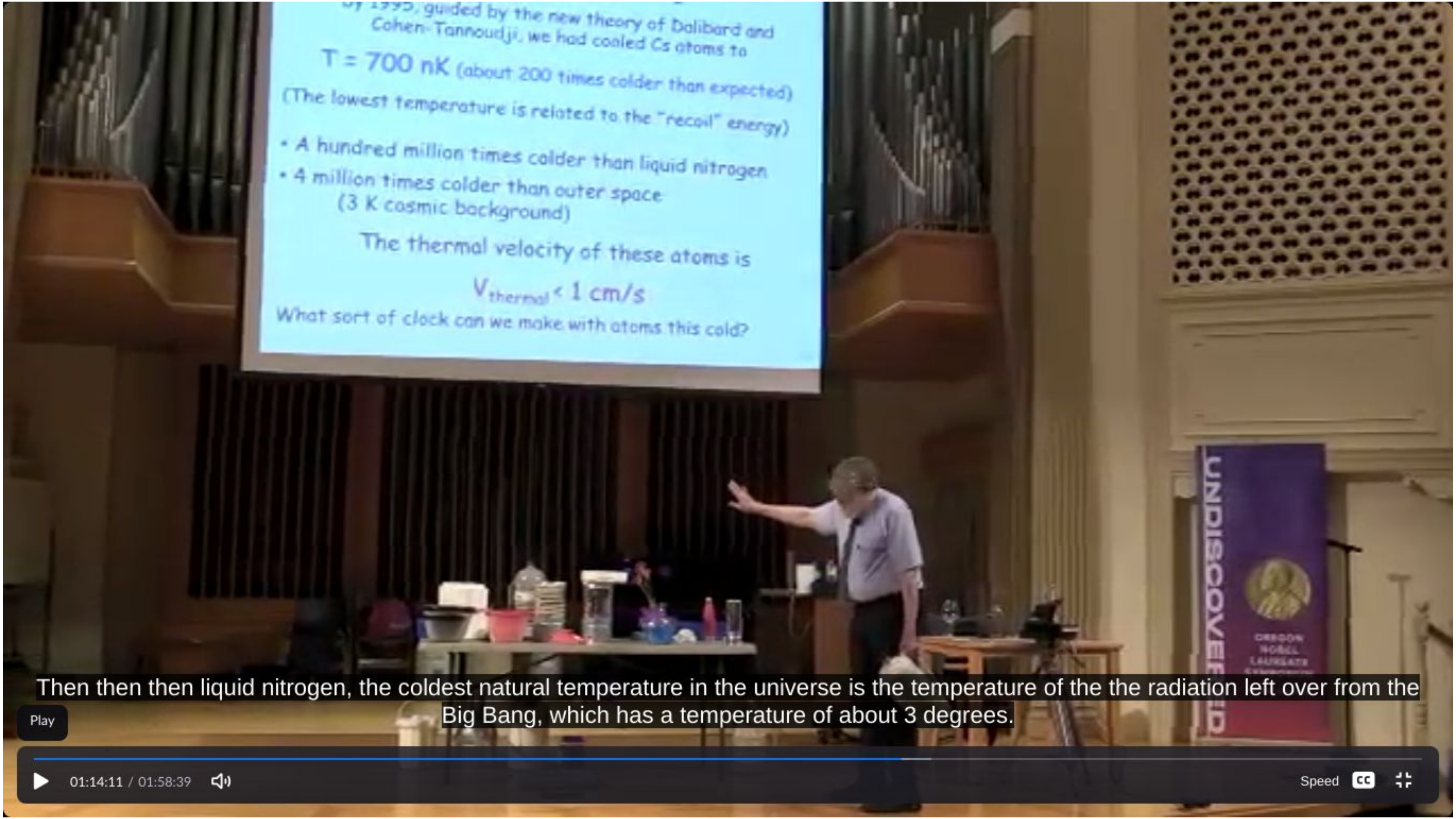
UNDISCOVERED
This is just fantastic. So we got the the atoms down 100 million times colder.
01:13:50 / 01:58:39
Speed
CC


Press Esc to exit full screen
UNDISCOVERED
This is just fantastic. So we got the the atoms down 100 million times colder.
01:13:54 / 01:58:39
Speed
CC

With this tool, the motion of the universe is revealed and a host of new questions can be investigated.

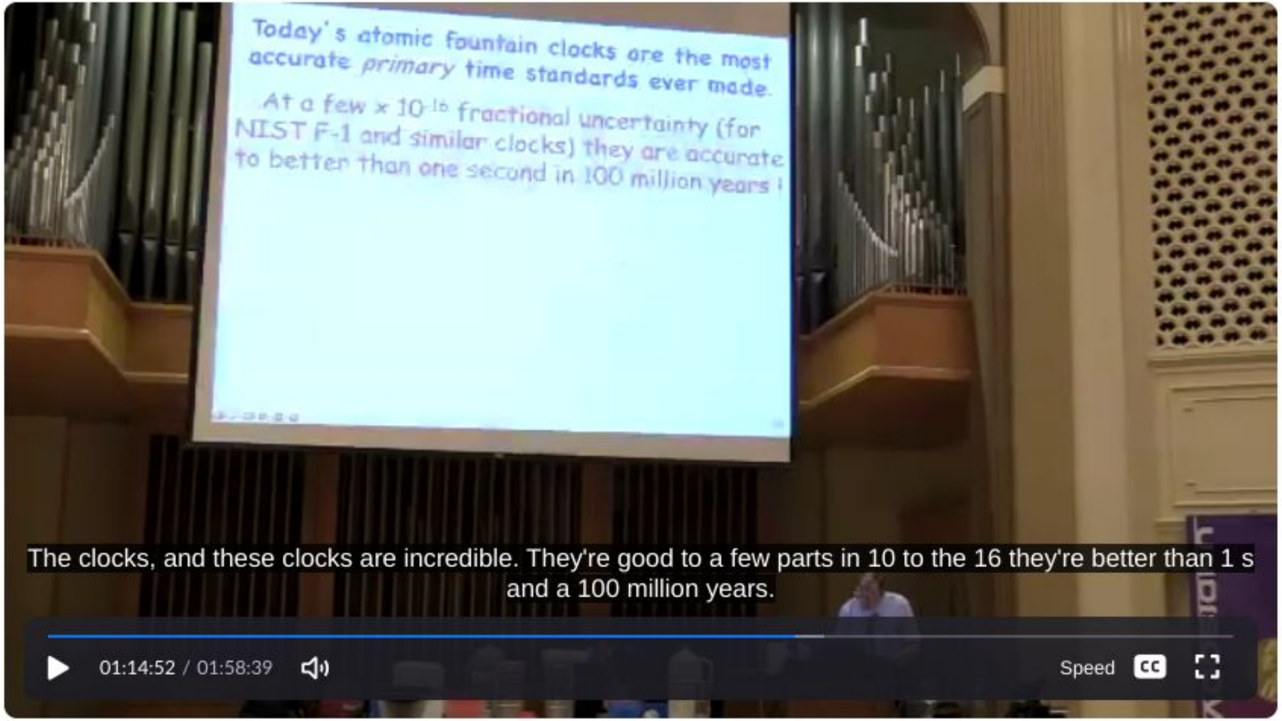
And galaxies aren't the only things that can be investigated with redshifts. Astronomers have learned to tease out the subtle tug of a distant planet on its parent star, thus revealing the planet to astronomers. If a star in our Milky Way galaxy has a hidden planet – and if astronomers see that the star sometimes exhibits a slight redshift and other times a slight blueshift – the astronomers infer that star is alternating between moving toward and away from us. They refer to this movement as a "wobble" of the star in space. *Something* must be pulling on the star, causing it to wobble. By measuring how far the absorption lines shift, an astronomer can determine the mass of the invisible companion and its distance from the star, and come to the conclusion that a planet is in orbit around the star!


guided by the new theory of Dalibard and
Cohen-Tannoudji, we had cooled Cs atoms to
T = 700 nK (about 200 times colder than expected)
(The lowest temperature is related to the "recoil" energy)
• A hundred million times colder than liquid nitrogen
• 4 million times colder than outer space
(3 K cosmic background)
The thermal velocity of these atoms is
$V_{thermal} < 1$ cm/s
What sort of clock can we make with atoms this cold?
UNDISCOVERED
Then then then liquid nitrogen, the coldest natural temperature in the universe is the temperature of the the radiation left over from the Big Bang, which has a temperature of about 3 degrees.
Play
01:14:11 / 01:58:39
Speed
CC

So when I talk about the coolest stuff in the universe, i'm really serious. This really is the coolest stuff in the universe.

So now, what kind of a clock? The velocity of these atoms is less than a centimeter per second in the old clocks? It was over 100 meters per second. Here is a picture of the kind of clock that is made


Atomic Fountain Clock
Per second. Here is a picture of the kind of clock that is made at NIST in Boulder Don Meikov and Steve Jeffords, cool down cesium atoms to below a micro kelvin.
01:14:38 / 01:58:39
Speed



Audio Transcript

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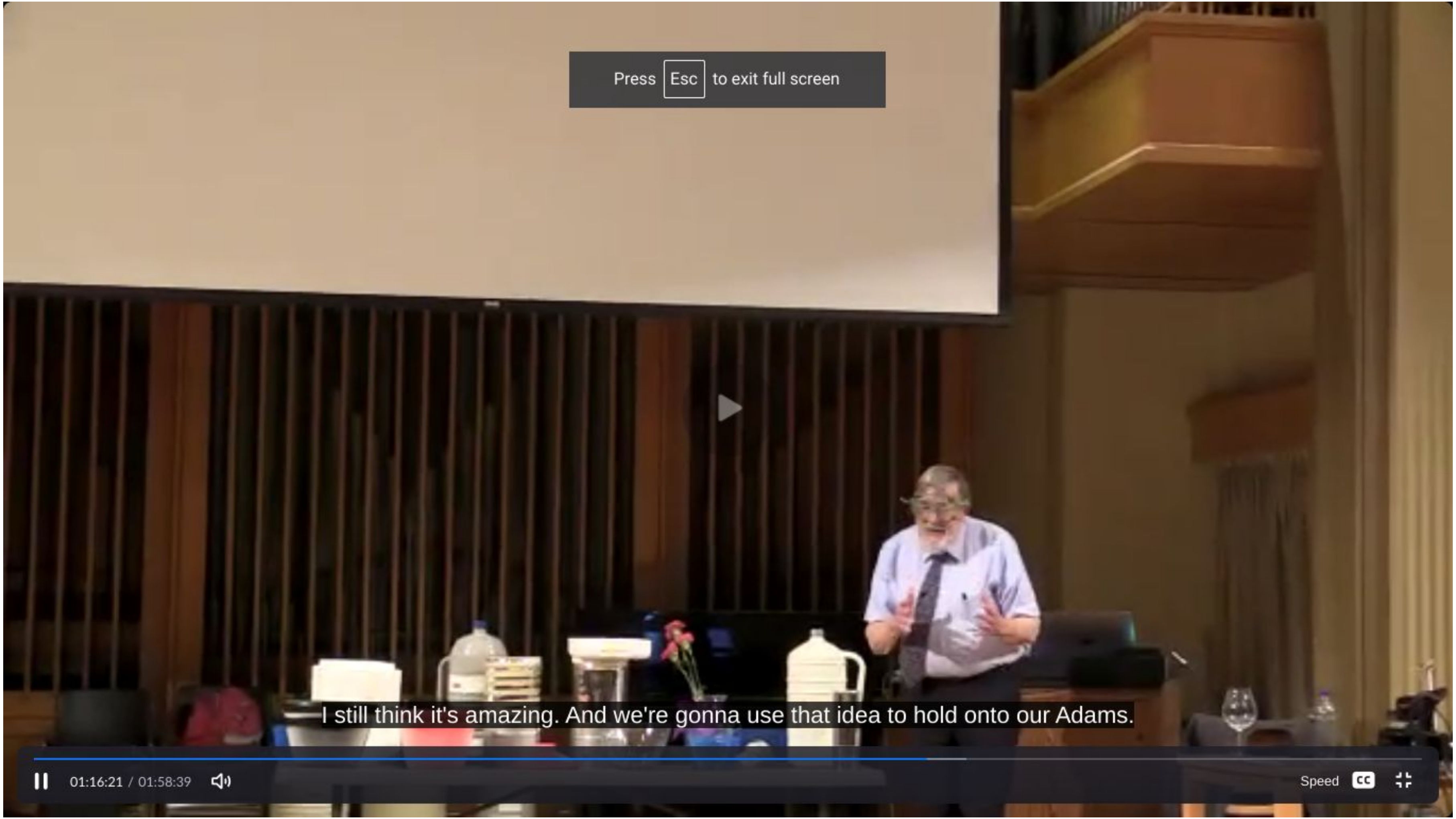
at NIST in Boulder Don Meikov and Steve Jeffords cool down caesium atoms to below a micro kelvin. Here

they launched them up.

They come back down after a second, so, instead of having a few milliseconds, they have a full second little hit. The clocks.

and these clocks are incredible. They're good to a few parts in 10 to the 16. They're better than 1 s and 100 millionyears. But what if we want to

Resume Transcript Auto-Scroll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I still think it's amazing. And we're gonna use that idea to hold onto our Adams.
01:16:21 / 01:58:39
Speed
CC


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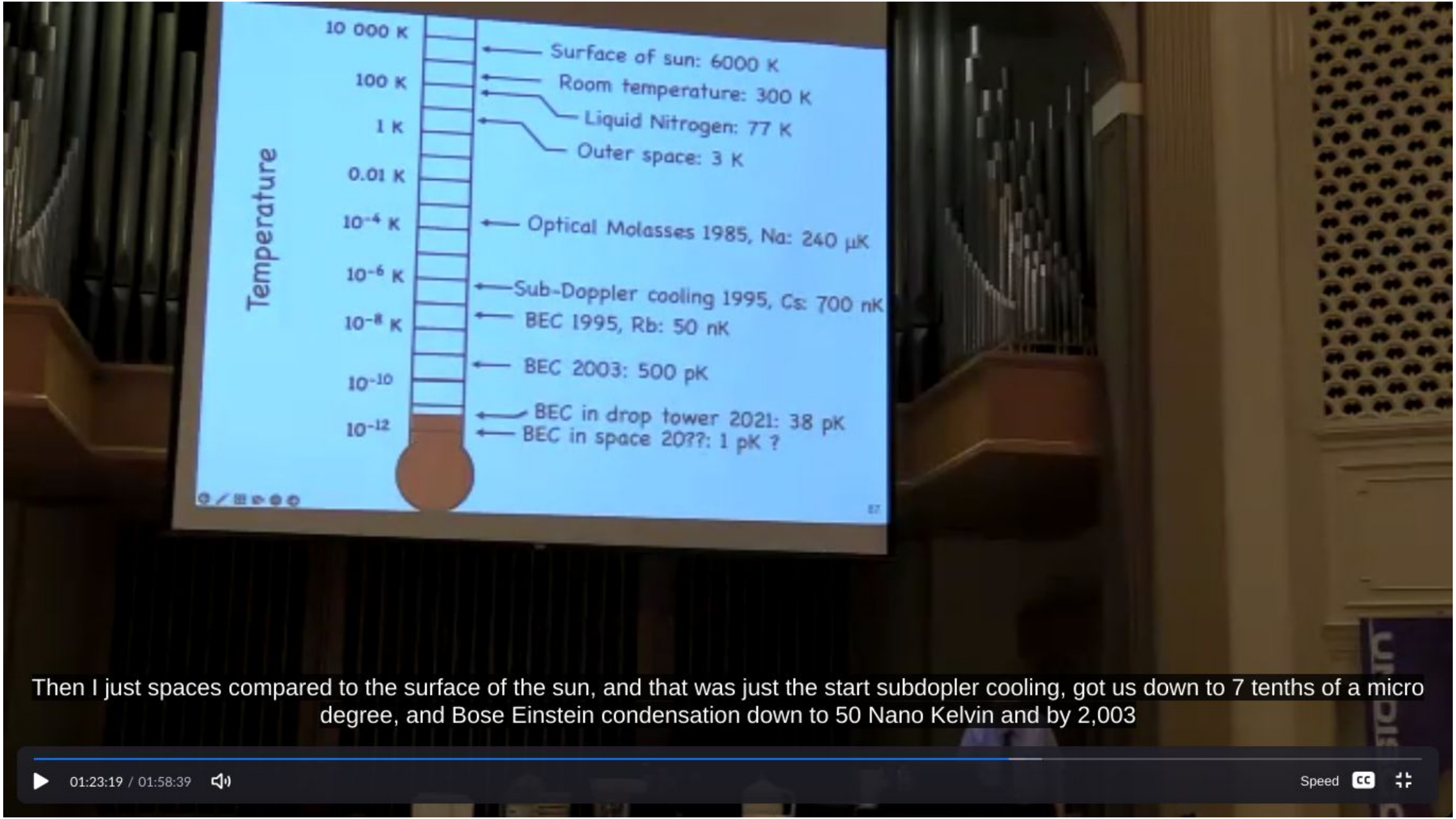
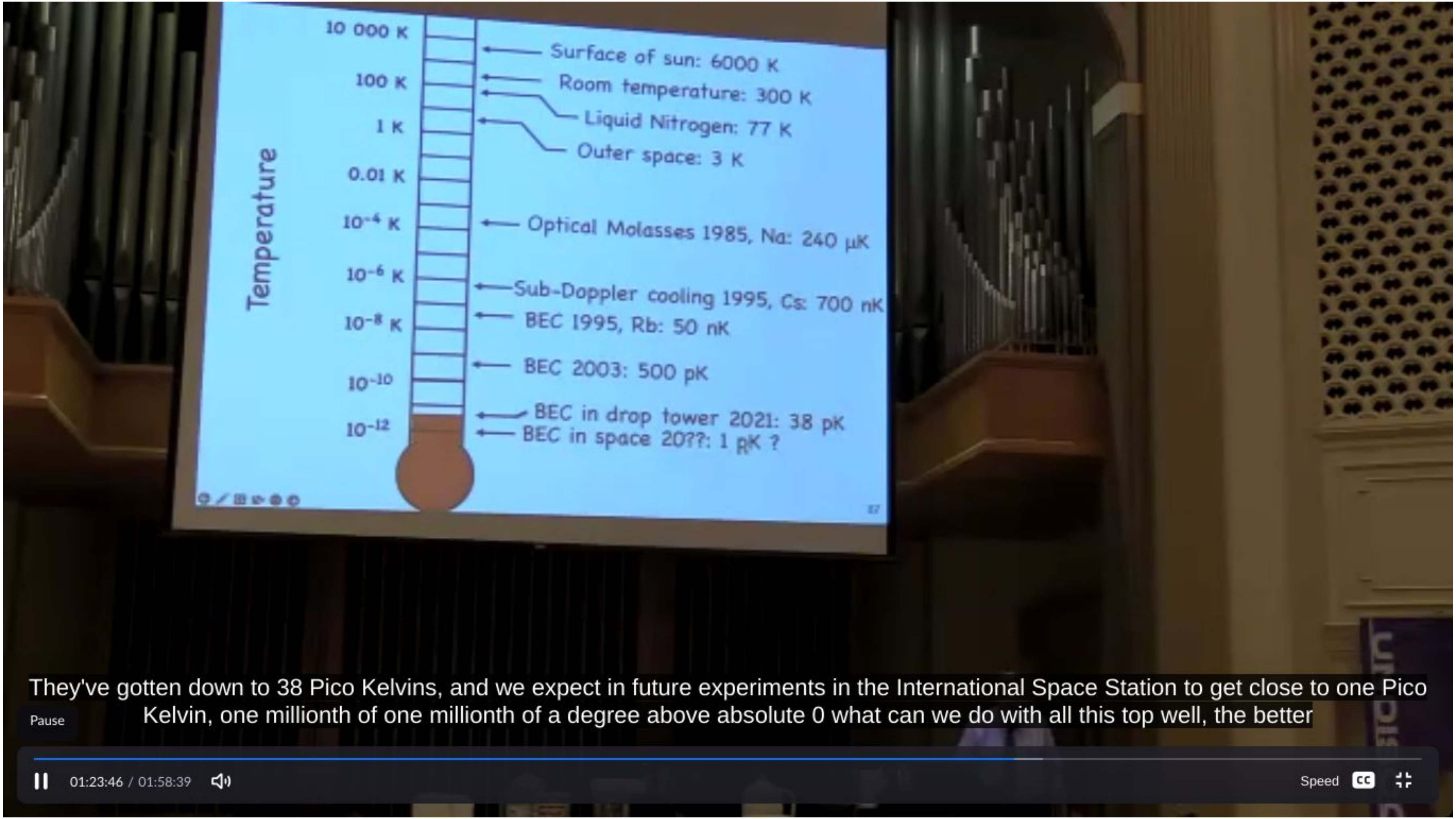
But but wait! Any two-bit magician can levitate a woman and then pass a ring around her, carefully avoiding the wires that are holding her up. But you've never seen a magician do this.
01:18:17 / 01:58:39
Speed
CC


Temperature
10 000 K
100 K
1 K
0.01 K
10^-4 K
10^-6 K
10^-8 K
10^-10
10^-12
Surface of sun: 6000 K
Room temperature: 300 K
Liquid Nitrogen: 77 K
Outer space: 3 K
Optical Molasses 1985, Na: 240 μK
Sub-Doppler cooling 1995, Cs: 700 nK
BEC 1995, Rb: 50 nK
BEC 2003: 500 pK
BEC in drop tower 2021: 38 pK
BEC in space 20??: 1 pK ?
Then I just spaces compared to the surface of the sun, and that was just the start subdopler cooling, got us down to 7 tenths of a micro degree, and Bose Einstein condensation down to 50 Nano Kelvin and by 2,003
01:23:19 / 01:58:39
Speed
CC


Linfield University
s is the real deal. There is nothing holding this thing up except the magnetic field that's the toy version.
Speed
ad of for a
second, and we have lots of different kinds of traps, not just magnetic traps, but also laser traps, Dave weinel in
01:19:40 / 01:58:39
Speed



10 000 K
100 K
1 K
0.01 K
10^-4 K
10^-6 K
10^-8 K
10^-10
10^-12
Temperature
Surface of sun: 6000 K
Room temperature: 300 K
Liquid Nitrogen: 77 K
Outer space: 3 K
Optical Molasses 1985, Na: 240 μK
Sub-Doppler cooling 1995, Cs: 700 nK
BEC 1995, Rb: 50 nK
BEC 2003: 500 pK
BEC in drop tower 2021: 38 pK
BEC in space 20??: 1 pK ?
They've gotten down to 38 Pico Kelvins, and we expect in future experiments in the International Space Station to get close to one Pico Kelvin, one millionth of one millionth of a degree above absolute 0 what can we do with all this top well, the better
Pause
01:23:46 / 01:58:39
Speed
CC


NIST laser cooling group
BUILDING 216
Press Esc to exit full screen
of at NIST, and find out the new mysteries, the things that are just over the horizon to teach us about the way in which the the universe works.
01:25:56 / 01:58:39
Speed
CC

For 3 solar mass black hole

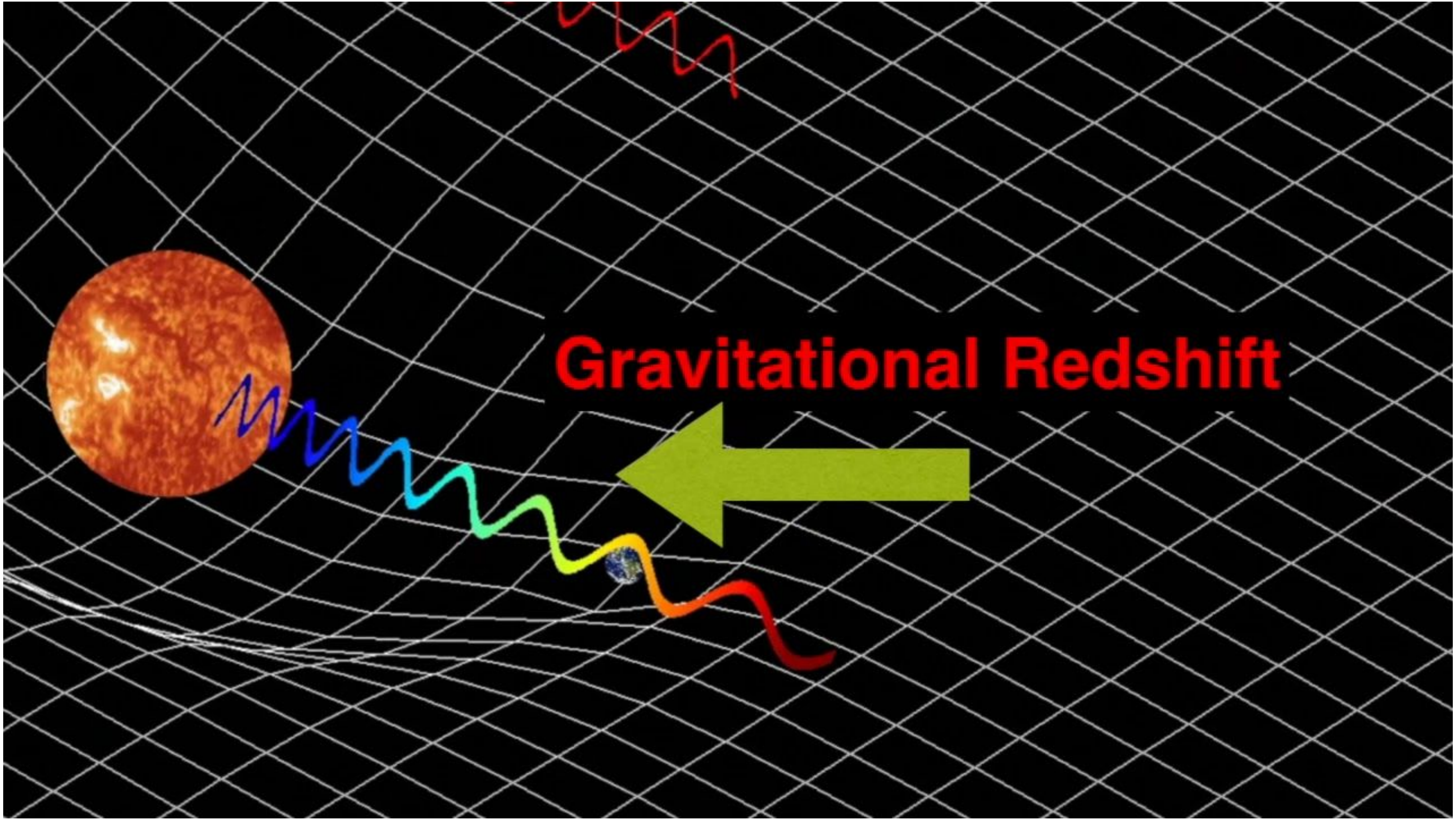
"Photon sphere", orbit of light at 13.5 km, 3/2 x the event horizon radius.

Event horizon or Schwarzschild radius at

$$R = \frac{2MG}{c^2}$$

or 9 km for 3 solar masses.

R = 9 km for three solar masses
R = 3 km for Sun
R = 9 mm for Earth's mass


Gravitational Redshift

LASER COOLING AND TRAPPING OF NEUTRAL ATOMS

https://www.nobelprize.org/uploads/2018/06/phillips-lecture.pdf

Nobel Lecture, December 8, 1997

by

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INTRODUCTION

In 1978, while I was a postdoctoral fellow at MIT, I read a paper [1] by Art Ashkin in which he described how one might slow down an atomic beam of sodium using the radiation pressure of a laser beam tuned to an atomic resonance. After being slowed, the atoms would be captured in a trap consisting of focused laser beams, with the atomic motion being damped until the temperature of the atoms reached the microkelvin range. That paper was my first introduction to laser cooling, although the idea of laser cooling (the reduction of random thermal velocities using radiative forces) had been proposed

Slow atomic beam of sodium using radiation pressure

Molasses

Traps

Laser beam **tuned to atomic resonance** first laser cooling experiment [4], in which they cooled a cloud of Mg ions held in a Penning trap. At essentially the same time, Neuhauser, Hohenstatt, Toschek and Dehmelt [5] also reported laser cooling of trapped Ba^+ ions.

Those laser cooling experiments of 1978 were a dramatic demonstration of the mechanical effects of light, but such effects have a much longer history. The understanding that electromagnetic radiation exerts a force became quantitative only with Maxwell's theory of electromagnetism, even though such a force had been conjectured much earlier, partly in response to the observation that comet tails point away from the sun. It was not until the turn of the century, however, that experiments by Lebedev [6] and Nichols and Hull [7, 8] gave a laboratory demonstration and quantitative measurement of radiation pressure on macroscopic objects. In 1933, Frisch [9] made the first demonstration of light pressure on atoms, deflecting an atomic sodium beam with resonance radiation from a lamp. With the advent of the laser, Ashkin [10] recognized the potential of intense, narrow-band light for manipulating atoms and in 1972 the first "modern" experiments demonstrated the deflection of atomic beams with lasers [11, 12]. All of this set the stage for the laser cooling proposals of 1975 and for the demonstrations in 1978 with ions.

Comet tails, deflection of atomic beams and the laser cooling proposed in

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Electromagnetic radiation exerts a force,

Diverts comet tails

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The Nobel Prize in Physics 1997

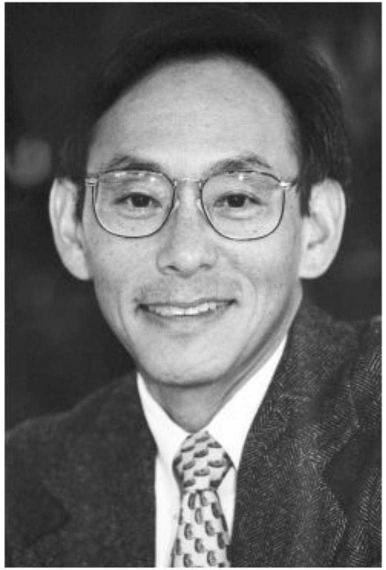

Photo from the Nobel Foundation archive.

Steven Chu

Photo from the Nobel Foundation archive.

Claude Cohen-

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William D. Phillips