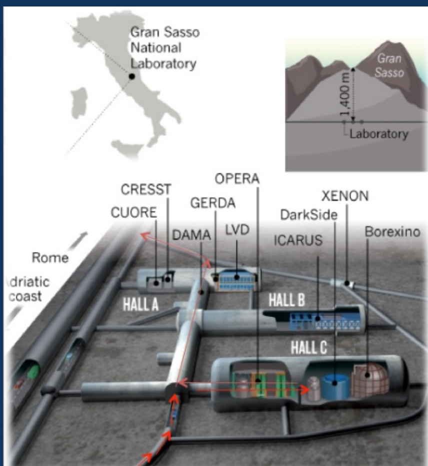
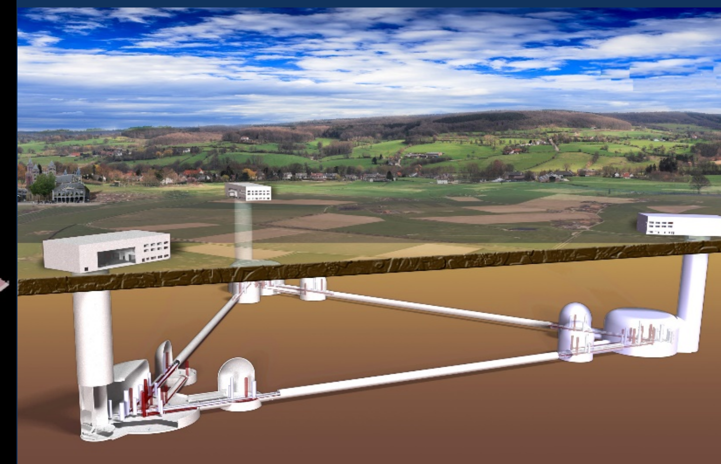
Viewing the Universe from Deep Undeground

Underground Labs

Gravitational Waves



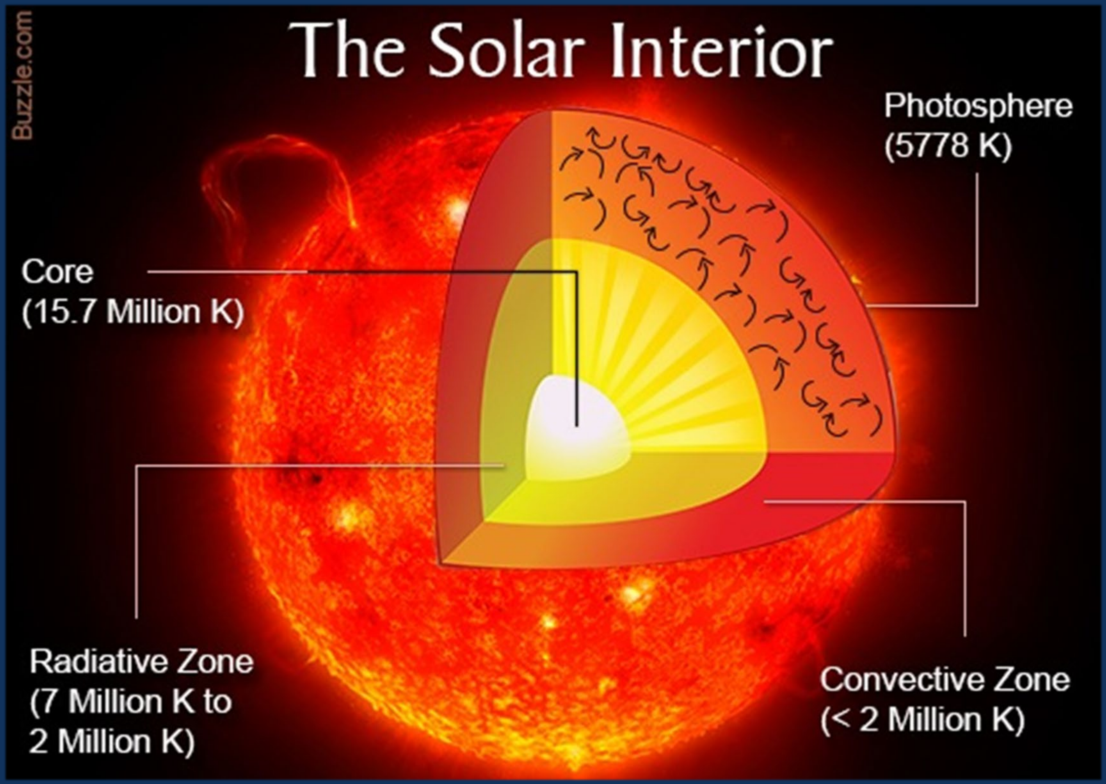


Gran Sasso, Italy

SNOLAB, Canada

Einstein Telescope

Sudbury Neutrino Observatory (SNO) 1999-2006



The middle of the sun is so hot that the centers of the atoms (nuclei) fuse together, giving off lots of energy and particles called neutrinos.

Studies of solar Neutrinos.

We showed:

1. **That calculations of how the sun burns are extremely accurate**
2. **Neutrinos change their type as they travel from the solar core to Earth.**
3. **Together with SuperKamiokande studying atmospheric neutrinos in Japan:**

- **Neutrinos have a finite rest mass.**

This requires changes to the Standard Model of Elementary Particles.

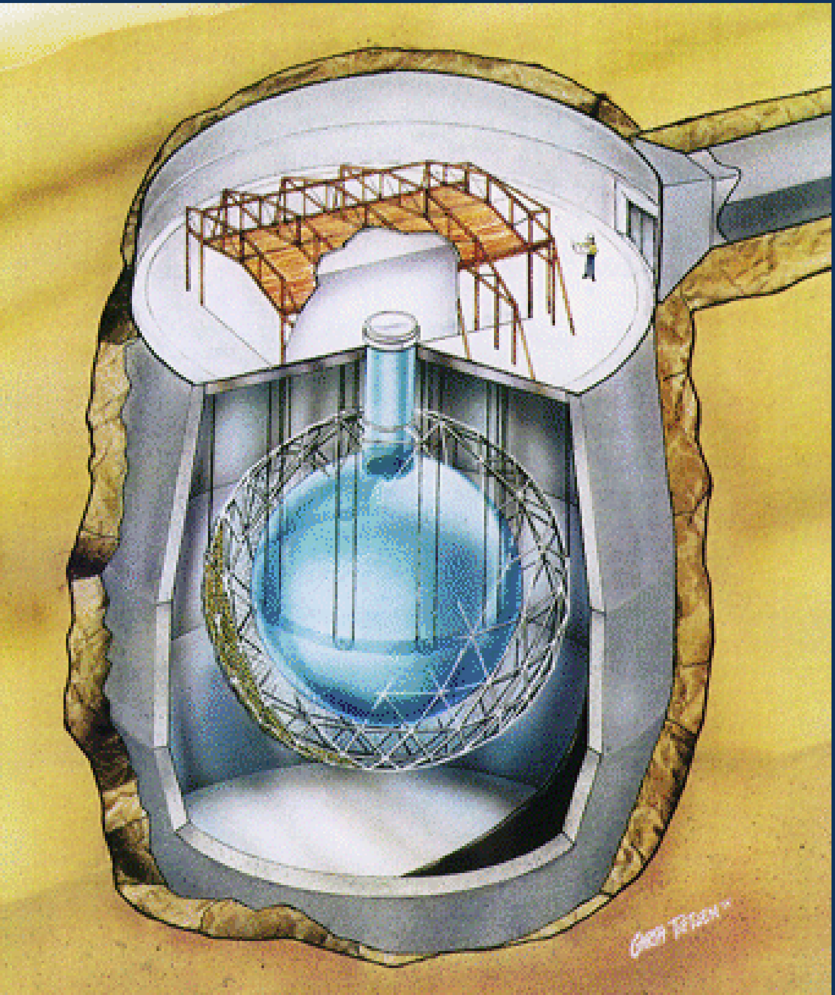
Sudbury Neutrino Observatory (SNO) Canada

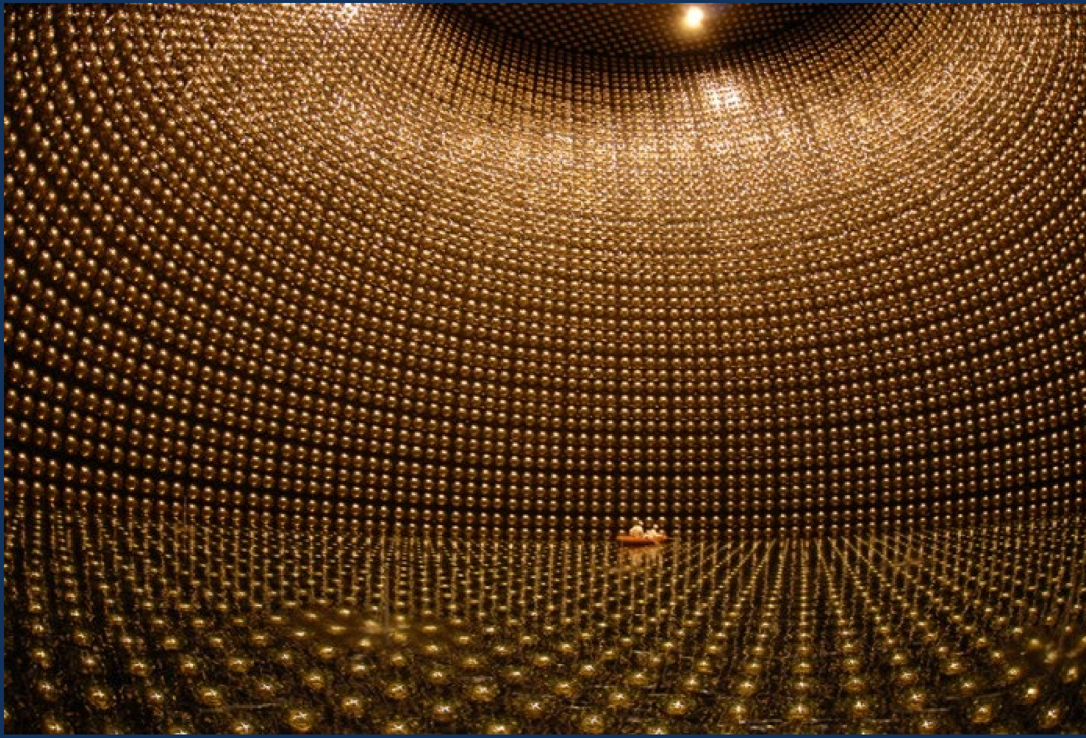
Solar Neutrinos

SuperKamiokande

Japan

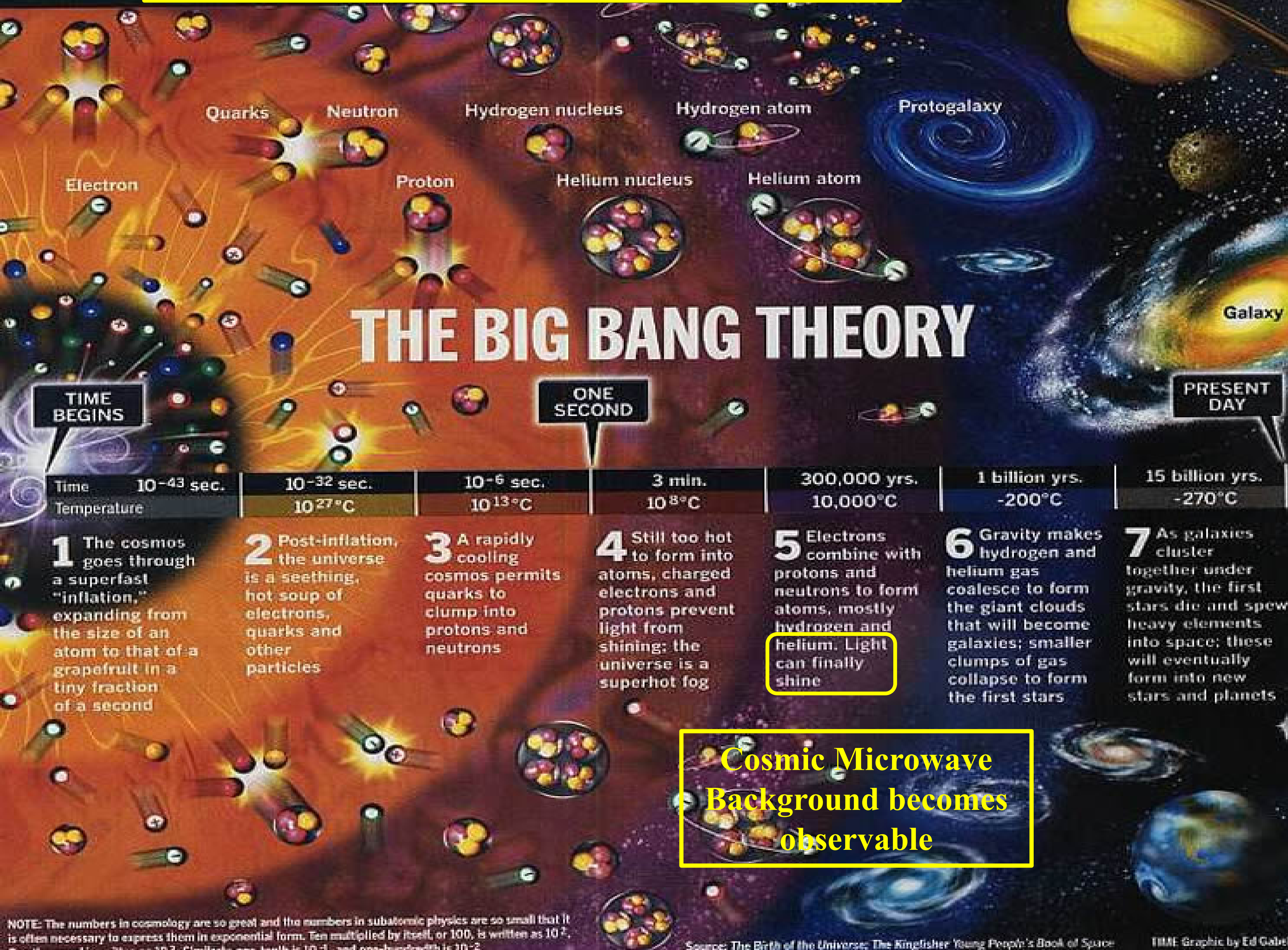
Atmospheric Neutrinos

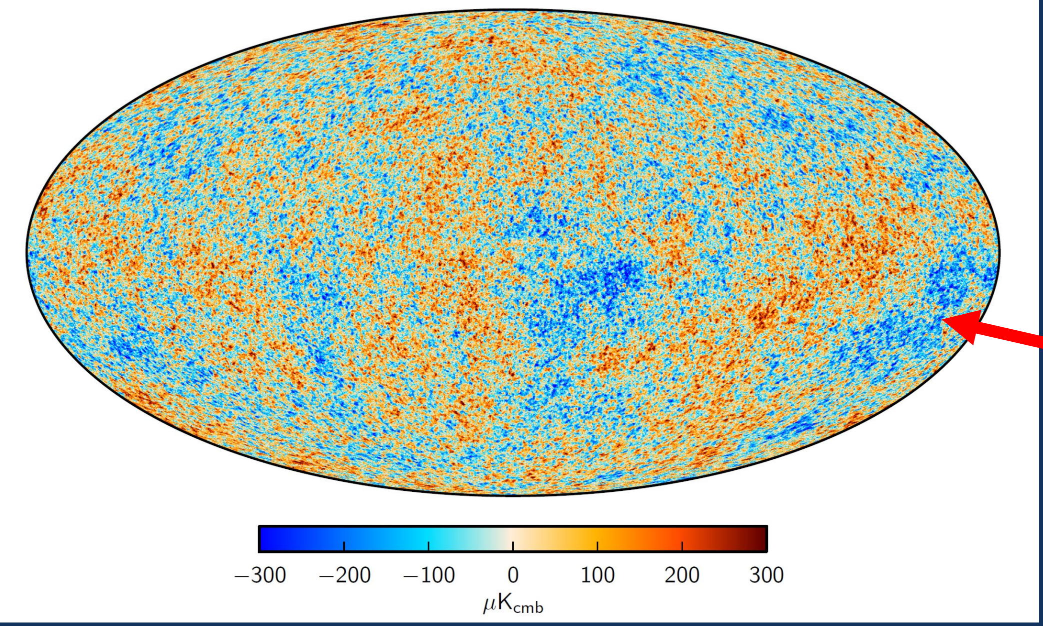




Nobel Prize 2015

Impact of Future Underground experiments



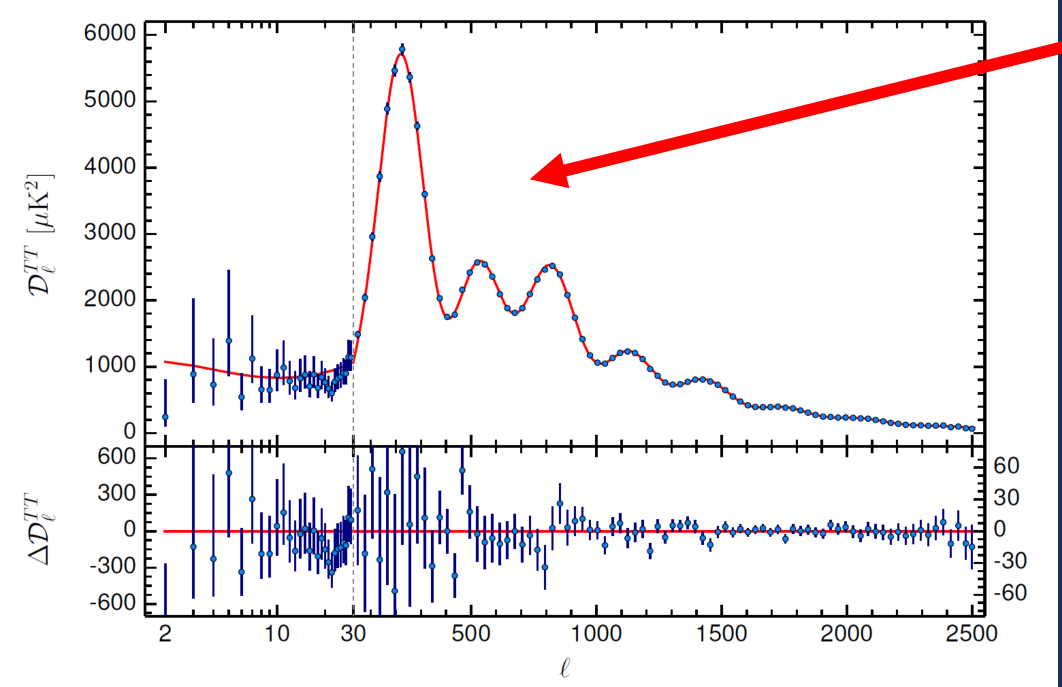


Measurements of the Cosmic Microwave Background by the Planck Satellite Mission 2015

Remarkable measurements of light at 2 degrees above absolute zero. These small variations (1 part in 100000) grow to form our universe (Stars, Galaxies).

An amazing model (see fit on left) called:
Lambda Cold Dark Matter provides beautiful fits to this and other data such as the large scale structure of the Universe.

Only 6 parameters used, including the amounts of Matter, Dark Matter, Dark Energy and other parameters that affect how the Universe evolves.



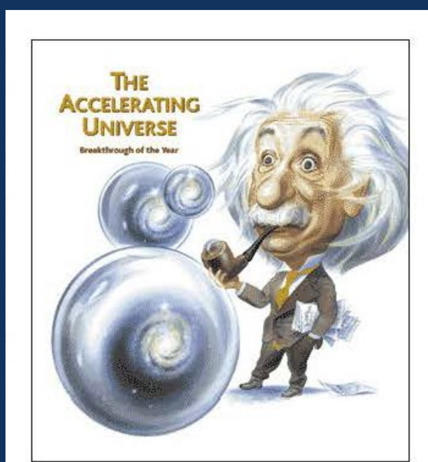
Nobel Prizes for Cosmology

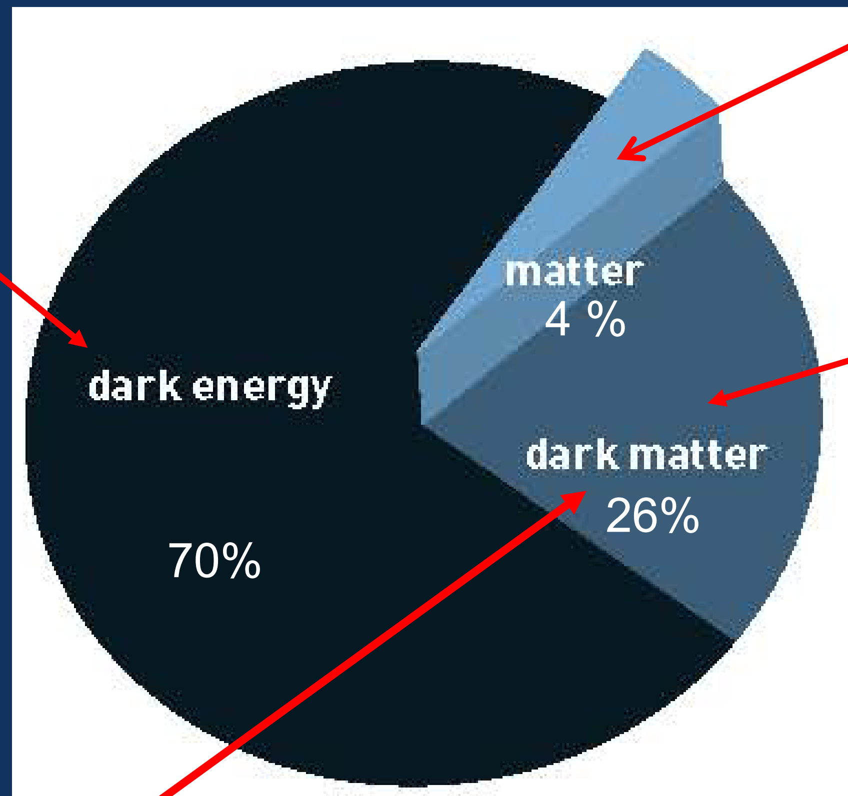
- **1978: Penzias and Wilson – Arno Allan Penzias and Robert Woodrow Wilson "for their discovery of cosmic microwave background radiation"**
- **2006: Mather and Smoot – "for their discovery of the blackbody form and anisotropy of the cosmic microwave background radiation"**
- **2011: Perlmutter, Schmidt and Riess - "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"**

Composition of the Universe as we understand it today

(Very different than 20 years ago thanks to very sensitive astronomical and astrophysical experiments such as measurements of the cosmic microwave background, large scale structure and distant supernovae.)

Responsible for accelerating the Universe's expansion





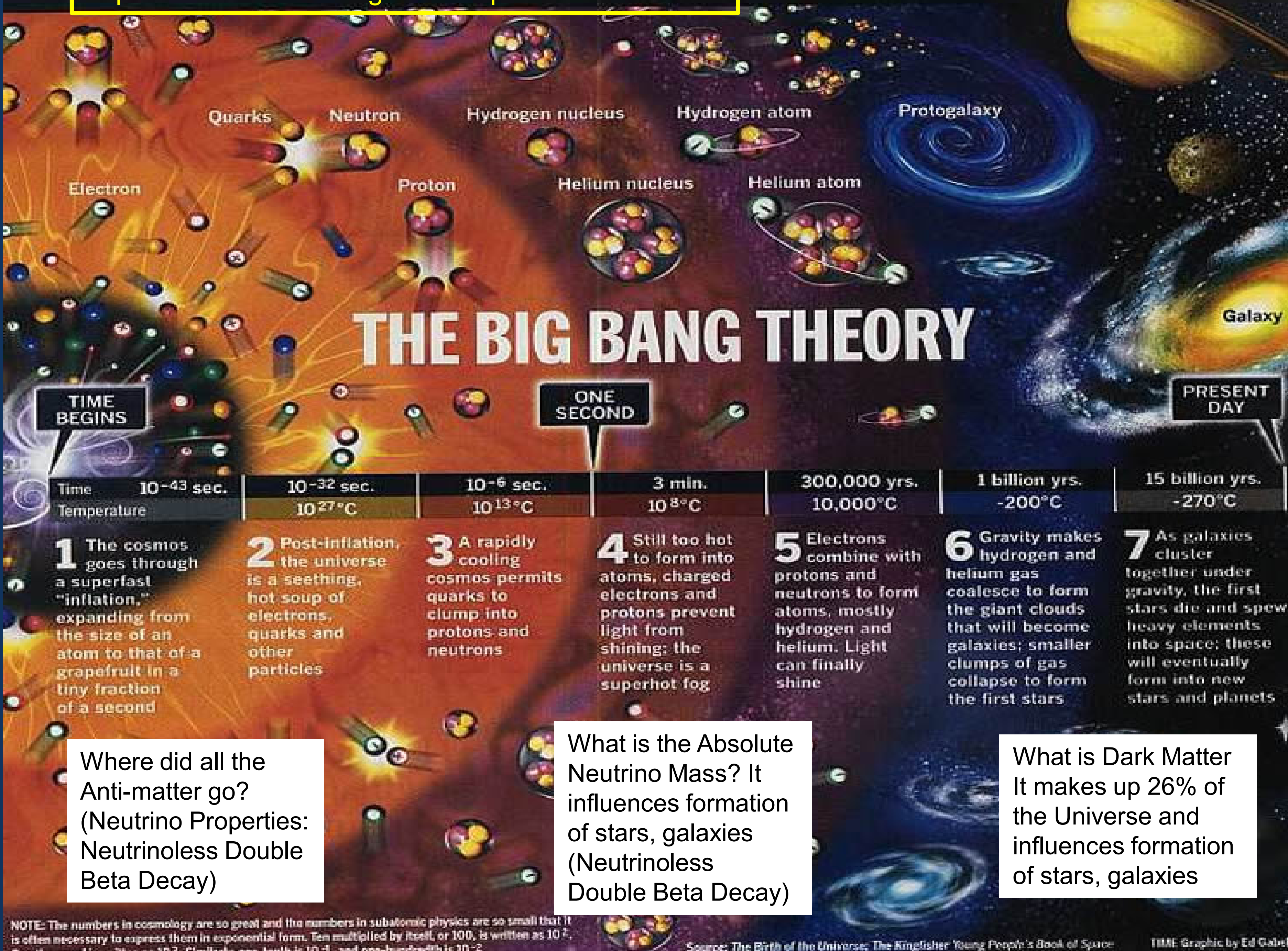
US!!!

Neutrinos Are only a few %

With underground labs we look for Dark Matter particles left from the Big Bang, with ultra-low radioactive background.

At CERN Accelerator: Try to create it for the first time since the Big Bang

Impact of Future Underground experiments



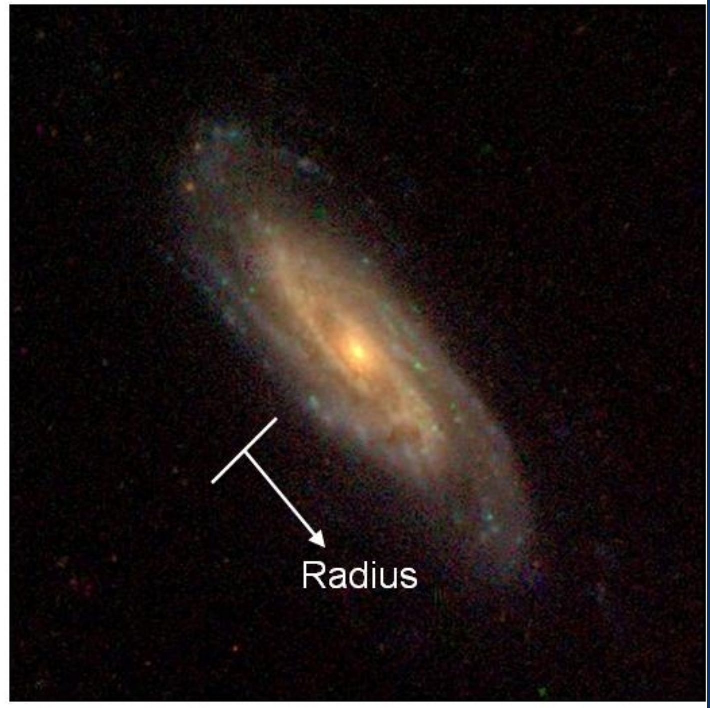
Where did all the Anti-matter go? (Neutrino Properties: Neutrinoless Double Beta Decay)

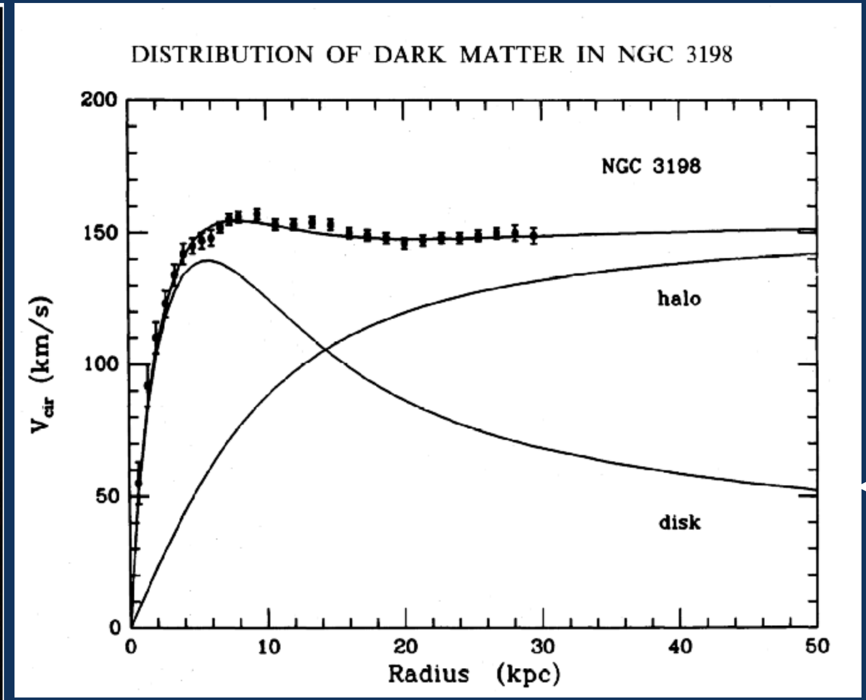
What is the Absolute Neutrino Mass? It influences formation of stars, galaxies (Neutrinoless Double Beta Decay)

What is Dark Matter It makes up 26% of the Universe and influences formation of stars, galaxies

The evidence for *dark matter* is strong from astrophysics measurements:

For example: SPIRAL GALAXIES WOULD FLY APART IF THEY ARE COMPOSED OF ONLY THE GLOWING MATTER





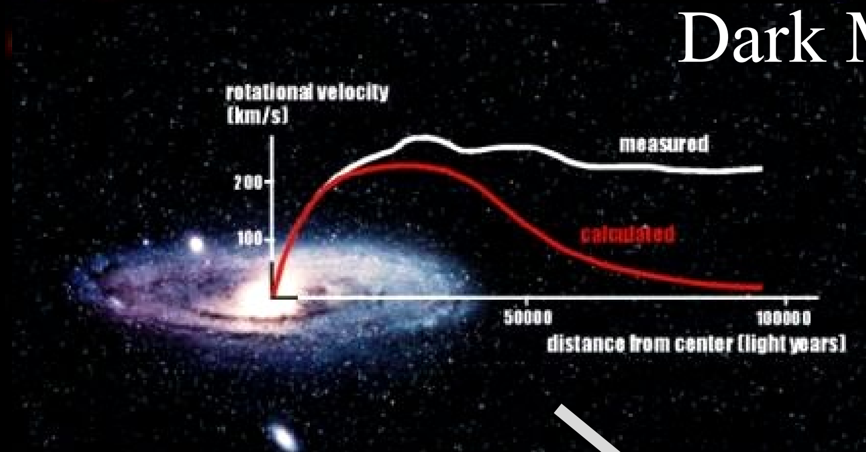
DARK MATTER: Weakly Interacting Massive Particles (WIMPS)

GLOWING MATTER

- **HOWEVER, WE DO NOT KNOW WHAT THE "WIMPS" ARE. THEY MUST BE STABLE ENOUGH TO SURVIVE 13 BILLION YEARS AND COULD BE SO MASSIVE THAT THE HIGHEST ENERGY ACCELERATORS HAVE NOT PRODUCED THEM YET.**

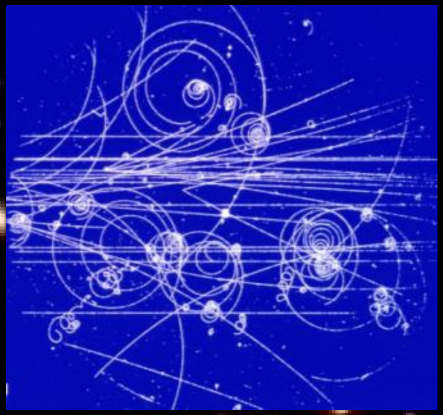
- **WE WILL LOOK FOR THEM STRIKING OUR DETECTORS PRODUCING LIGHT.**

Dark Matter



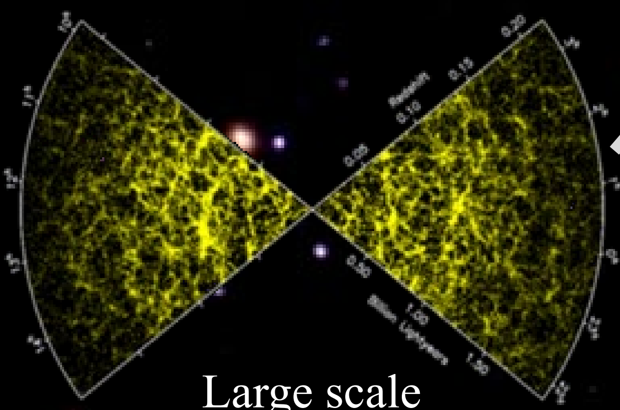
Here, but not yet observed directly in nature: **Weakly interacting**

Not yet observed in accelerator experiments: **Massive**



WIMP

(Weakly Interacting Massive Particle)



Large scale structure of the Universe: **Slowly moving ('cold')**

Interaction with ordinary matter: **Nuclear Recoils** (most backgrounds: electron recoils)

Predicted by SUSY: **Neutralino**
Universal extra dimensions: **Kaluza-Klein particles**

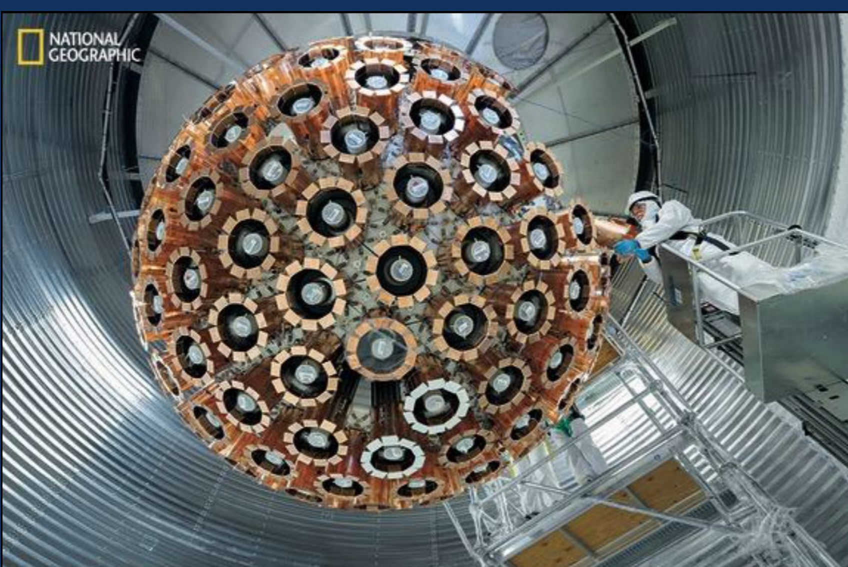
Dark Matter Detectors based on Liquid Argon

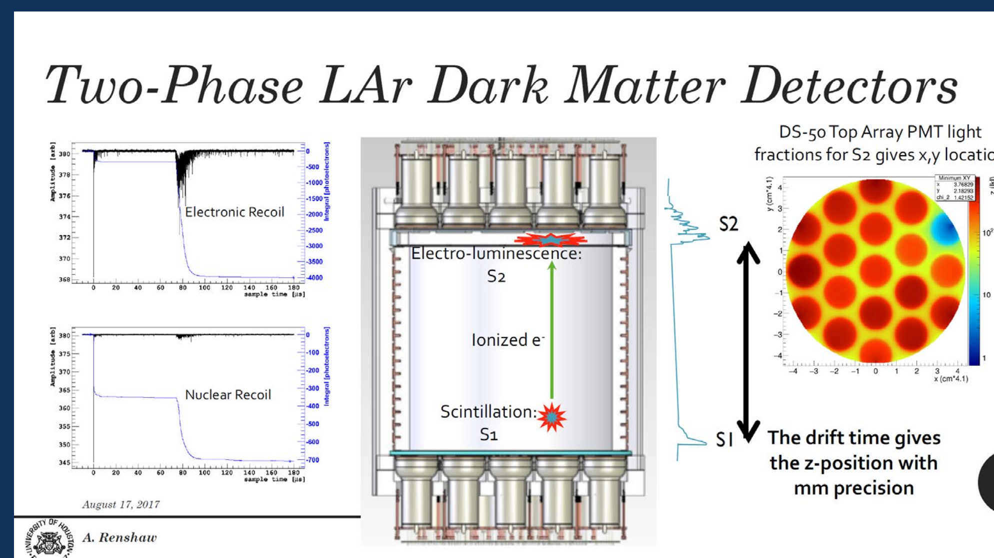
- **Dark Matter particles** penetrate through the rock above and strike Argon Nuclei making them recoil and emit light in **10 nanoseconds.**
- **Radioactivity** from local surroundings causes ionization of the argon and light emission over **10 microseconds**.

- These are easily distinguished by digitizing the pulses.

DEAP- 3600
SNOLAB

Darkside-50 and Future Darkside 20k
Gran Sasso





Global Argon Dark Matter Collaboration

Towards global argon collaboration:
DarkSide, DEAP, miniCLEAN, ArDM > 350 researchers

- 68 institutes
- 350 researchers
- Strong assistance from CERN
- 13 nations:

Brazil, Canada, China, France, Greece, Italy, Mexico, Poland, Romania, Spain, Switzerland, UK, USA

Sequence of experiments:

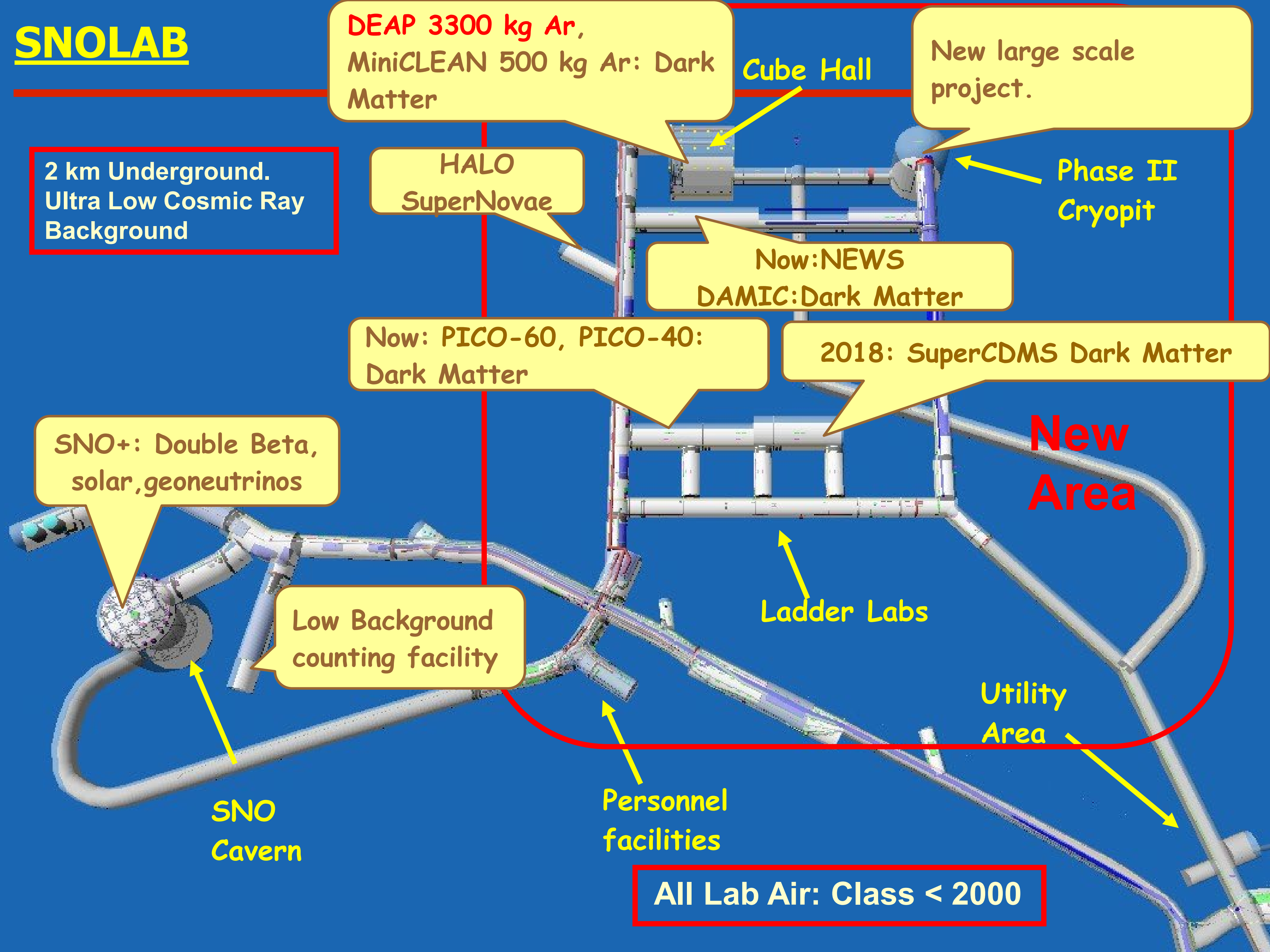
- DEAP: 3 tonnes
- DarkSide 20K: 20 tonnes
- Argo: 300 tonnes to reach the "Neutrino Floor"

Letter of support from Gran Sasso, SNOLAB, CanFranc Laboratory Directors

IMPROVEMENTS IN TECHNOLOGY FROM THESE EXPERIMENTS

- **Neutrino and Dark Matter experiments, like all particle physics experiments are continually developing new technologies.**
  - **Light detection devices such as photomultipliers and now Silicon photomultipliers are essential parts of radiation detection for nuclear medicine.**
  - **Silicon photomultipliers, together with liquid Xenon and Argon gamma ray detectors can lead to significant improvements in Positron Emission Tomography (PET) scanners – better resolution, lowering of the required dosage. (Patent Submitted)**

SNOLAB

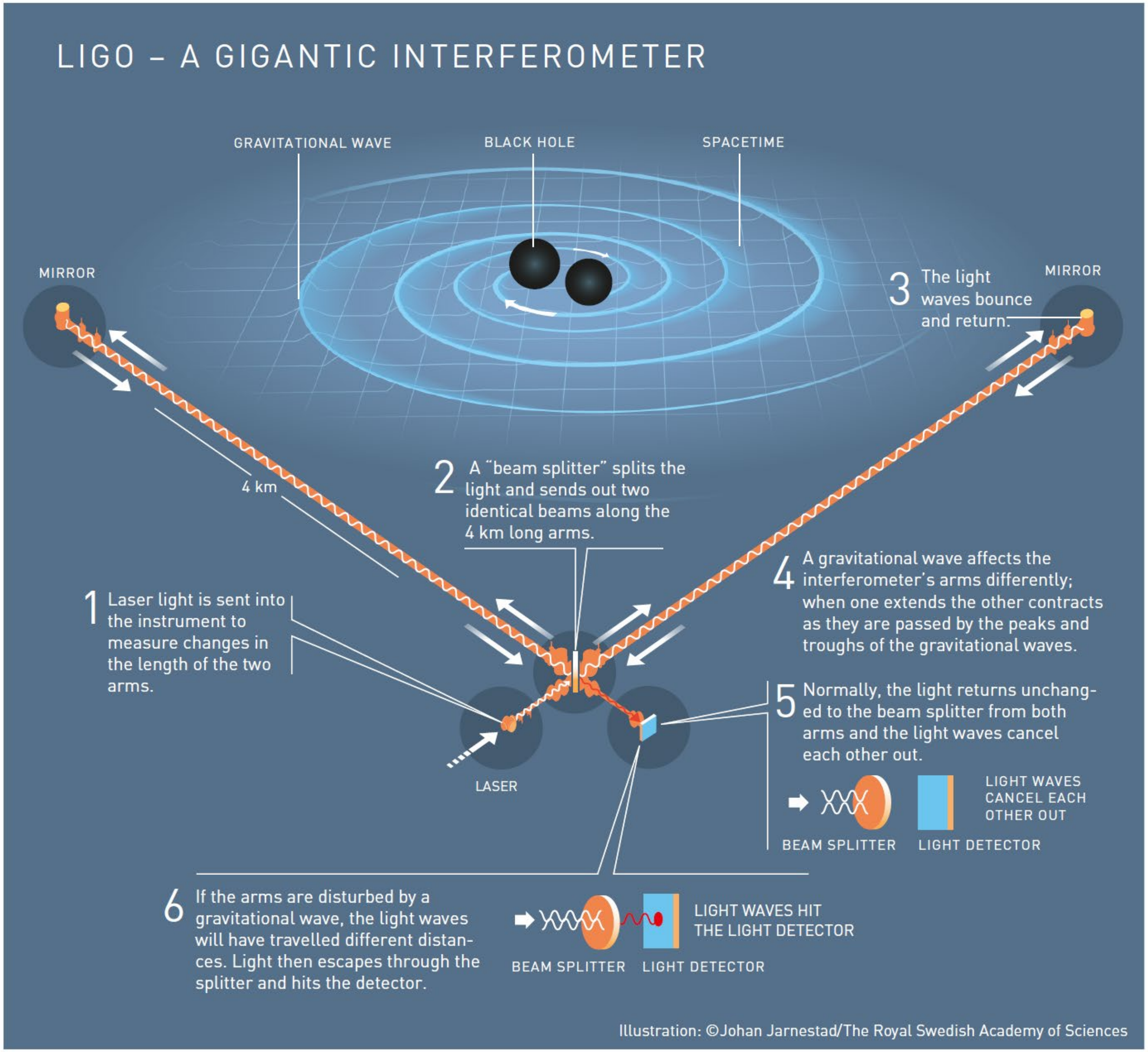


2 km Underground.
Ultra Low Cosmic Ray Background
DEAP 3300 kg Ar, MiniCLEAN 500 kg Ar: Dark Matter
Cube Hall
New large scale project.
Phase II Cryopit
HALO SuperNovae
Now:NEWS DAMIC:Dark Matter
Now: PICO-60, PICO-40: Dark Matter
2018: SuperCDMS Dark Matter
New Area
SNO+: Double Beta, solar,geoneutrinos
Low Background counting facility
Ladder Labs
Utility Area
SNO Cavern
Personnel facilities
All Lab Air: Class < 2000

SNOLAB Experimental Area

Stephen Hawking and fans observing the CRYOPIT area in September 2012

Gravitational Waves



GRAVITATIONAL WAVES FROM COLLIDING BLACK HOLES

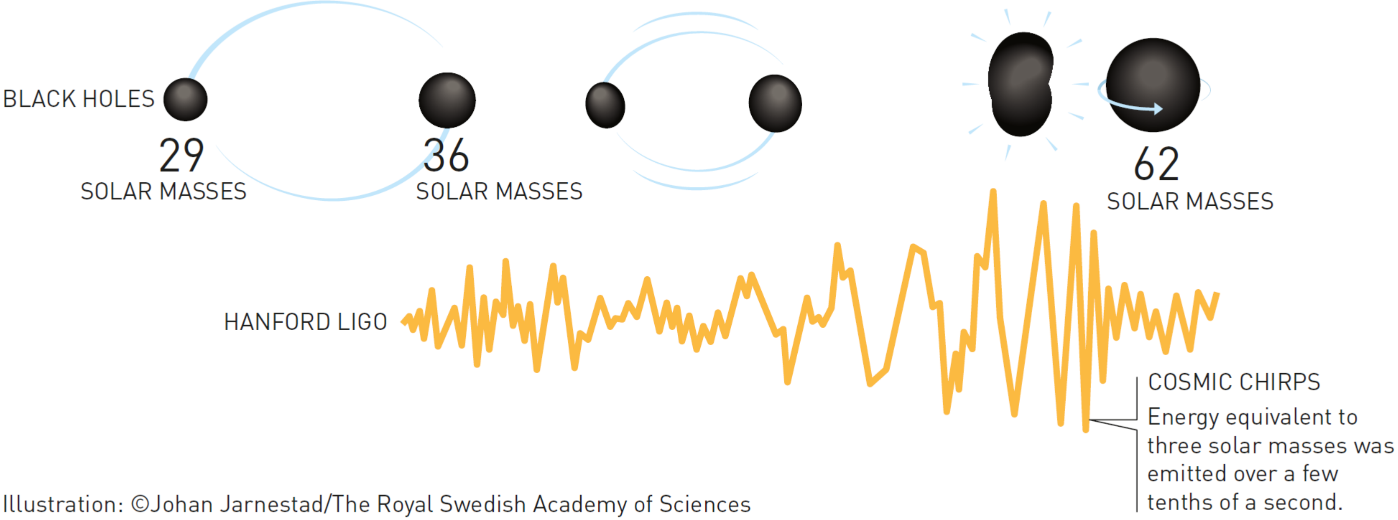
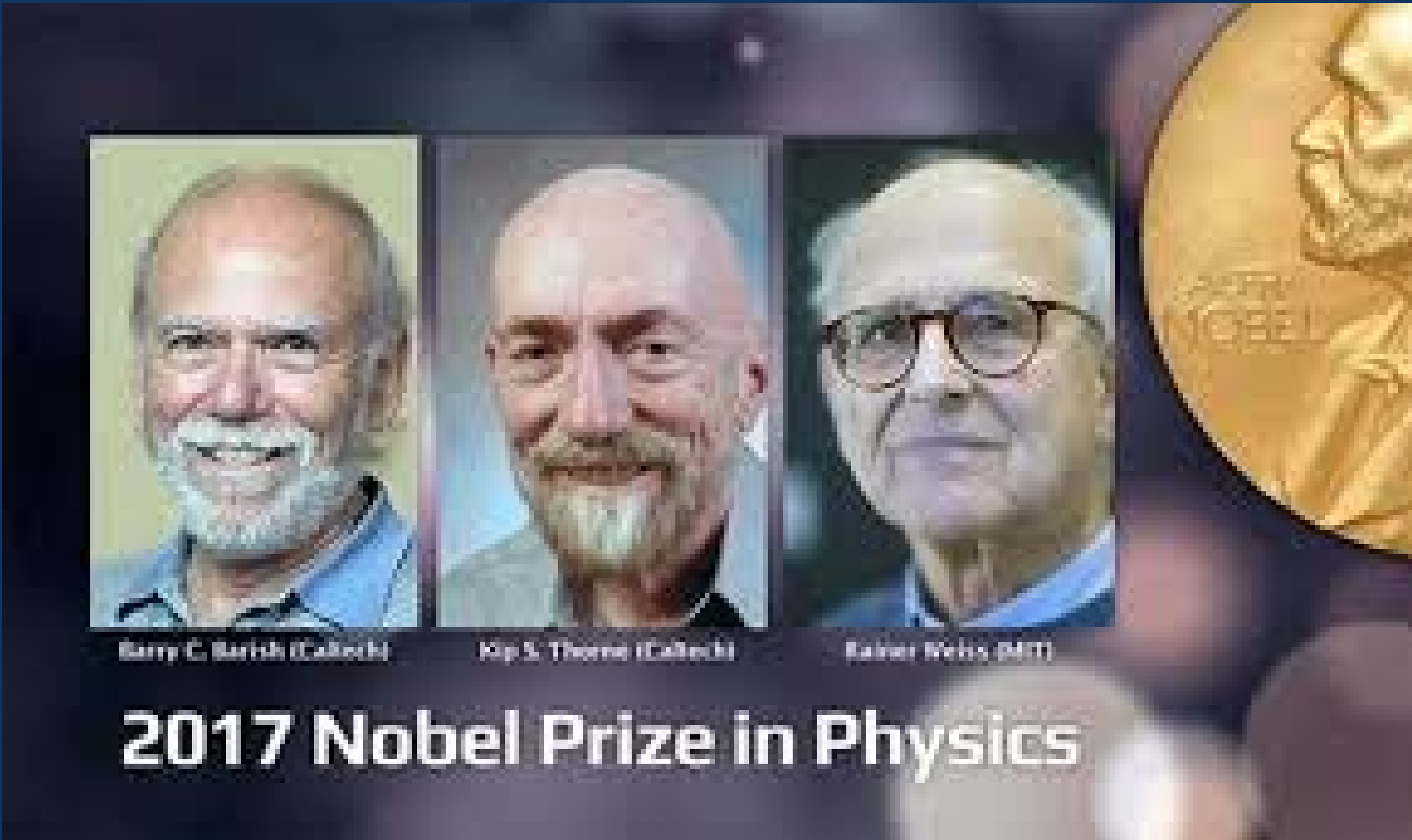


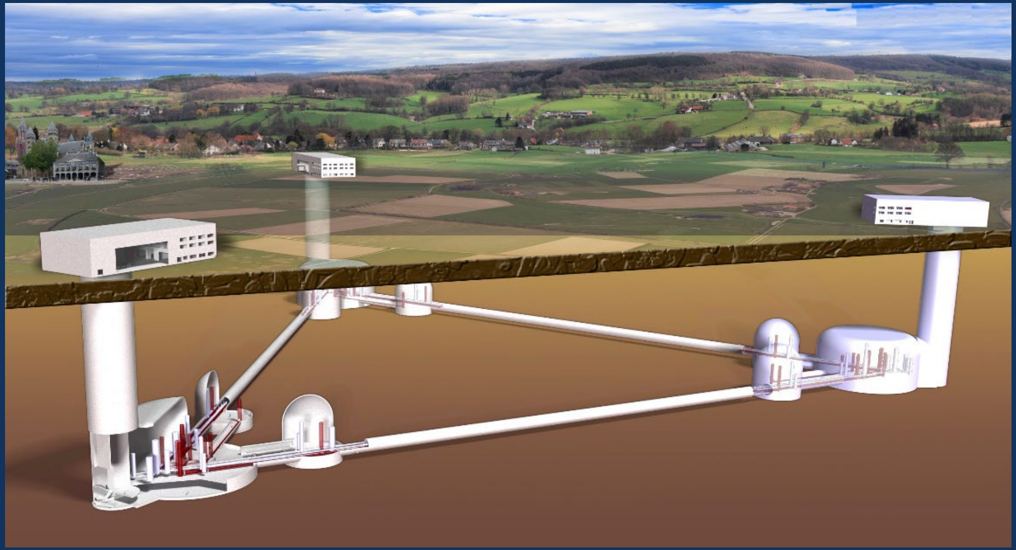
Illustration: ©Johan Jarnestad/The Royal Swedish Academy of Sciences


Barry C. Barish (Caltech)
Kip S. Thorne (Caltech)
Rainer Weiss (MIT)
2017 Nobel Prize in Physics

Gravitational Wave projects at AstroCeNT

- **VIRGO**

- **Einstein Telescope**



An entirely new opportunity for Astronomical measurements, Just opening up for the future: Multi-Messenger Astronomy

ASTROCENT has a Bright future ahead.

We are looking forward to very fruitful collaborations with:

- The Global Argon Dark Matter Collaboration
- INFN LABORATORI NAZIONALI DEL GRAN SASSO
- LSC LABORATORIO SUBTERRANEO DE CANFRANC
  CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY
- SNOLAB MINING FOR KNOWLEDGE
  CREUSER POUR TROUVER... L'EXCELLENCE
- McDonald Institute