The Importance of Ultra Low Temperature Research - An Interview with Dr. Zuyu Zhao

Interview conducted by Beth Ellison

Dr. Zuyu Zhao, Executive Vice President and Principle Scientist at Janis Research, talks to AZoM about the importance of Ultra Low Temperature research and its use in cosmology.

BE: How low do temperatures have to be to be classed as ultra low?

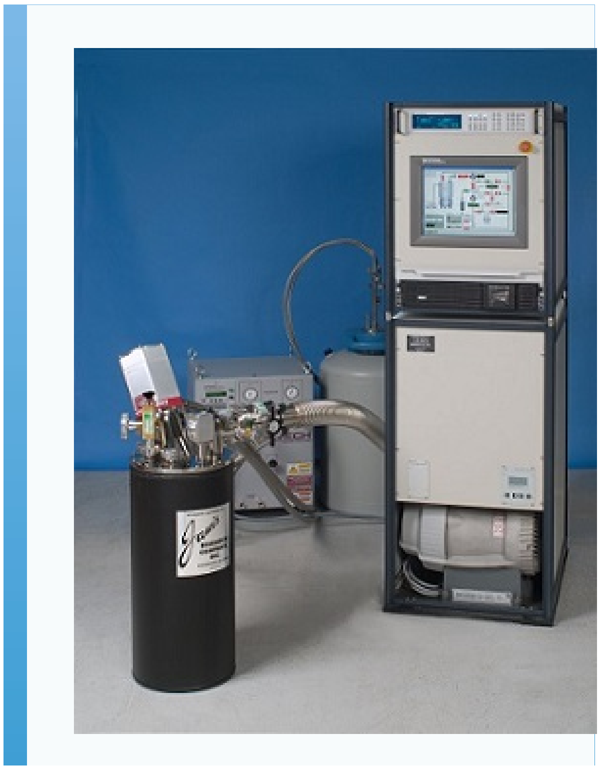
ZZ: There is no international definition for Ultra Low temperatures, but people generally seem to agree that the temperatures must be below one kelvin, whereas cryogenics involves a much wider range of temperatures from -150 °C or 123 K down to absolute zero.

BE: Why is Ultra Low Temperature research important?

ZZ: Ultra Low Temperatures are needed for more reasons than I can imagine. Firstly, a lot of physics phenomenon and properties will not happen above that temperature. For example, liquid He-3 becomes superfluid around 2.44 mK near 34 bar pressure, and we have many examples of new materials, phases and physics phenomenon that only take place below 1 Kelvin.

The second reason is noise. For all substances, atoms keep moving even at zero temperature (called Zero Point Motion). Because they move, they have some thermal energy, which is equal to KT, where K is the Boltzmann constant and T is the temperature in Kelvin.

KT measures the thermal energy of the particle at a certain temperature. The higher the temperature, the more energy, or the more actively the particle is moving. Because of the way that the measurement is carried out, a signal is generated called the thermal noise signal. This is something you don't want to see – it interferes with the real signal which is often very small.



There is a physical property called the 'Signal to Noise Ratio', which is the ratio of the real signal versus noise signal. Normally, if the ratio is 100:1 it will be considered to be very good, but if the ratio is 1:1, it's not good at all and you cannot see a signal. So, you can see that the lower the temperature you have, the less the thermal noise signal, the better the signal to noise ratio. These are the two most basic reasons why people need Ultra Low Temperatures.

Third of all, people are more and more interested in researches in the "quantum regime", or in the "ground state" of material, i.e. the "physical" energy "E" of the material is comparable to the thermal energy "$K_B T$". Since most of the "E" is normally very small, the only way to achieve "quantum regime" is to lower the temperature.

BE: How are these Ultra Low Temperatures reached?

Janis' Dilution Fridge at ACTPol

ZZ: There are four main methods for most general researches. To reach 0.3 K and above, we can use Helium-3 cryostat. To reach 50 mK and above, we can use the Paramagnetic Adiabatic Demagnetization Refrigerator, known as a PADR, or just ADR. To reach 10 mK and up, you can use the dilution refrigerator systems.

To reach 1.0 mK or lower, you need a Nuclear Adiabatic Demagnetization Refrigerator, or NADR. These approaches are most frequently used in laboratories for “general” researches because they have relatively large cooling power, and a relatively long cooling time.

There are also a few other approaches for reaching these temperatures and much lower, right down to the nanokelvin range. However, these methods aren’t appropriate for normal lab experiments, such as measuring resistance, because they offer very little cooling power, or they are designed for specific experiments.

One example is laser cooling on atoms, where laser light absorbed by a moving atom cancels out the momentum so that it almost still and at a very low temperature of a few nanokelvin.

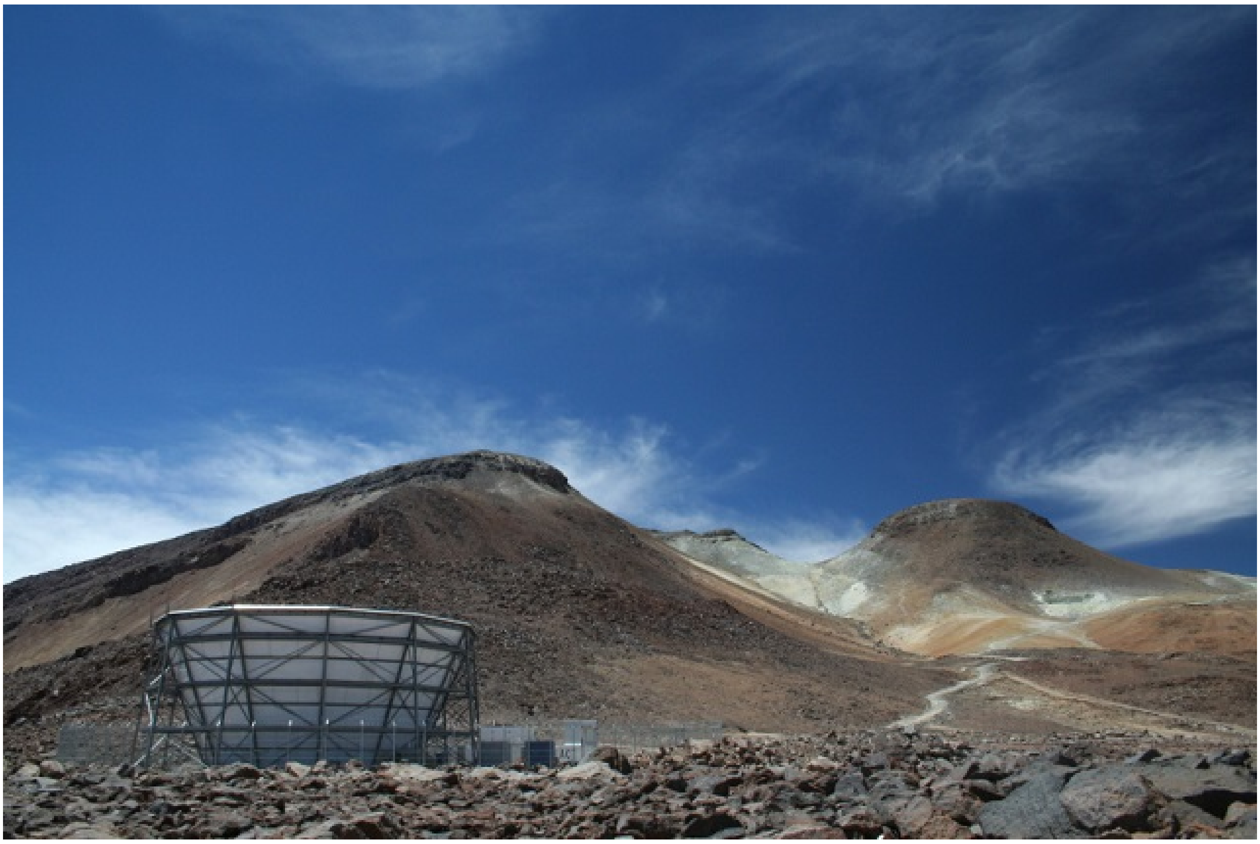
Another method is evaporative cooling, which usually uses a “magnetic trap”. These approaches can only be applied in certain physics experiments.

BE: Why are Ultra Low Temperatures used in scanning tunnelling microscopy (STM)?

ZZ: Scanning Tunnelling Microscopy is used in material or surface science. A voltage is applied between the STM tip and the sample, and some electrons pass over the gap via tunnelling, which is a quantum phenomenon.

You can imagine how weak the signal is – you just apply a few volts between a tip and the sample. The resolution is in the atomic range, so you cannot afford to have any large noise, either from mechanical vibration or from the thermal motion. For this reason, it is beneficial to use Ultra Low Temperatures.

There are lots of room temperature STMs, and they can do a lot of things, but the applications are limited. When I joined Janis in 1993, we were approached to develop the 0.3 Kelvin STM, and nowadays, people approach Janis for a 10 milliKelvin STM.



The Atacama Telescope, Chile
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BE: How are Ultra Low Temperatures used in Cosmology?

ZZ: For cosmology, a device called the Atacama Cosmology Telescope Polarimeter (ACTPol) has been developed.

It is an upgrade for the Atacama Cosmology Telescope that is polarization sensitive. It is located on Cerro Toco, Chile, at an elevation of 5190 m. In 2013, ACTPol achieved first light with one third of the final detector configuration.

The remaining two thirds of the detector array was installed during spring 2014, enabling full sensitivity, high resolution, observations at both 90 GHz and 150 GHz. ACTPol uses around three thosand transition-edge bolometers to produce measurements of polarization anisotropies on a small scale in the Cosmic Microwave Background.

ACTPol measurements will allow the scientists to probe the spectral index of inflation, as well as to constrain early dark energy and the sum of neutrino masses.

The information collected from ACTPoL will be used to study the universe, including its origin, etc.

Normally, this type of observatory would be built on top of a mountain and the system could not be operated year round, so the operation cost is very high.

All previous systems for this application were operated in so-called “single-shot” mode, i.e. the system has a certain “life time” to hold the low temperatures needed. The user has to re-energize the system once the “holding time” expired, which limits the efficiency.

It is highly desirable to develop a continuously operated system for this type of application, although it is challenging due to the operation conditions at the top of the high mountains.

To counter this, Janis developed the dilution fridge which can be put at the top of the mountain and can take data 24 hours a day. It has been there for a few years and it is still working. This is the first continuously operating ultra low temperature facility in the world.

BE: What equipment does Janis supply for reaching ultra low temperatures?

We have the Helium-3 cryostats and the dilution refrigerators as our standard products. For the time being, we are not offering nuclear NADR, but we are working with a customer to supply this, where we are responsible for pre-cooling to temperatures of 10 mK, before they reduce it down to 1 mK.

BE: What developments are expected in the near future?

ZZ: We have already finished a system to reach 0.3 K, and we’ve made quite a few 0.05 K Cryogen Free ADR systems. We are working with Penn State University on this, and we are involved in producing a Cryogen Free Dilution Refrigerator, which will be able to be continuously operated and will reach 0.03 Kelvin**,** or maybe even lower. This is different to cryogen free ADR, which is single shot, and cannot be continuously operated.

BE: So why is it important to use cryogen free systems?

ZZ: Liquid helium-4 is expensive. Nowadays, we pay $18 per litre. When I was a student, I paid $1 per litre, and when I joined Janis in 1993, it was $9 per litre. The U.S. is the only country that has abundant resource of Helium gas in the ground, so people just use it and let it go. But in other countries, they have a recovery system as they are not allowed to release it, and they have to import it from the U.S. either as liquid or a gas they can liquefy.

Now, the U.S. government have realized that reserves of helium are running out, and, like oil, you cannot create Helium gas once is has been used up. This is why we are beginning to use alternative, cryogen free approaches to cool down systems.

About Dr. Zuyu Zhao

Dr. Zuyu Zhao received his B.S. degree from Fudan University in 1982. He came to the United States in 1983 with the World Bank Scholarship program, and graduated from Northwestern University with a Ph.D. degree of Physics in 1990. He then spent two and a half years working at Harvard University as a post-doc, and set up a new lab pursuing Bose-Einstein condensation on spin polarized hydrogen.

Dr. Zhao was appointed as Harvard Affiliate for 5 years after he left and joined Janis.

Dr. Zhao joined Janis Research Company in 1993 and focused on developing custom ultra-low temperature facilities for the research and science community. He currently serves on the Board of Directors, and is Executive Vice President and Principal Scientist of the company, as well as the Director of the Janis ULT group.

Dr. Zhao has also served as Advisory Committee Member for AIP Physics Today and as an AIP Corporate Associate Advisory Committee Member.

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Company Background

Since 1961 Janis Research Company has been providing the scientific and technical community with the highest-quality cryogenic equipment for research, characterization, and industrial applications.

Over the years, the company’s list of customers has grown to include some of the world's largest corporations and best-known research centers and institutions. The reasons for this record of success are simple: precision engineering and quality manufacturing; ease-of-operation; day-after-day reliability and performance; and a level of service and support unmatched in the industry.

For more information on Janis Research, please refer to the respective sections of the company’s website.