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研究課題名（和文）超新星爆発によるニュートリノ信号と重力波信号の相関の研究

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研究成果の概要（和文）：超新星爆発は宇宙で最も劇的で重要な出来事である。本研究は超新星爆発によるニュートリノと重力波の相関の研究であり、調査研究のために開発された200トンガドリニウム水チェレンコフ検出器 EGADSを最先端の超新星ニュートリノ検出器への改造を目的とした。2015年4月には0.2%硫酸ガドリニウムを添加し、新たな電子回路および計算機を搭載し、世界初の高い効率で中性子捕獲が可能な水チェレンコフ検出器として運用を開始した。加えて、近傍超新星が発生した時にニュートリノと重力波の信号相関の予測に関する研究を行った。

研究成果の概要（英文）：Core collapse supernova explosions are among the most dramatic and important events to take place in the universe. This research is a study of the correlation between neutrino and gravitational wave by supernova explosion, and aimed at developing the world's most advanced-technology supernova neutrino detector. In April 2015, the EGADS detector has been full of water enriched with 0.2% gadolinium sulfate, equipped with new electronic circuits and computers, and began operation as a water Cherenkov detector capable of neutron capture with high efficiency. In addition, we studied the prediction of signal correlation of neutrino and gravitational wave when neighboring supernovae occurred.

研究分野：天体素粒子物理

キーワード：宇宙線　重力波　超新星爆発　ニュートリノ　ガドリニウム

１．研究開始当初の背景

The detection of a handful of neutrinos from Supernova 1987A on February 23rd, 1987, by the Kamiokande and IMB experiments was a pivotal moment in the history of both particle physics and astronomy. For the first time, a distant stellar event had been recorded – on opposite sides of the planet, yet - using an entirely new messenger; not by sensing visible light or one of its relatives in the electromagnetic spectrum, but rather via the observation of a burst of purely subatomic particles. These neutrino measurements served to confirm the basic theory of supernova explosions and nucleosynthesis, as well as to constrain a number of key parameters regarding the neutrinos themselves (lifetime, mass, speed of travel vs. light, etc.). It was the birth of neutrino astronomy, and for this work Koshiba-sensei famously received the 2002 Nobel Prize in physics.

We now stand at the threshold of another new era in astronomy.

When we began this grant, gravitational waves - though widely expected to exist as part of Einstein's Theory of General Relativity - had not yet been observed. Supernova neutrinos had only been seen once, during the famous supernova in 1987. The detectors in operation at the start of this grant, both for neutrinos and gravitational waves, were both becoming so sensitive that remarkable discoveries were surely right around the corner.
And indeed, during the term of the grant gravitational waves were seen experimentally for the very first time.

This was the dawn of a new era in astrophysics; the era of true multi-messenger studies had arrived.

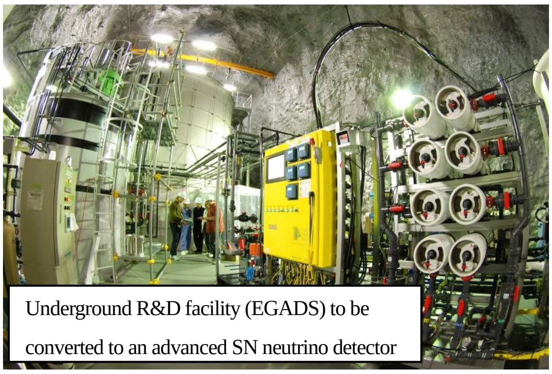
２．研究の目的

Out of all these supernova messengers, only gravitational waves and neutrinos are certain to travel through any obscuring dust or gas and remain undiminished upon their arrival at Earth. They are also the only types of radiation released during the stellar collapse itself. The electromagnetic signals typically are made (and arrive at Earth) hours later, as they are generated by the sub-lightspeed shockwave impinging on the dying star's stellar atmosphere well after the explosion is over.
Therefore, to look deep inside the exploding star itself and get the most complete picture of this once-in-a-lifetime event, it will be necessary to combine neutrino and gravitational wave information in particular. We must be ready to receive these messengers when they arrive.

３．研究の方法

We proposed to enhance the capabilities and readiness of our neutrino detectors such that they will extract the maximum possible amount of information from the next supernova explosion, no matter where in our galactic neighborhood it takes place. Specifically, to cover the volume of local space which the first operational phases of the new GW detectors will probe, we converted an existing large-scale R&D facility – originally designed to test gadolinium loading of water Cherenkov (WC) detectors - into the world's most advanced-technology supernova neutrino detector. It was to be capable of real-time tagging and identification of individual supernova neutrino interactions withnanosecond-scale time resolution. It will be available for coincident
detection during the early phases of GW commissioning expected to take place during the coming years.

While a modest 200 tons in size, this new advanced-technology
supernova neutrino detector will be well-matched to record nearby galactic explosions in their entirety. The expected number of detected SN neutrinos scales as follows: 37 events @ 30,000 light-years (ly), 3690 events @ 3,000 ly, and 369,000 events @ 300 ly.



Underground R&D facility (EGADS) to be converted to an advanced SN neutrino detector

Once this new advanced technology has been demonstrated in the 200 ton detector, it will then be available for use in existing and future generations of large WC supernova neutrino detectors like Super-Kamiokande and Hyper-Kamiokande. From Betelgeuse to Andromeda, very close to very distant explosions, we will be ready to add our crucial neutrino data to the multi-messenger supernova picture.

４．研究成果

The EGADS (Evaluating Gadolinium's Action on Detector Systems) laboratory is located one kilometer underground in the Mozumi mine in northern Gifu-ken, near the Super-Kamiokande neutrino detector. Originally designed as an R&D test bed for studying the effects of dissolving gadolinium (Gd) salts in a water Cherenkov detector (Gd makes neutrons visible, which has many potential physics benefits), the purpose of this Kakenhi was to convert EGADS into the world's most advanced supernova neutrino detector.

This ambitious goal has been achieved.

Since April 2015, the 200-ton EGADS detector has been full of water enriched with 0.2% gadolinium sulfate by mass. Once the detector itself was operating at peak efficiency, it was time to make sure the DAQ and data pipeline were equally capable. We performed a complete upgrade of the front-end electronics. To accomplish this, new, deadtime-less, zero-energy-threshold readout boards (known as QBEE's) for all 240 photomultiplier tubes in EGADS were installed.

We then added a custom-made 56-core realtime computer to receive and analyze every byte of data (include all PMT dark noise and radioactively induced backgrounds) as it is collected. It filters the data in real time, and is capable of immediately identifying a supernova signal as genuine thanks to the dissolved gadolinium, which acts like an amplifier for these signals.

By the conclusion of the grant we unquestionably had the most advanced supernova neutrino detector in the world; EGADS now stands for Employing Gadolinium to Autonomously Detect Supernovas. This high technology detector is specifically suited for near-field supernova explosions and coincident GW detection, and is a pioneer in the new era of multimessenger astronomy.

５．主な発表論文等
（研究代表者、研究分担者及び連携研究者には下線）

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６．研究組織

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