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CYGNUS

**Kentaro Miuchi¹, Elisabetta Baracchini^{2,3,4}, Gregory Lane⁵,
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¹ Department of Physics, Graduate School of Science, Kobe University, 1-1 Rokkodai-cho, Nada-ku, Kobe, Hyogo, 657-8501, Japan

² Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, I-00040, Italy

³ Istituto Nazionale di Fisica Nucleare, Sezione di Roma, I-00185, Italy

⁴ Department of Astroparticle Physics, Gran Sasso Science Institute, L'Aquila, I-67100, Italy

⁵ (please update) Australian National University, Australian Capital Territory, Canberra, 0200, Australia

⁶ Department of Physics and Astronomy, University of Sheffield, Hounsfield Road, S3 7RH, Sheffield, United Kingdom

⁷ Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawaii 96822, USA

E-mail: miuchi@phys.sci.kobe-u.ac.jp

Abstract. Directional information in the direct dark matter searches is believed to be able providing a clear discovery of the galactic WIMP dark matter, together with a further potential to investigate the properties of the dark matter. CYGNUS is a concept to detect the galactic WIMP dark matter particles with directionality. In this paper, physics motivation and technological R&D status will be reviewed.

1. Introduction

Revealing the nature of the unknown gravitational source in the universe, or the dark matter, is one of the important problems in today's physics. Weakly Interacting Massive Particles (WIMPs) have been, and still are, one of the most motivated DM candidates, and a number of experimental efforts were carried out to search for WIMPs. Given the Earth's motion with respect to the Galactic halo an apparent WIMP wind is expected to be observable, coming from the Cygnus constellation. Directional information in the direct searches can therefore provide a correlation with an astrophysical source that offers an unique key for a positive, unambiguous identification of a DM [1].

Several groups have independently carried out R&Ds programs to develop detectors with directional sensitivity since 1990s [2, 3, 4]. In 2007, some of these independent groups started biannual workshops named "CYGNUS" and the community started to grow. After a couple of collaborative works on physics and technologies [5, 6, 7], the group made a next step forward as a CYGNUS "proto-collaboration" in 2016. We are currently working on a feasibility study on the WIMPs search and possible other galactic-source physic [8]. These studies are based on the experience of past and on-going activities [9, 10, 11, 12]. In this paper, physics motivation and technological R&D status will be reviewed.



2. Physics motivations of CYGNUS

The "CYGNUS" concept is shown in Figure 1. Milky Way Galaxy is surrounded by a dark matter halo and the Solar System is traveling through the halo at a speed of about 230 km/s. A typical halo model indicates that the dark matter particles are gravitationally trapped in the galaxy and randomly moves with a most probable velocity of 220 km/s. This relative movement creates an anisotropy in the incoming directions of the dark matter particles at Solar System. Given the apparent direction of the Solar System's motion towards the Cygnus constellation, an apparent WIMP wind coming from this is expected to be observable, with a change in direction of about 180° for every 12 sidereal hours due to Earth's axis orientation with respect to DM wind. Since the direction of Cygnus has a diurnal change and a phase changes in half a year's time, the signal is expected to show a very specific property which is different from any backgrounds originated from the detector components or rocks around. A very characteristic signature of a DM candidate can therefore be obtained with detectors sensitive to the direction of nuclear recoils induced by WIMP scattering.

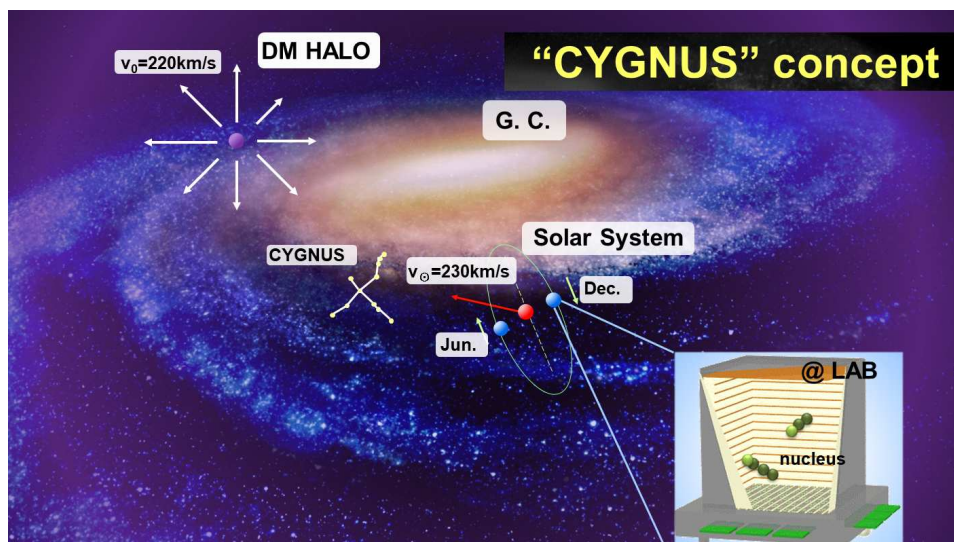


Figure 1. A schematic drawings of the concept of "CYGNUS". The relative movement of the Solar System with respect to the galactic halo creates an anisotropy in the incoming directions of dark matter particles, namely the direction of Cygnus constellation, at the Solar System.

The primary physics motivation of CYGNUS is to detect a WIMP signal with a directional detector. Although inherently challenging, gaseous TPCs constitute the natural approach to directional DM searches, thanks to their inherent 3D tracking capability and the possibility to measure dE/dx for sense determination and background discrimination. A preliminary study indicates that we need at least $O(10)$ m³ active gas volume at atmospheric pressure to investigate spin-dependent interactions below the ^8B neutrino floor of xenon nuclei using fluorine [8]. A larger detector with an optimized gas mixture and a dedicated readout system can enable us to go below the ^8B neutrino floor of fluorine. Once the WIMP signal is confirmed, the nature of the WIMPs can be precisely studied in terms of cosmology and particle physics. In this way the physics target of CYGNUS is widely extended beyond the discovery of the dark matter.

3. R&Ds in CYGNUS

The most recent technological breakthrough in this field is the discovery of so-called "minority carriers" in negative-ion drift gas [13]. The DRIFT group observed the presence of several species

of negative ions with different masses in CS₂ gas with a tiny addition of oxygen. Since anions mobility depends on the mass, the difference in time of arrival of different anions effectively provides a measurement of the absolute position of the event along the drift direction, that typically cannot be determined with self-triggering time-projection chambers. This feature allows to reject background events originating from the cathode plane, where most of the Radon progeny recoils reside. More recently, a safer gas, SF₆, has been identified to possess similar properties [18], attracting the attention of the community because of its high fraction of fluorine nuclei which is a good target for spin-dependent WIMP searches.

Many works on SF₆ as a dark matter detector gas have been performed so far. Some of the pioneering works are on the detector study with micro patterned gaseous detectors (MPGDs), such as gas electron multipliers (GEMs), micromegas, and micro pixel chambers (μ -PICs) [16, 17, 15]. One of the interesting finding was that thin GEMs ($\sim 50 \mu m$) work well with gas at low pressure (20-100 Torr), while thick ones ($\sim 400 \mu m$ and more) are required for higher pressure gas (100-400 Torr). Recently, gas purification study [18], readout electronics development [18, 19] and simulation works [20] are also being carried out.

In parallel, alternative gas mixtures with electron drift are been explored [21, 22, 23], that can allow for fiducialization via fit to the ionisation cloud diffusion, that can be performed only with very high granularity readout.

CYGNUS, as a collaboration, plans to build several detectors at multiple sites all over the world (See Figure 2). World-wide activities are ongoing and planned. UK group is leading a design of a low background a large detector with a volume of 10 m³. This study is based on the experience of developing and running the largest directional detector of 1 m³ in DRIFT collaboration. Japanese group developed a 1 m³ chamber which has 18 windows for several types of readout. The chamber is planned to be installed at Kamioka Observatory in early 2020. In parallel, it carried on several crucial low background studies for future detector development, for reduced intrinsic radioactivity of the readout and amplification plane [24] and the field cage [25]. The Italian group is focusing on GEMs amplification and optical readout via sCMOS cameras and PMT, with both electron drift and negative-ion drift options. A 1 m³ TPC is being developed and will be installed underground at Laboratori Nazionali di Frascati as a demonstrator of the potentialities and scalability of the optical approach. US CYGNUS members have developed pixel readout detectors since the early 2010s [26, 27] and are also testing strip read-out detectors which appear suitable for much larger target volumes. Australia community has recently started direct dark matter activities and now excavating an underground laboratory which should be ready in 2020.

4. Conclusions

CYGNUS is a concept to detect the galactic WIMP dark matter particles with directionality. CYGNUS plans to build several detectors at multiple sites all over the world. Feasibility study and detector R&Ds for a clear discovery and nature investigation of the WIMPs are on going.

Acknowledgments

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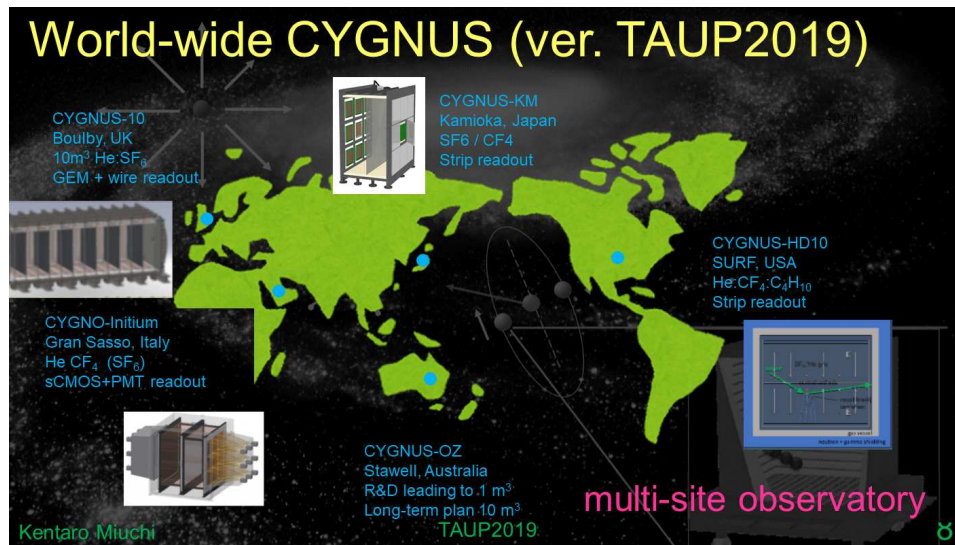


Figure 2. A world-wide CYGNUS activities.

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