Review of Direction-Sensitive Direct Dark Matter Search

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DarkOn 2017

Contents
Dark Matter Direct detection
Physics
Experiments
expected direct DM signals

- ① observed * events
- ② energy spectrum
- ③ seasonal modulation
- ④ material dependence
- ⑤ direction-sensitive
アイディアは1980年代から

Detection of Dark Matter Using Low Pressure Gas Detectors (TPC's)

G. Masek, K. Buckland, M. Mojaver

Physics Department, University of California, San Diego 92093

R&Dは1990年代から

Low Pressure Gaseous Detector for Particle Dark Matter

K. N. Buckland, M. J. Lehner, G. E. Masek, and M. Mojaver

Physics Department, University of California at San Diego, La Jolla, California 92093

(Received 22 March 1994; revised manuscript received 29 June 1994)

FIG. 1. A schematic view of the low pressure TPC and optical system.

FIG. 2. A false color CCD image resulting from a $^{252}$Cf neutron source. The colors black, blue, red, and white represent the order of increasing light intensity levels. The area displayed represents a 25 cm by 25 cm section of the detector plane. See the text for a description of image features.
Physics cases
Direction-Sensitive Dark Matter Search concept “CYGNUS”

WIMP-WIND from “CYGNUS”
“CYGNUS” concept

seasonal modulation (expected)

Clear Discovery
+ study the nature of DM after discovery
“CYGNUS” physics towards discovery

Potential to search beyond the “neutrino floor”†

† neutrino-nucleus coherent scattering
Size and Physics Reach

Physics Reports 627 (2016) 1–49


- オーダー 1m^3 ～ 0.1kg 程度
- 方向感度での必要事象数 10～100事象
“CYGNUS” physics after discovery

Test the DM motion
- ex. Sagittarius stream

Legend:
- GC
- Sagittarius stream
- SUN
- constellation “CYGNUS”

Our GALAXY

expected

standard HALO

standard HALO + stream

galactic coordinate

streams, halo model...
“CYGNUS” physics after discovery

Test the interaction by scattering angle

PHYSICAL REVIEW D 92, 023513 (2015)

some operators are distinguishable
“CYGNUS” physics after discovery

Test the interaction by scattering angle ②

iDM (inelastic scatterings dark matter) and normal dark matter (FFeDM (form factor elastic dark matter)) show different angular DISTRIBUTION
Experimental Status
Experimental concept

Recoil nuclear track detection < 100keV
challenge: short track
a few mm in low pressure gas
a few 100 nm in solid

Most typical “CYNGUS”: low pressure gas TPC

2D readout + timing → 3D tracking
DRIFT: pioneer of “CYGNUS” concept

- early 2000s ~
  - large TPC
  - low BG study

- 2mm pitch multi-wire proportional chamber
- not very direction-sensitive
Cygnus, gas TPCs

- MWPC (2mm pitch)
  - First started direction-sensitive method
  - Underground
  - Low background
  - Large size (1m³)

- μ-PIC (400μm pitch strip)
  - direction-sensitive limit
  - Underground

- optical (CCD) readout
  - quenching factor measurement

- Pixel readout (ATLAS FE-I4) chip
  - R&D in the surface lab

- DMTPC [US+UK]
  - 2cm
  - 10cm
  - 25cm
  - 1m

- D3 [Hawaii]
  - 10cm
  - 2cm

- MIMAC [France]
  - 1m
  - 10cm

- NEWAGE [Kobe+]
  - 30cm
  - 40cm

- DRIFT [UK+US]
議論：

gas: asymmetryは大きいが信号数は少ない

→ 固体や液体で何とかならない？
**Cygnus, others**

**NEWSdm**
- [Japan+Italy]
  - emulsion (20~50nm crystal)
  - good position resolution
  - large mass
  - No time resolution

**DeCANT**
- [Italy]
  - • Carbon nano tube
  - • large mass
  - • Proof of concept is ongoing

**ZnWO₄**
- [Italy, Japan]
  - • columnar recombination
  - • large mass
  - • need to confirm in low energy

**Liq Ar**
- [Italy, Japan]
  - • “anisotropic” scintillator
  - • large mass
  - • need to confirm in low energy

**α/β ratio**
- [R. Cerulli, INFN-LNAGS]

**Graphical Data**
- α/β ratio vs. energy of α particles (MeV)
- Scintillation yield vs. drift electric field [V/cm]

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**Gianluca Cavoto INFN Roma**
- IDM 2016
- 18th 22nd July 2016
- The University of Sheffield
“CYGNUS”

Concept to collaboration

2007 ~ biannual workshop

2007 Boulby

2009 Boston

2011 Aussois

2013 Toyama

2015 LA

2017

for 10th anniversary

2016 Sep –

proto-collaboration

4 WGs

NEWAGE/CYGNUS-Kamioka test chamber
The CYGNUS Galactic Directional Recoil Observatory Proto-Collaboration Agreement

Now that conventional WIMP dark matter searches are approaching the neutrino floor, there has been a resurgence of interest in the possibility of introducing recoil direction sensitivity into the field. Such directional sensitivity would offer the powerful prospect of reaching below this floor, introducing both the possibility of identifying a clear signature for dark matter particles in the galaxy below this level but also of exploiting observation of coherent neutrino scattering from the Sun and other sources with directional sensitivity. There has also been significant progress recently in development of technology able to record the directional information from nuclear recoils at low energy \((\text{sub}-100 \text{ keV})\) necessary for these goals. This includes progress on improving the sensitivity of low pressure gas time projection chamber technology but also on novel ideas with higher density targets, such as ultra-fine grain emulsions, scintillation materials, columnar recombination with noble gas targets and concepts using nano-technology. Such world-wide directional expertise, if pooled together and directed at converging on an optimised design, likely at multiple underground sites and different
We the undersigned agree to work together on the CYGNUS programme, noting that this does not automatically imply participation in the CYGNUS collaboration when that is formed.

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約40名（うち日本人22名）
**CYGNUS activities**

- steering committee (Spooner (英), Miuchi (日), Vahsen (米), Baracchini (伊), Barberio (豪))
- WGs’ chairs (occasional TV meetings)
  - gas (Miuchi)
  - simulation (Vahsen)
  - vessel (Spooner)
  - BG (Baracchini)
SUMMARY

- Direction sensitive dark-matter search
- Discovery and further investigation
- Many small size R&Ds are actively ongoing