Development of diamond detector for dark matter search

Atsuhiro UMEMOTO (QUP, Postdoc)

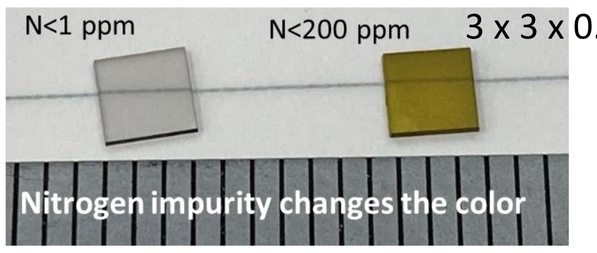
Diamond

unique physical properties make useful for a wide range of applications

- **highest Debye temperature among crystals ⇒ bolometer[1]**
- **small current leakage at RT and radiation hardness ⇒ semiconductor detector[2]**
- **presence of many color centers (caused by impurity or defect) ⇒ scintillator[3]**

(1) Eur. Phys. J. C 82, 851 (2022)
(2) C.S. Bodie, et al., NIM A (2021)
(3) A. Umemoto, et al., NIM A (2021)

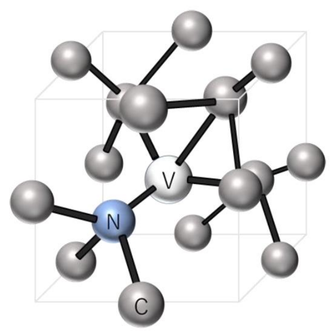
synthetic diamond substrate

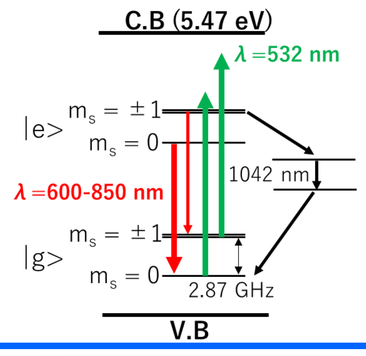


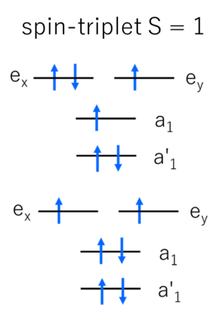
band gap	5.47 eV
density	3.52 g/cc
Baliga FOM	44000
Debye temperature	2250 K
e-h creation energy	13 eV

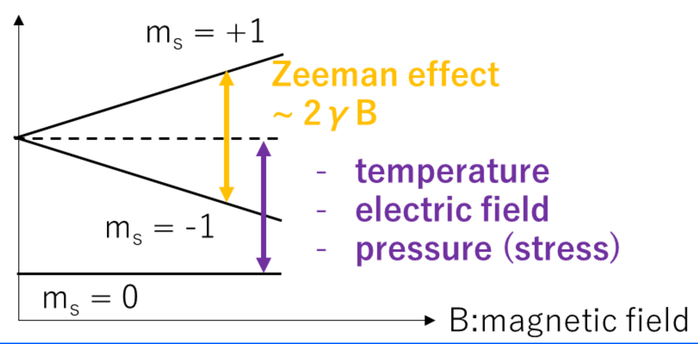
etc..

And quantum sensing using NV center enable particle detection with high resolution





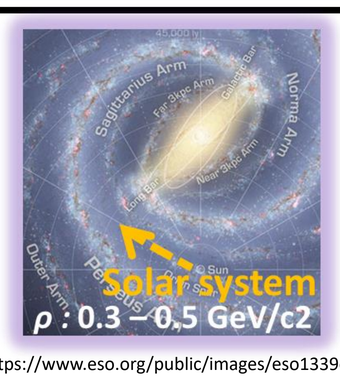




Dark matter

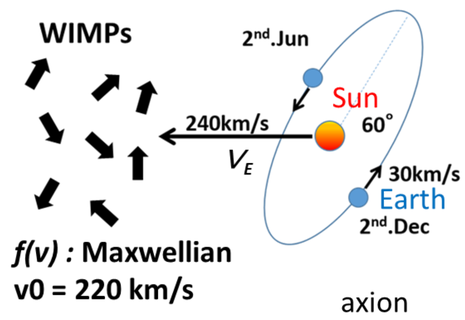
- longer decay life-time than the age of universe
- non-zero mass
- no electromagnetic charge
- and etc..

⇒ Beyond the standard model



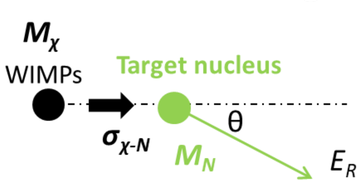
https://www.eso.org/public/images/eso1339e/

- WIMP search

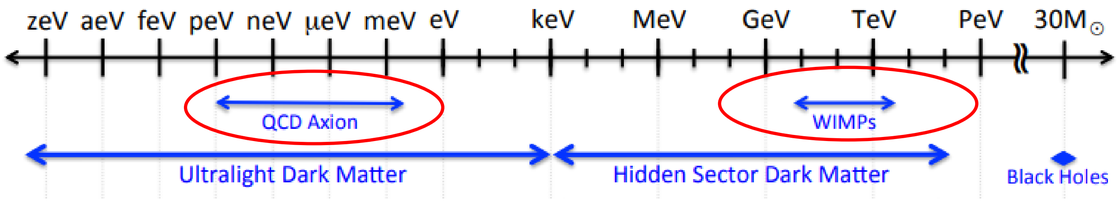


f(v) : Maxwellian
v0 = 220 km/s

recoil signals



Dark matter candidate (huge discovery space)



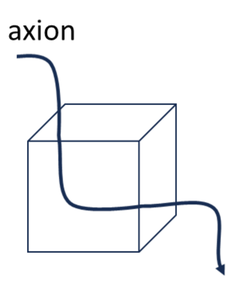
US Cosmic Visions: New Ideas in Dark Matter 2017 : Community Report

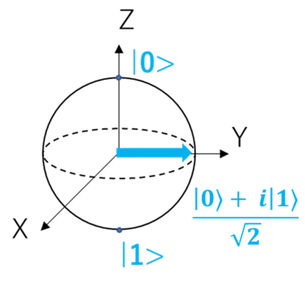
- Axion search

would be considered classical waves interact with the electron spin

$$a(t,\vec{x}) = a_0 cos(m_{DM}(t - \vec{v}\cdot\vec{x}) + \delta)$$

$$\vec{B}_{eff} = \sqrt{2\rho_{DM}} \times g_{aee}\vec{v}_{DM} \quad H_{eff} = \gamma_e \vec{B}_{eff}\cdot\vec{S}_e cos(m_{DM}t + \delta)$$



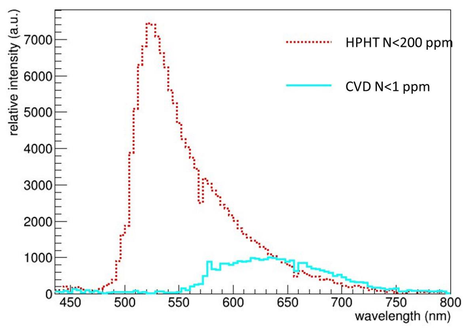


time evolution of the Bloch vector of the spin-triplet states

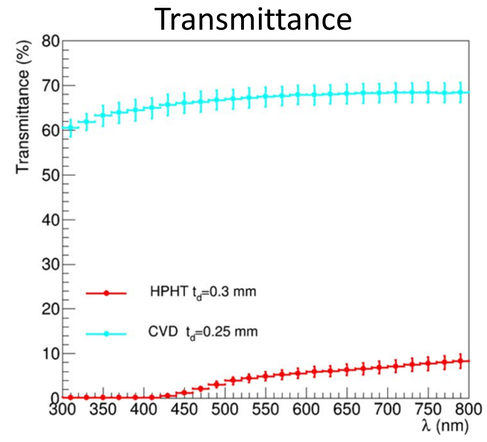
R&D study of diamond for WIMP search

- diamond scintillator

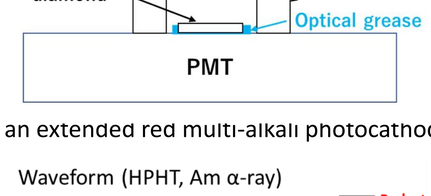
X-ray radio-luminescence



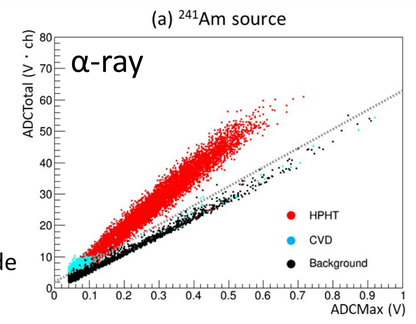
Transmittance

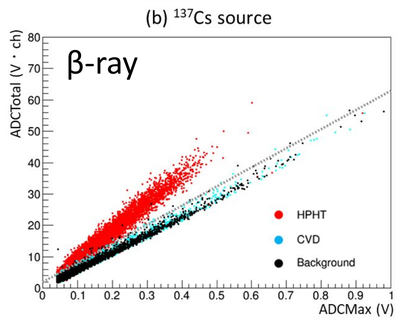


Color center : C center (single substitutional nitrogen atom replacing a carbon) for HPHT, and NV center for CVD



*R669 with an extended red multi-alkali photocathode



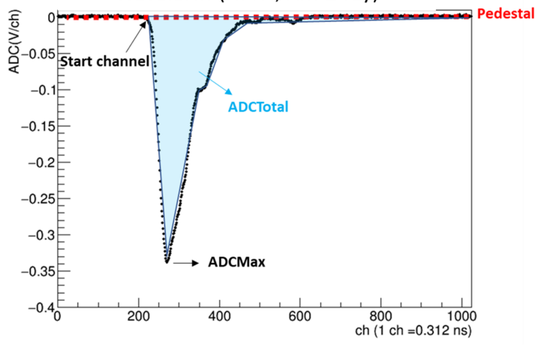


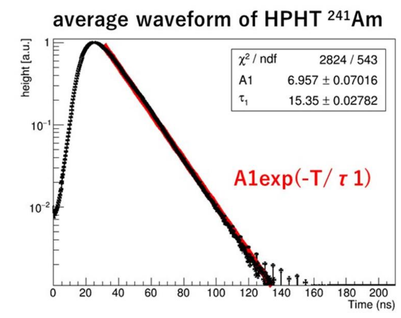
Estimation of light yield

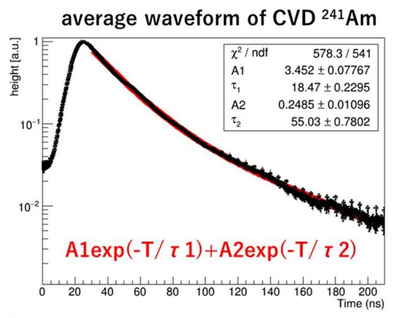
$$N_{p.e.} = \eta_0 \int \varepsilon_{PMT}(\lambda) I(\lambda) \int \frac{\Omega(\theta)}{4\pi} \int E_{dep}(z) T(\theta, z, \lambda) dz d\theta d\lambda$$

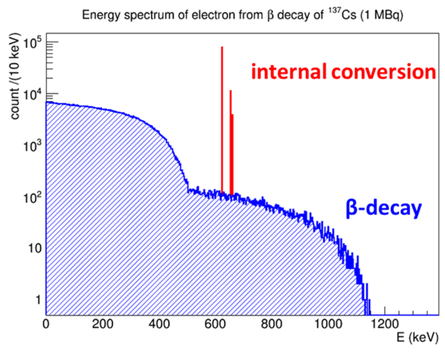
$$\mathrm{ADCTotal} = N_{p.e.} \times \mathrm{ADCTotal}_{(1p.e.)}$$

⇒Light yield η_0 (ph/MeV) was estimated using HPHT β-ray data

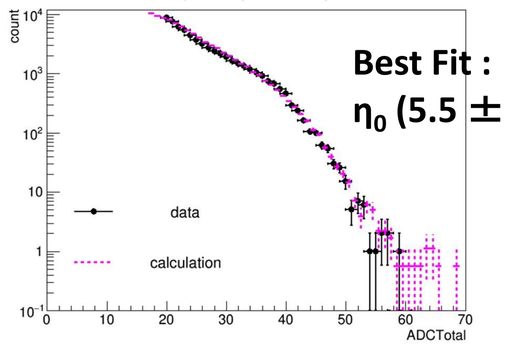








HPHT β-ray analysis



Best Fit :
η_0 (5.5 ± 0.5) × 10^4 (ph/MeV)

- diamond bolometer

Microwave kinetic inductance detector (MKID)

Pattern with Al for super conducting device (MKID) was fabricated on 5 x 5 mm diamond substrate by Dr. Murayama (NAOJ)

- Axion search

Characteristics of NV center for sensing

Magnetic field sensitivity : η

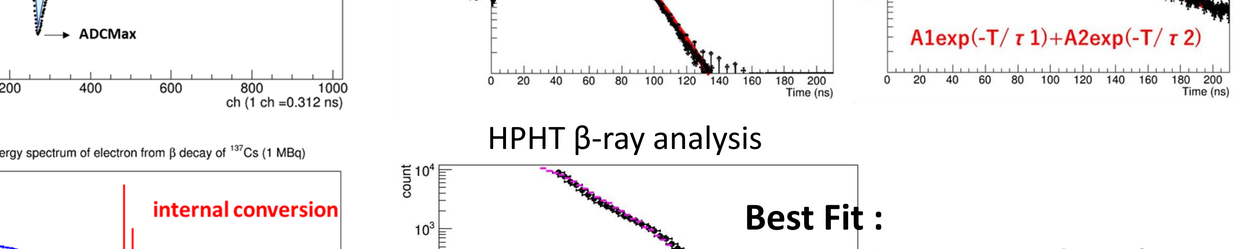
$$\eta \propto \frac{1}{\sqrt{n_{NV} T_2}}$$

n_{NV} : The number of NV

* Mizuochi, QUP symposium (2023)

AC magnetometry (Hahn echo)

⇒ensemble NV and low temperature experiment



Construction will start at Fuji Hall

Conclusion: The possibilities of diamond detector are endless, please stay tuned.

Acknowledgement

I would like to thank Shintaro Nomura, Takashi Iida and Shunsuke Honda (University of Tsukuba), Masao Yoshino and Koji Ishidoshiro (Tohoku University), Takashi Taniguchi, Masashi Miyakawa and Chikara Shinei (NIMS), Yoshuke Murayama and Tai Ohshima (NAOJ), Takuya Shiraishi (Kanagawa University), Hideo Iizuka and Norikazu Mizuochi (QUP) for their help to develop the diamond detector.