Nov 29, 2019

29th JGRG

Direct Dark Matter Detection Review

Kentaro Miuchi
(Kobe University)

Dark Matter
Direct Search
Future

科研費
KAKENHI

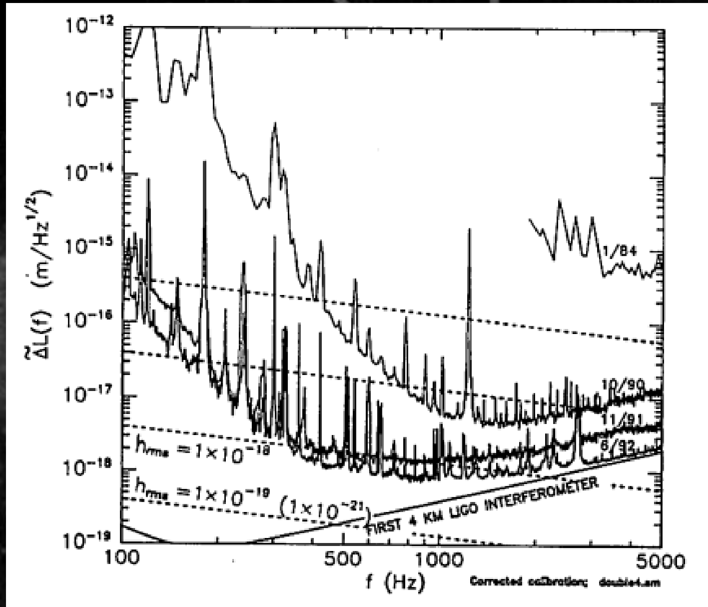
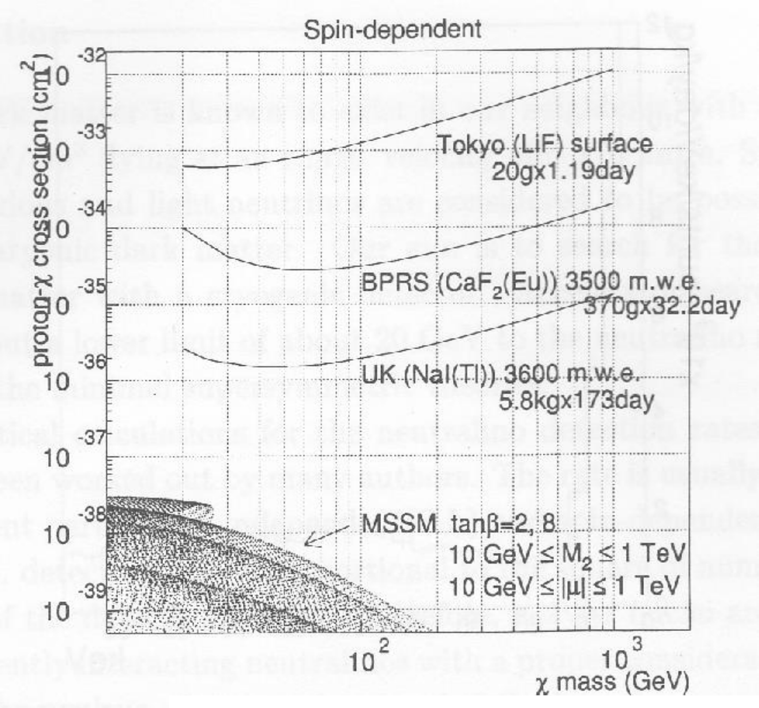


Figure 5. Displacement noise of the 40m prototype.

S. Kawamura
proceedings of 2nd JGRG (1992)

Years ago,
we were together

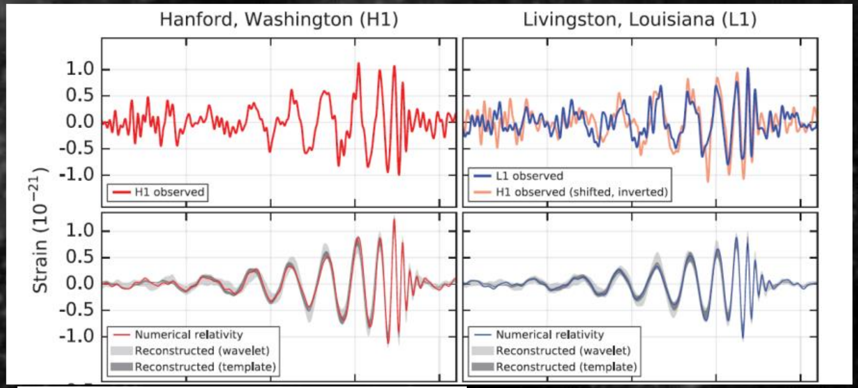


M. Minowa
proceedings of 2nd RESCUE (1996)

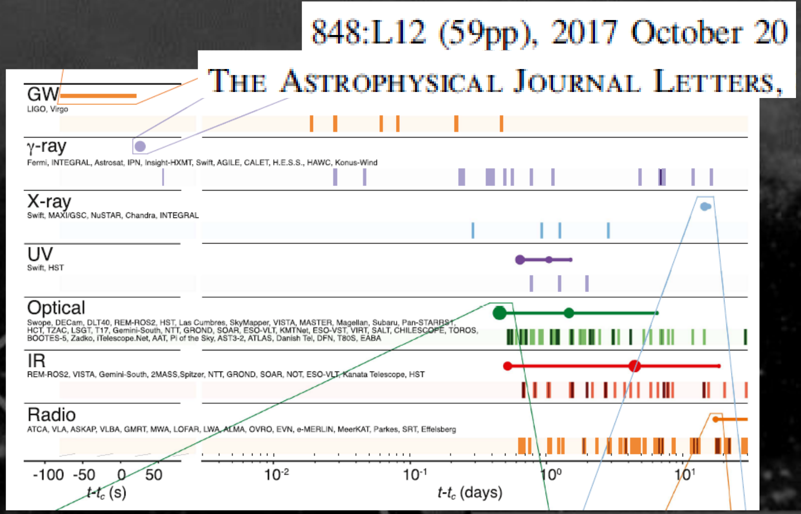
Hunting for the unseen

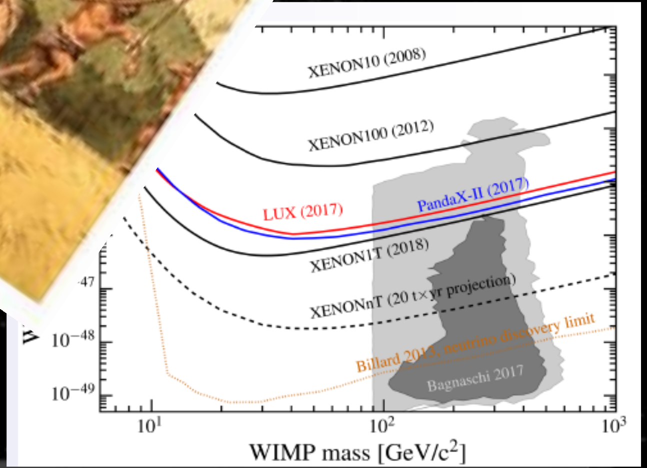
in a log-log field.

Now that you found it, you are one of them.



PRL **116,** 061102 (2016)





A. Colijn TAUP2019

We are still hunting

in the log-log field.

Dark Matter

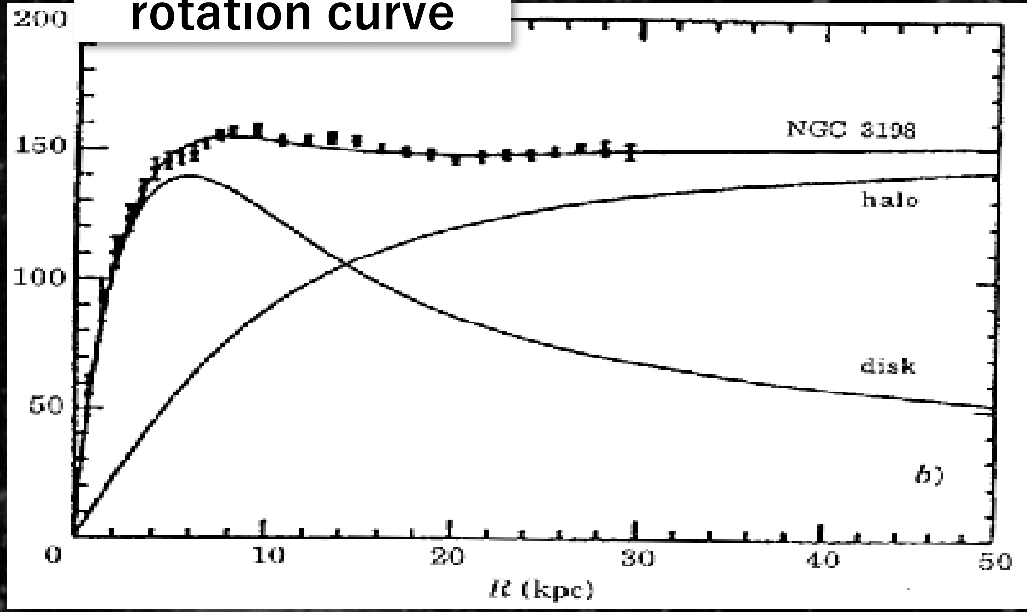
the uncultivated

• DM: seen in various scales in the universe

- @ galaxy: rotation curves (1970~)
- @ cluster of galaxies: collision of galaxy clusters (2007~)
- @ universe: CMB and other observations (2002~)

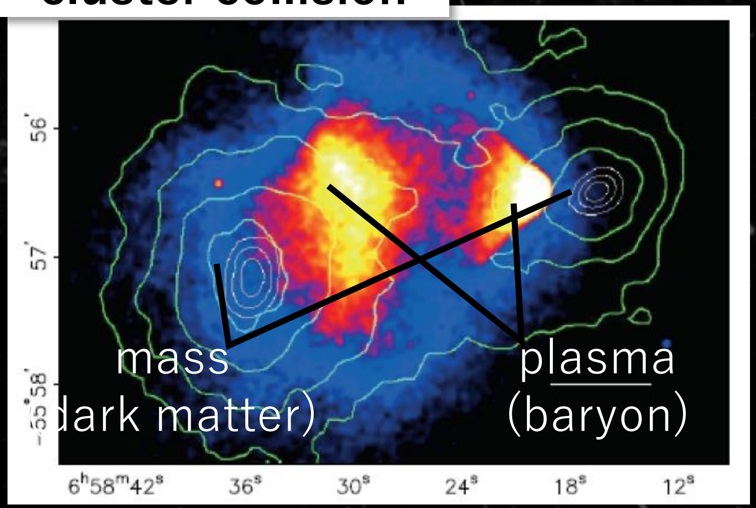
GR !

rotation curve



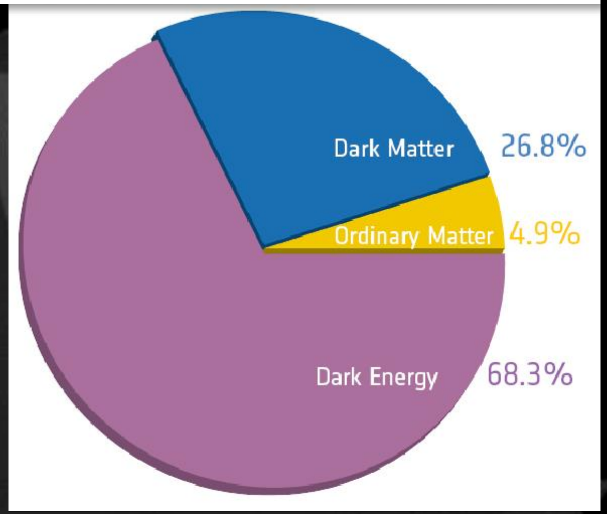
Annu. Rev. Astron. Astrophys. 29(1991)409

cluster collision



THE ASTROPHYSICAL JOURNAL, 648:L109–L113, 2006 September 10

pie chart of the universe



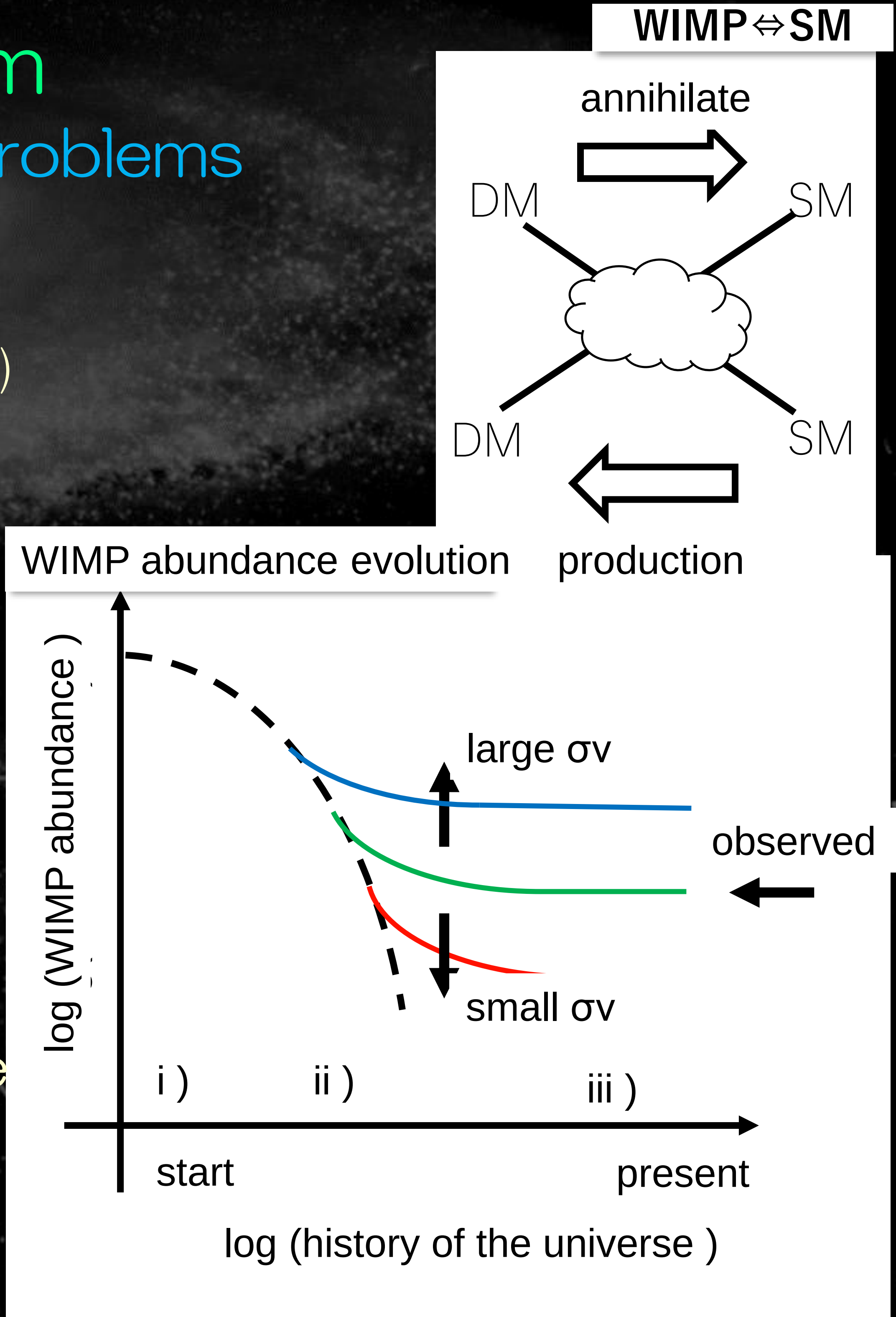
Plank team

• DM candidates: thousands of them

- "good" candidates would solve other problems
  - AXION (CP problem in QCD)
  - Primordial black hole (BHs are there!)
  - WIMPs (Weakly Interacting Massive Particles)

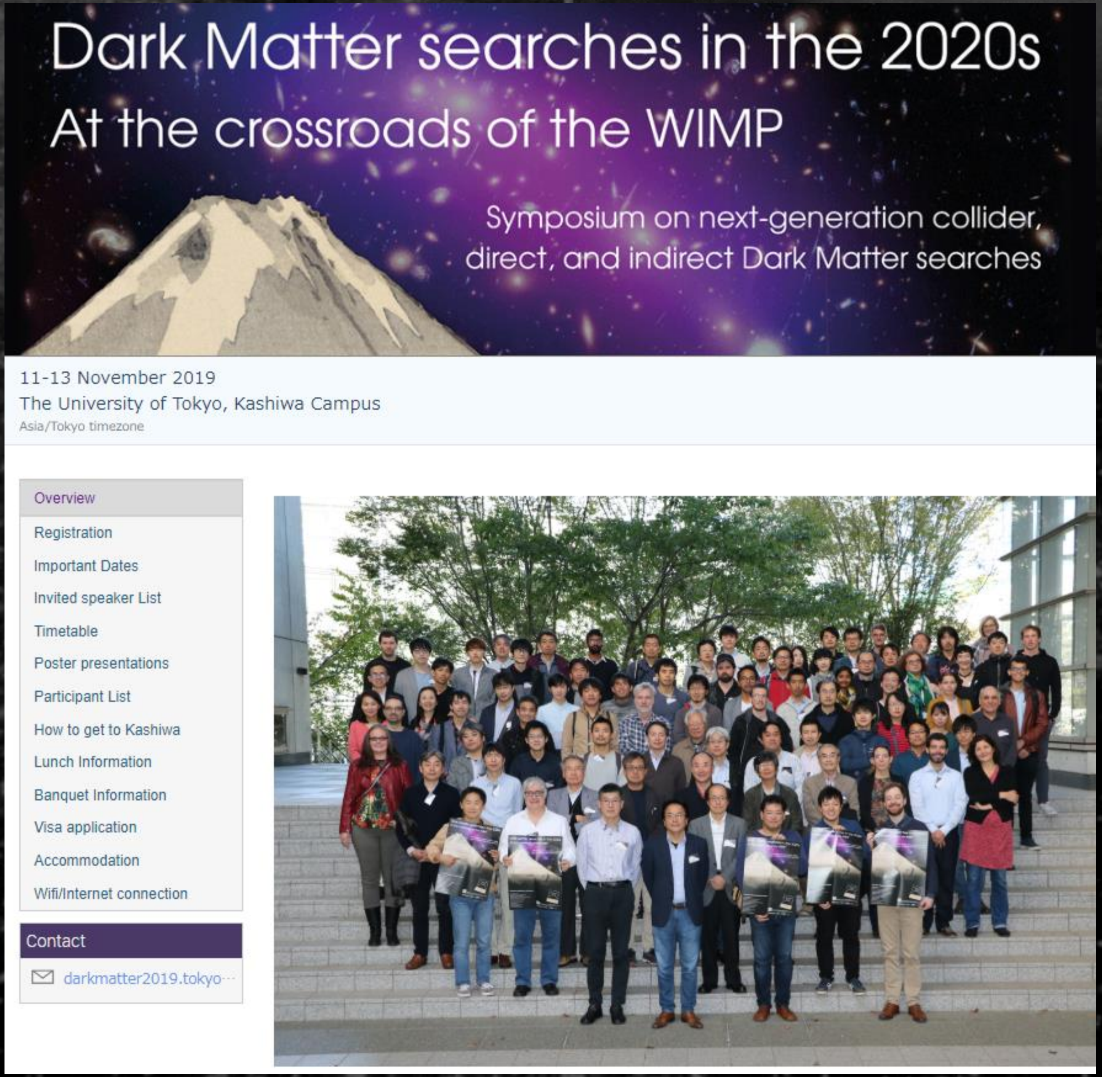
- WIMPs
  - Produced in the early universe
  - Annihilate
    rate ∝ cross section × velocity
  - Freeze out at some point
    abundance is fixed

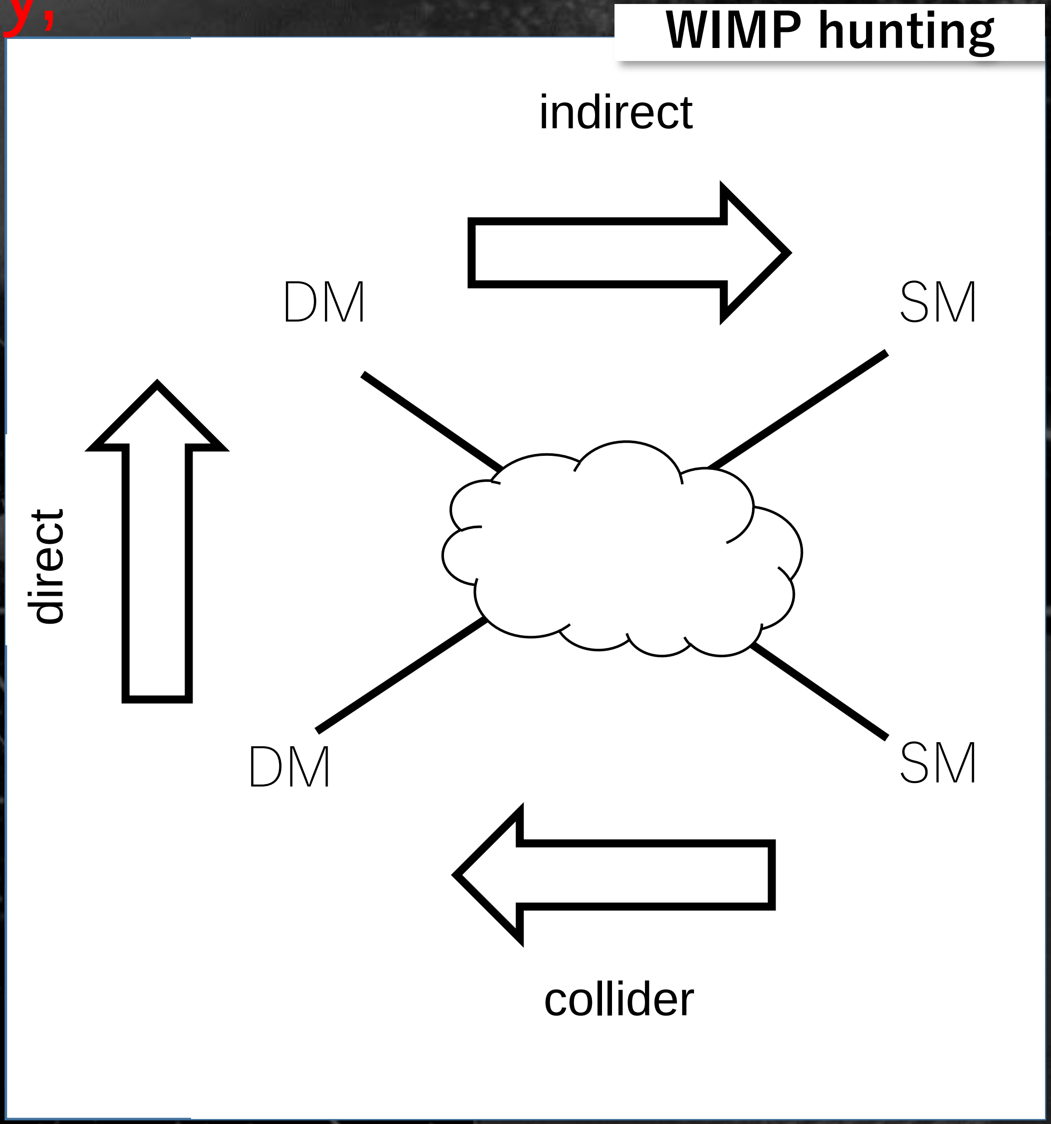
  - σ～weak scale explains present abundance
    ⇒WIMP miracle !



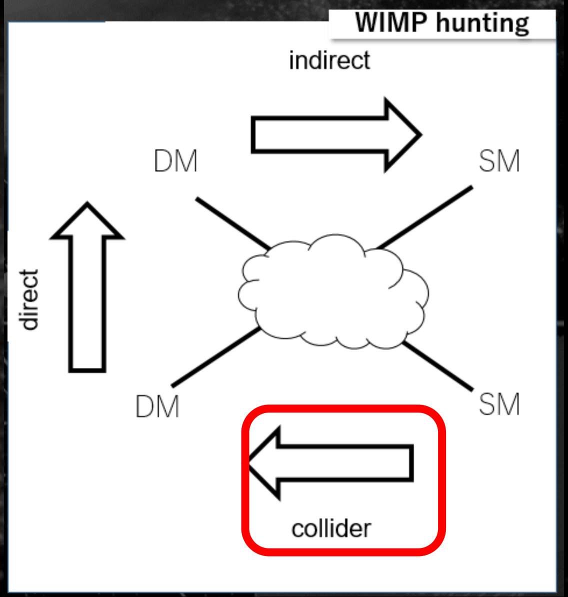
- WIMP hunting
  - WIMP-SM (standard model particle, i.e. quarks) particle interaction
    - Direct search
    - Indirect search
    - Collider

complementary, synergy





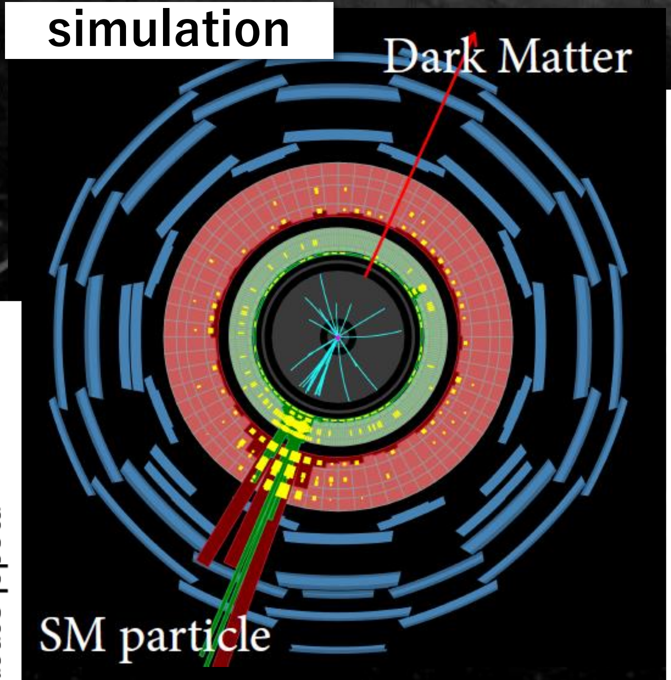
- Collider
  - LHC @ CERN
  - Missing E signal
  - Searches with various ways
  - No hint so far



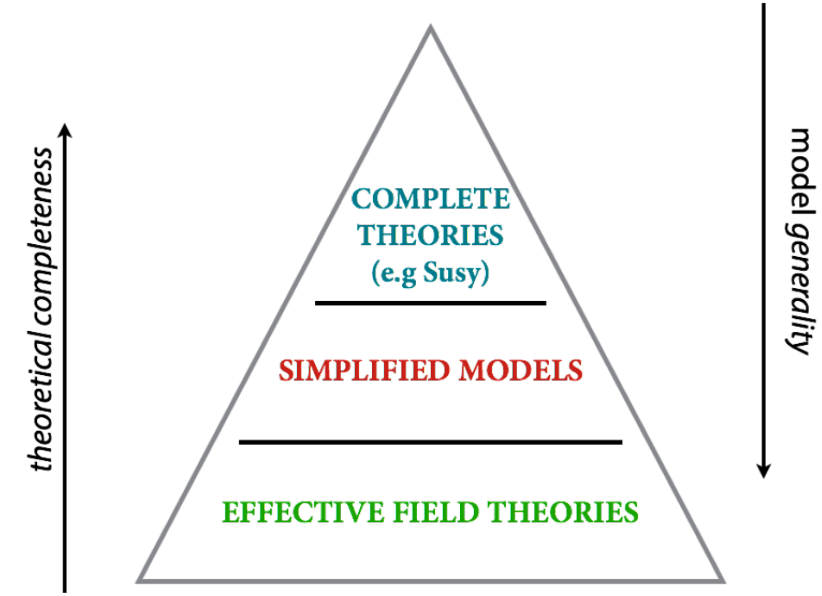
Dark matter searches at colliders.

Priscilla Pani
on behalf of ATLAS, CMS & LHCb

Dark Matter searches in the 2020 - Tokyo
11-13 November 2019



Theoretical framework

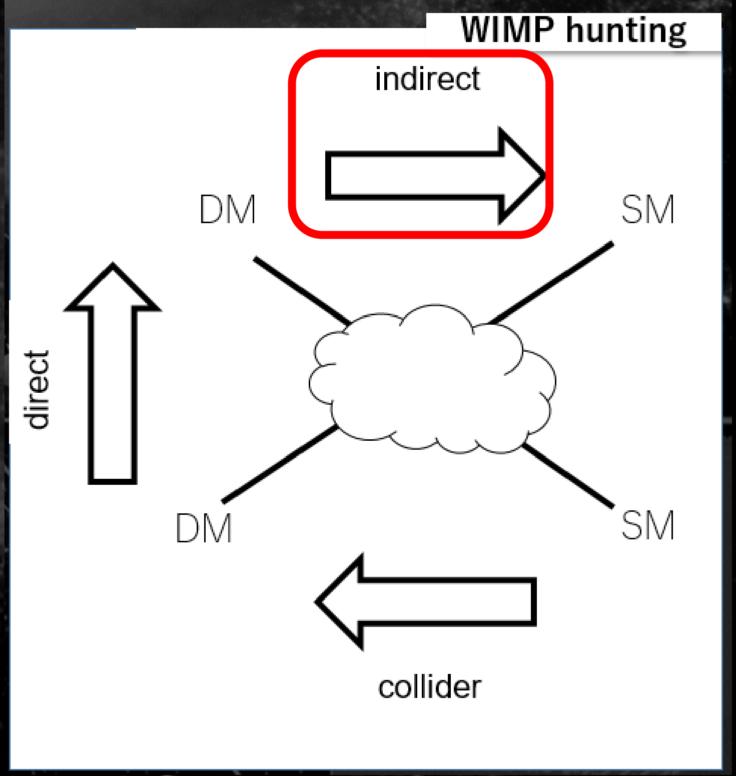


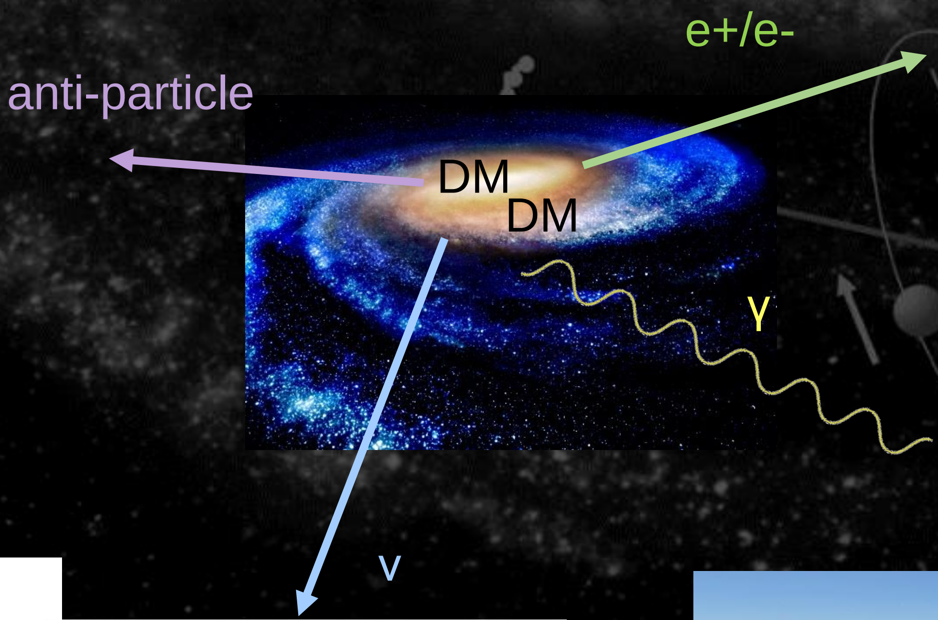
Conclusion - Cheat sheet

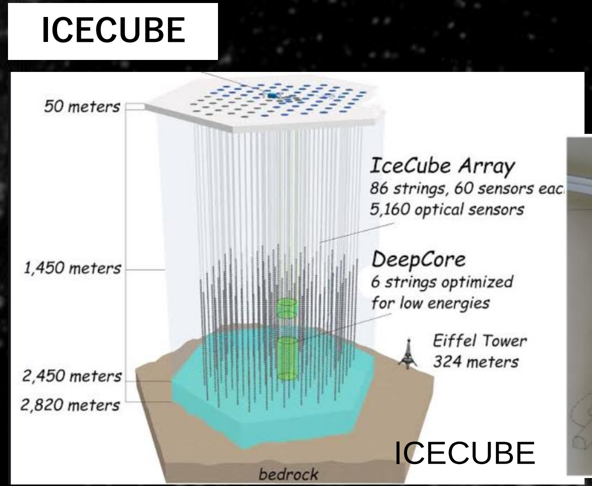
DM-mediator searches

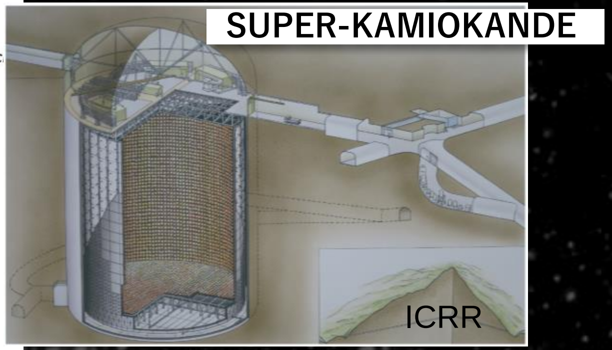
Signature	Dataset	Reference
Di-lepton resonance	139 fb^{-1}	1903.06248
Di-jet, Di-jet + ISR,	139 fb^{-1}	1901.10917, ATLAS-CONF-2019-007, 1808.03124
Di-bjet	80 fb^{-1}	ATLAS-CONF-2018-052
Di-jet + leptons	80 fb^{-1}	ATLAS-CONF-2018-015
Dijet + photons	36 fb^{-1}	1905.10331
Etmiss + Higgs	36 fb^{-1}	1908.01713
Etmiss + t/ttbar	36 fb^{-1}	1901.01553
Etmiss + jet	36 fb^{-1}	1712.02345
H invisible	36 fb^{-1}	Phys. Rev. Lett. 122 (2019) 231801
ATLAS DM summary	36 fb^{-1}	JHEP 05 (2019) 142

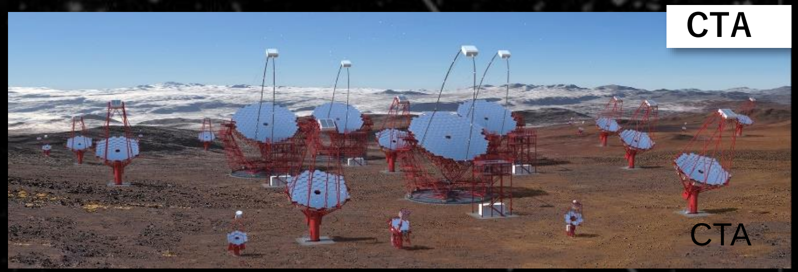
- Indirect Search
  - WIMP s annihilate @ Galactic Center, Dwarf Galaxy, sun…
  - No conclusive result yet





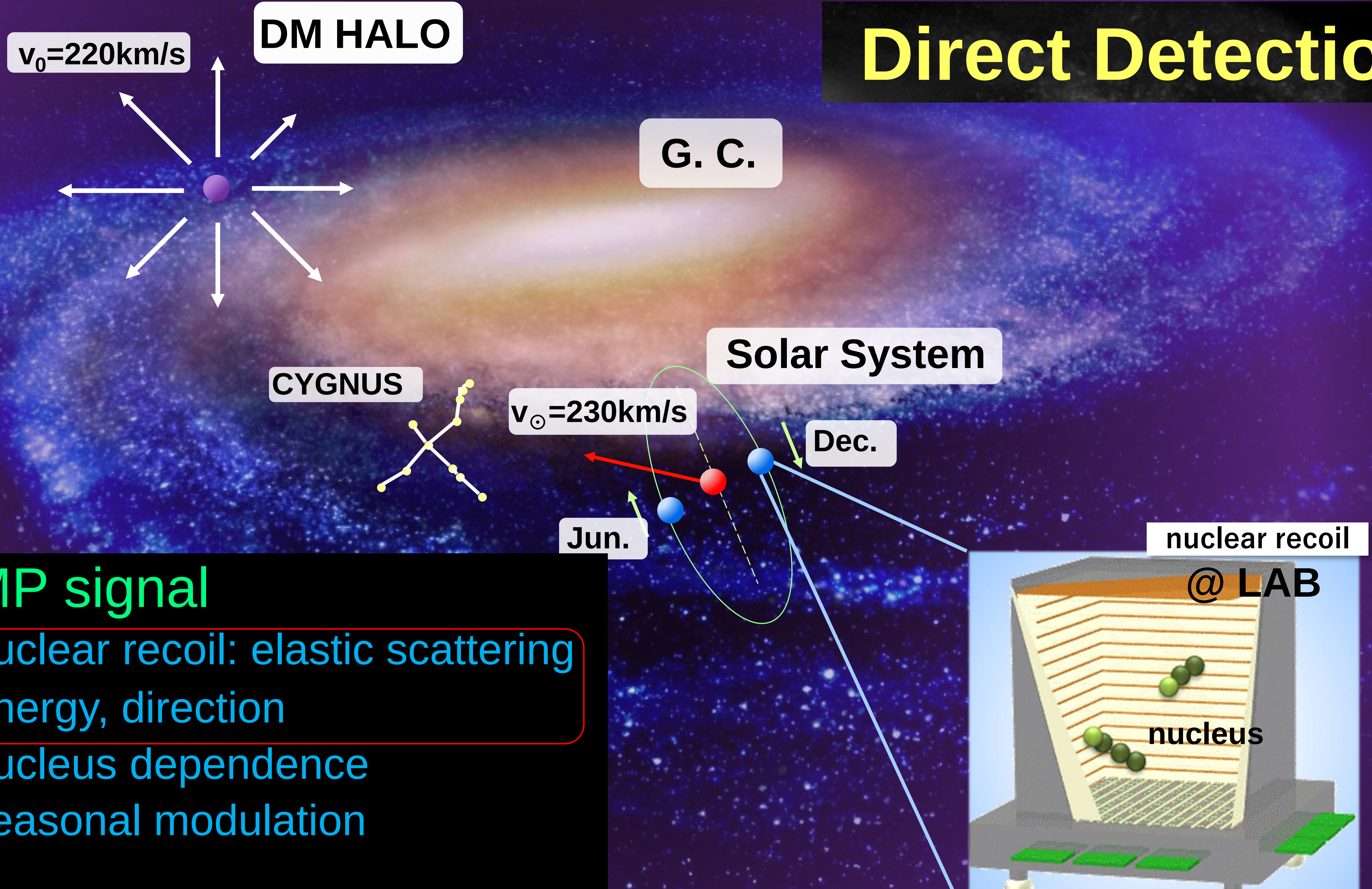






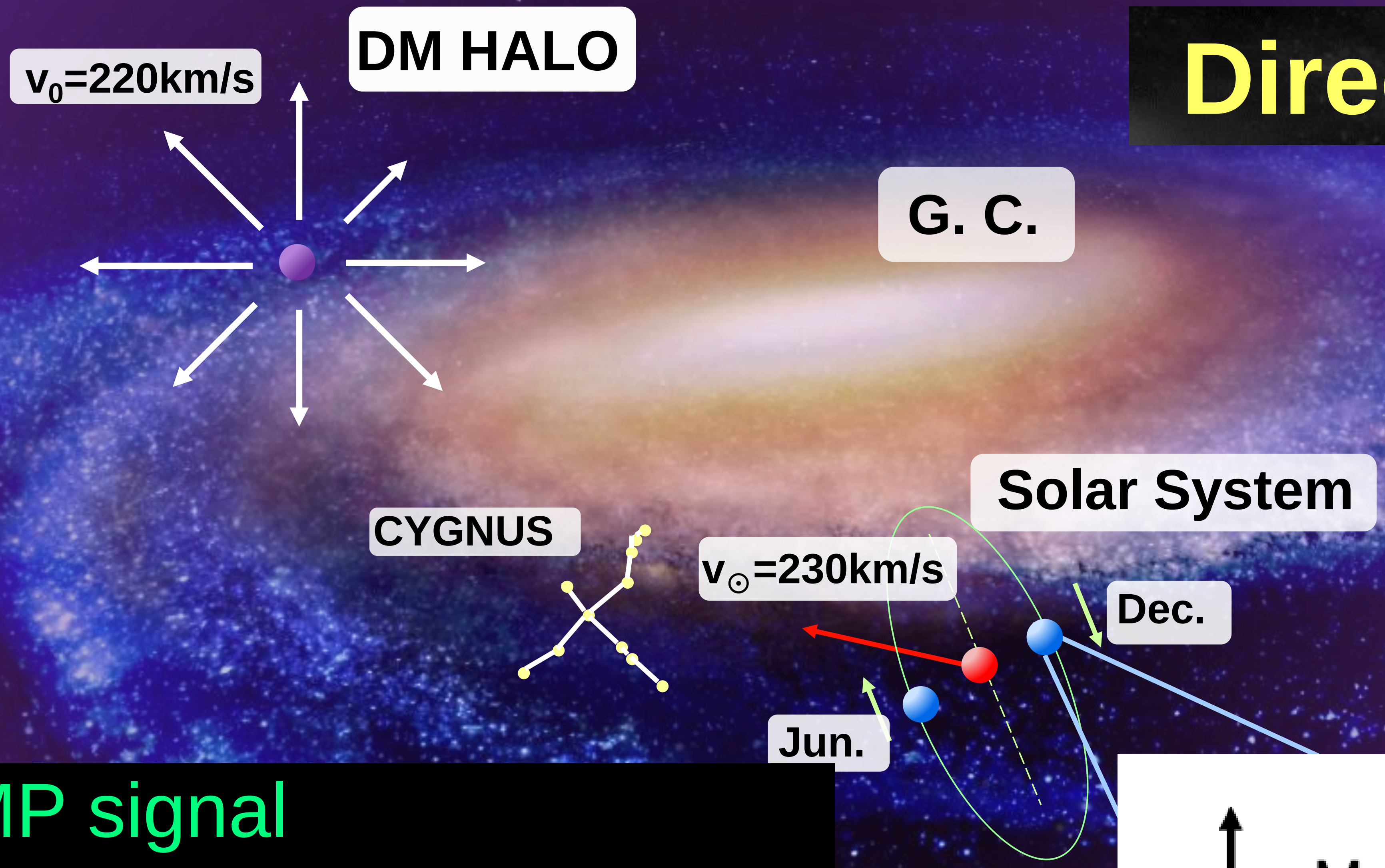
Direct Search

Direct Detection



- WIMP signal
  - nuclear recoil: elastic scattering
  - energy, direction
  - nucleus dependence
  - seasonal modulation

Direct Detection



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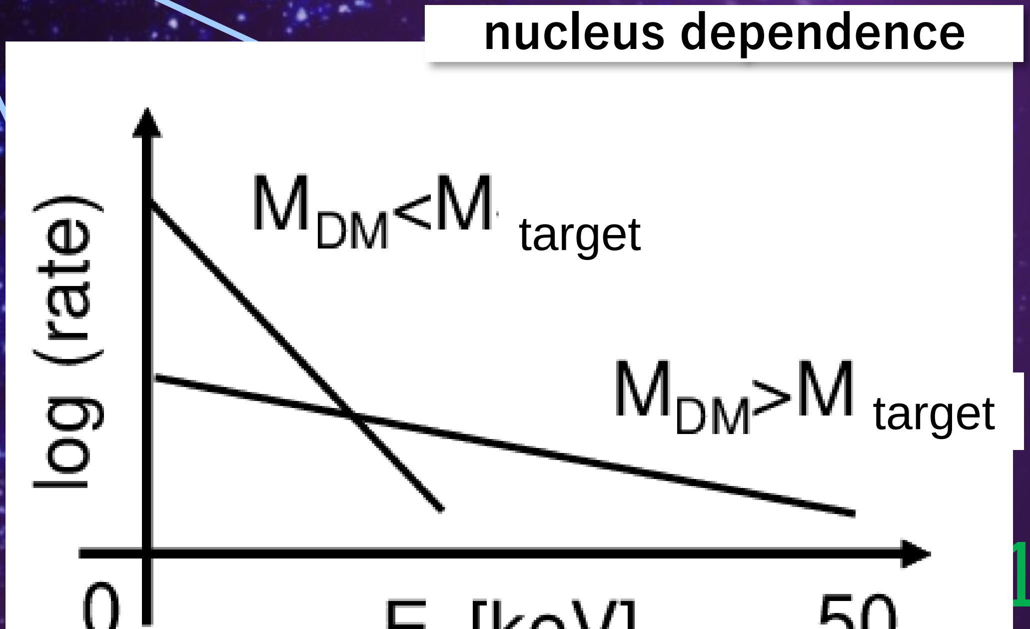
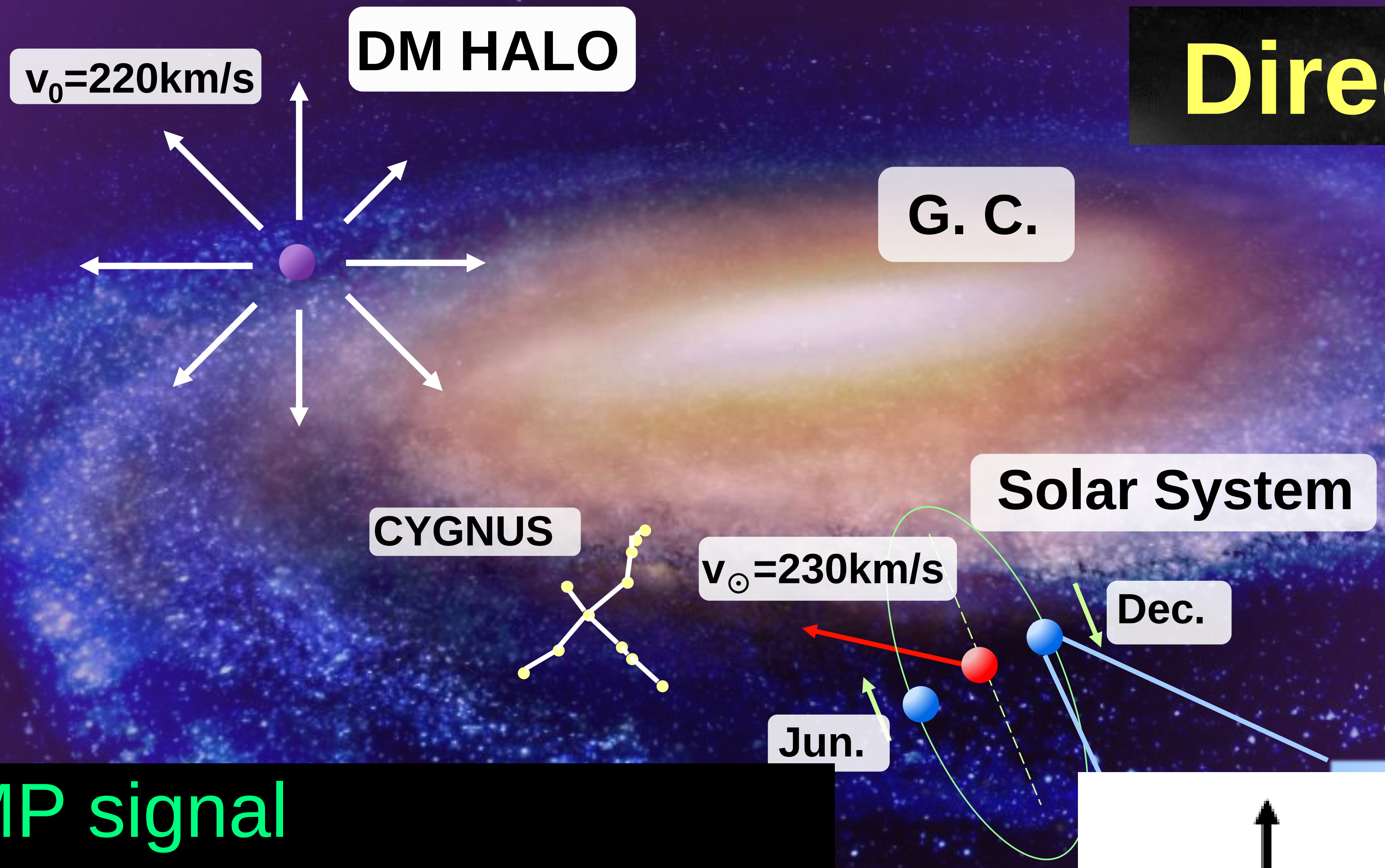


Direct Detection



- WIMP signal
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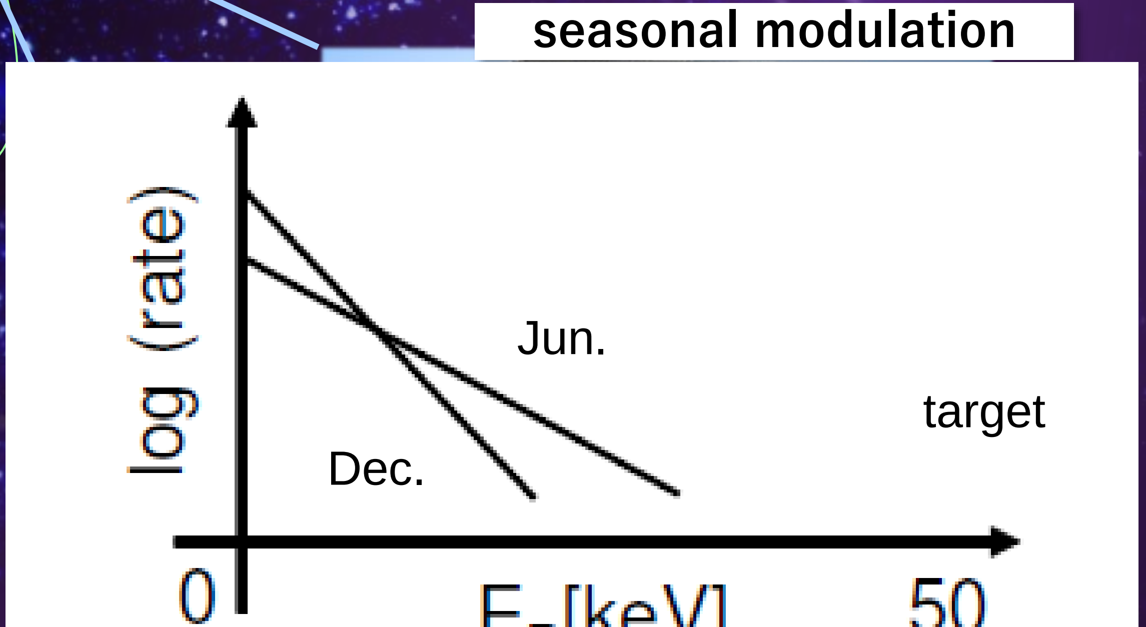
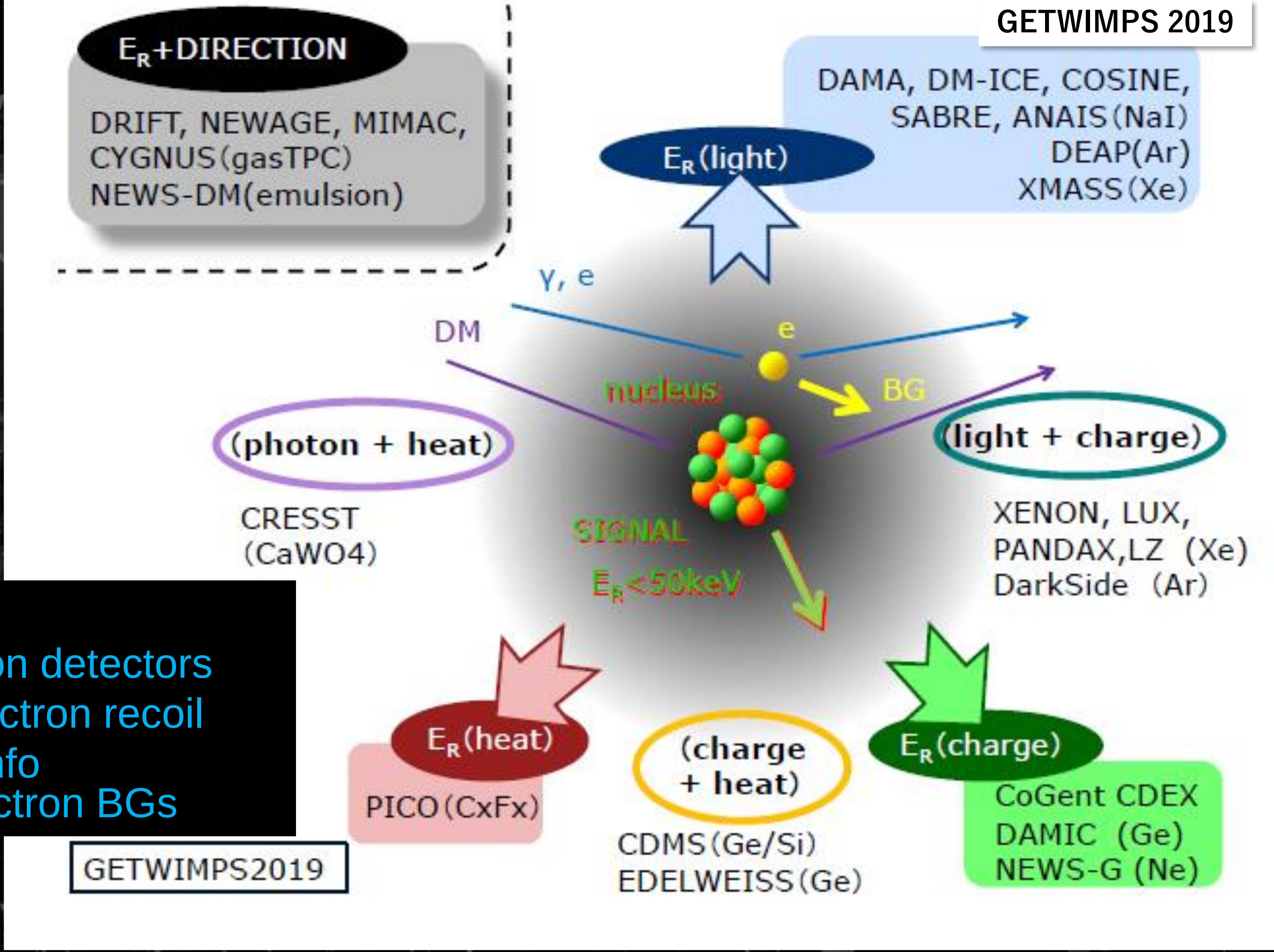
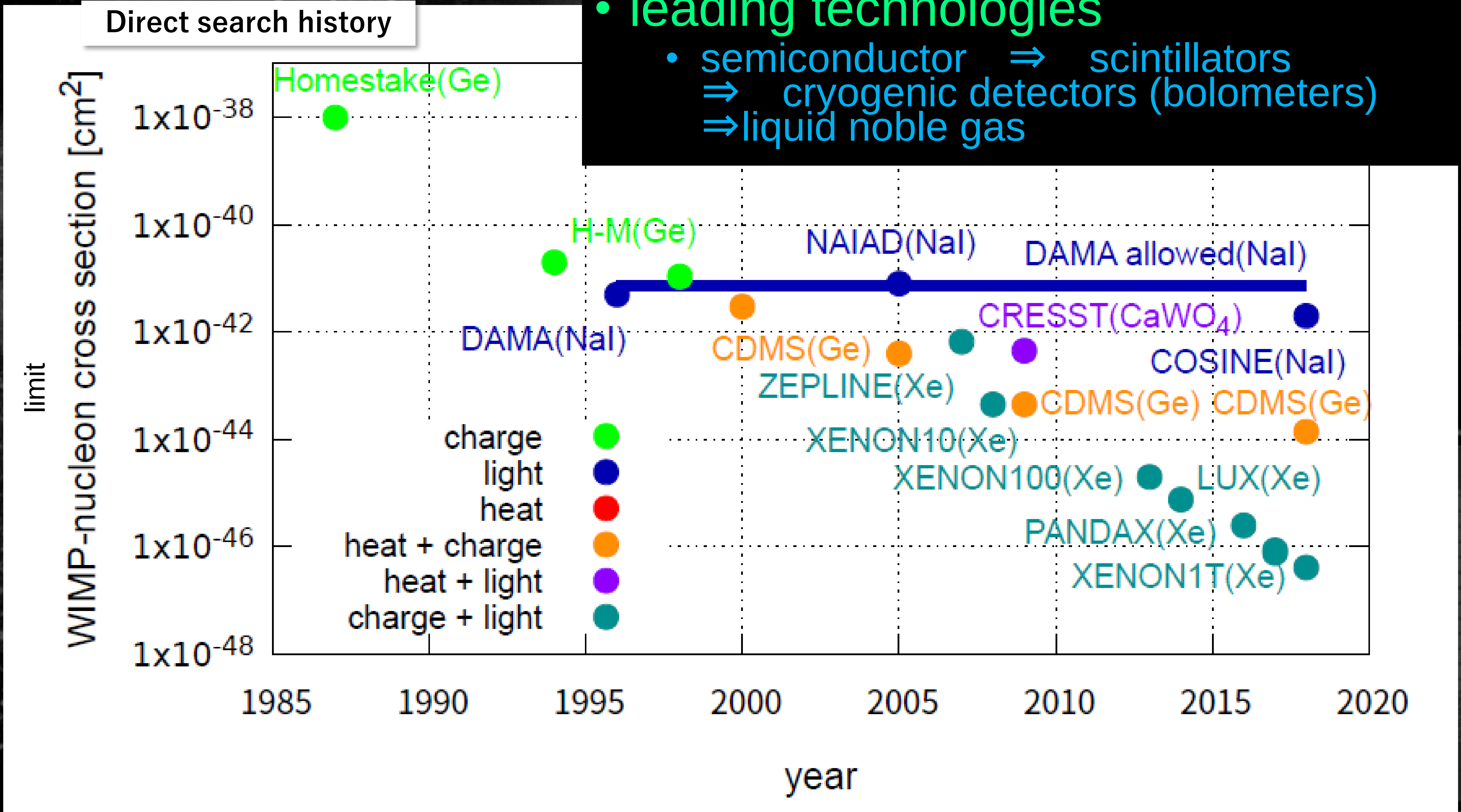




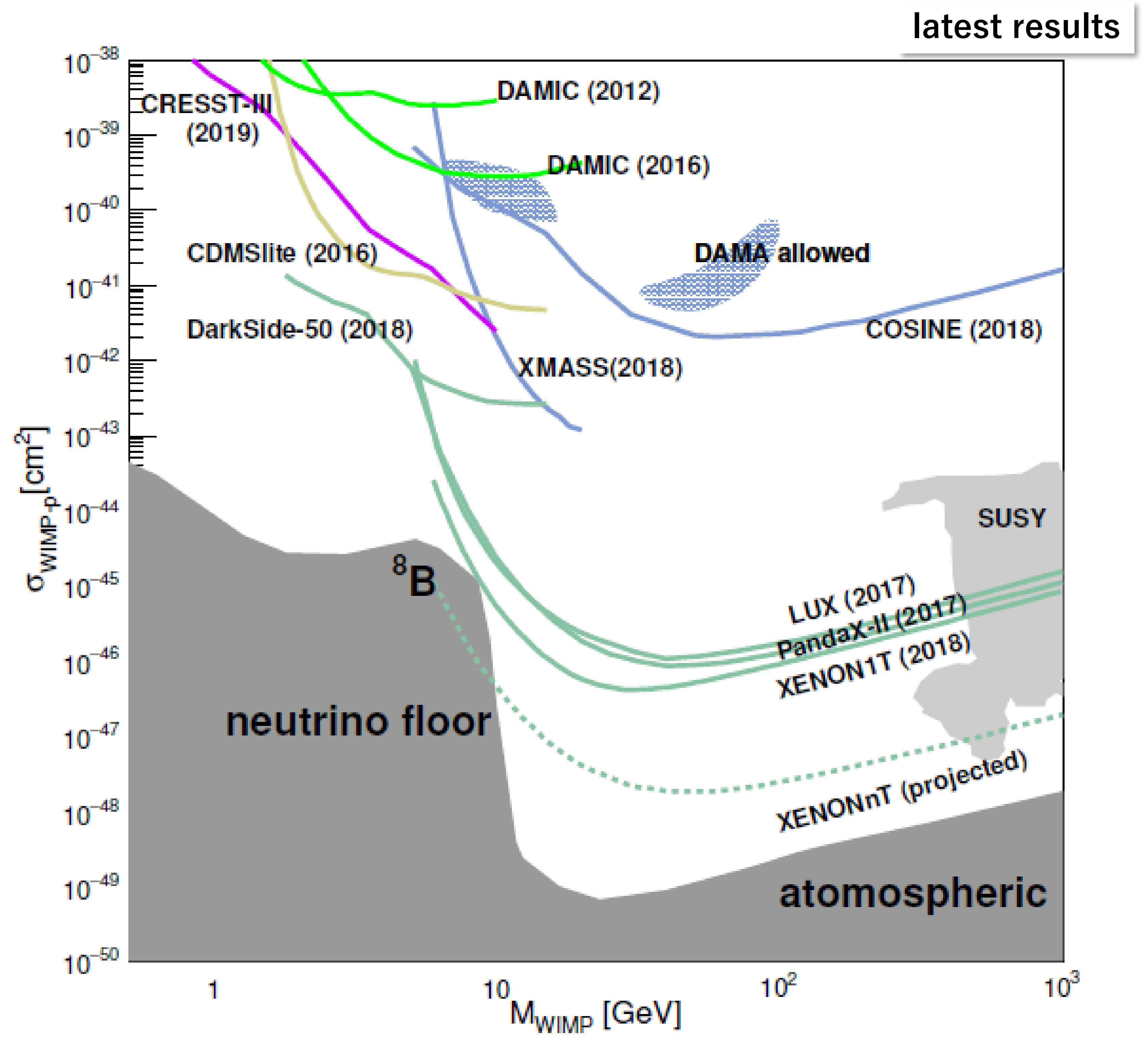
- Technologies
  - Ordinary radiation detectors
  - Background: electron recoil
  - more than two info
    ⇒ reject electron BGs

History

- leading technologies
  - semiconductor ⇒ scintillators
    ⇒ cryogenic detectors (bolometers)
    ⇒liquid noble gas

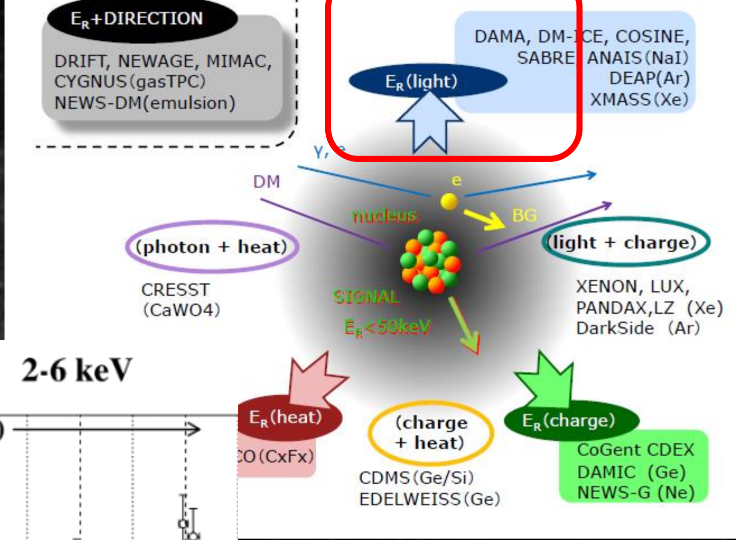


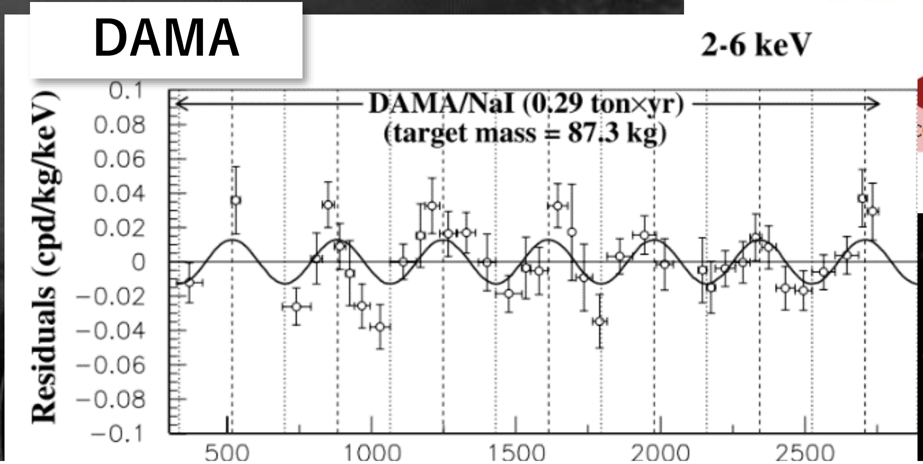
- Latest results
  - DAMA
    annual modulation
  - bolometers
  - liquid xenon



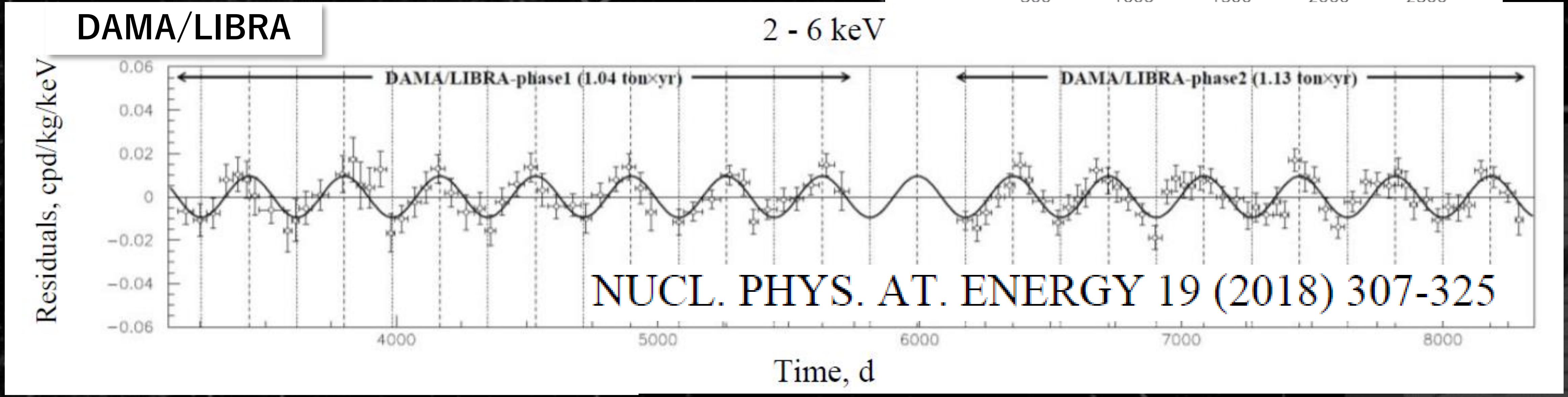
DAMA（NaI）

- 250kg NaI scintillators
- Annual modulation were reported：1998～
- Latest 2.46 ton year 12.9 σ
- SOMETHING is detected





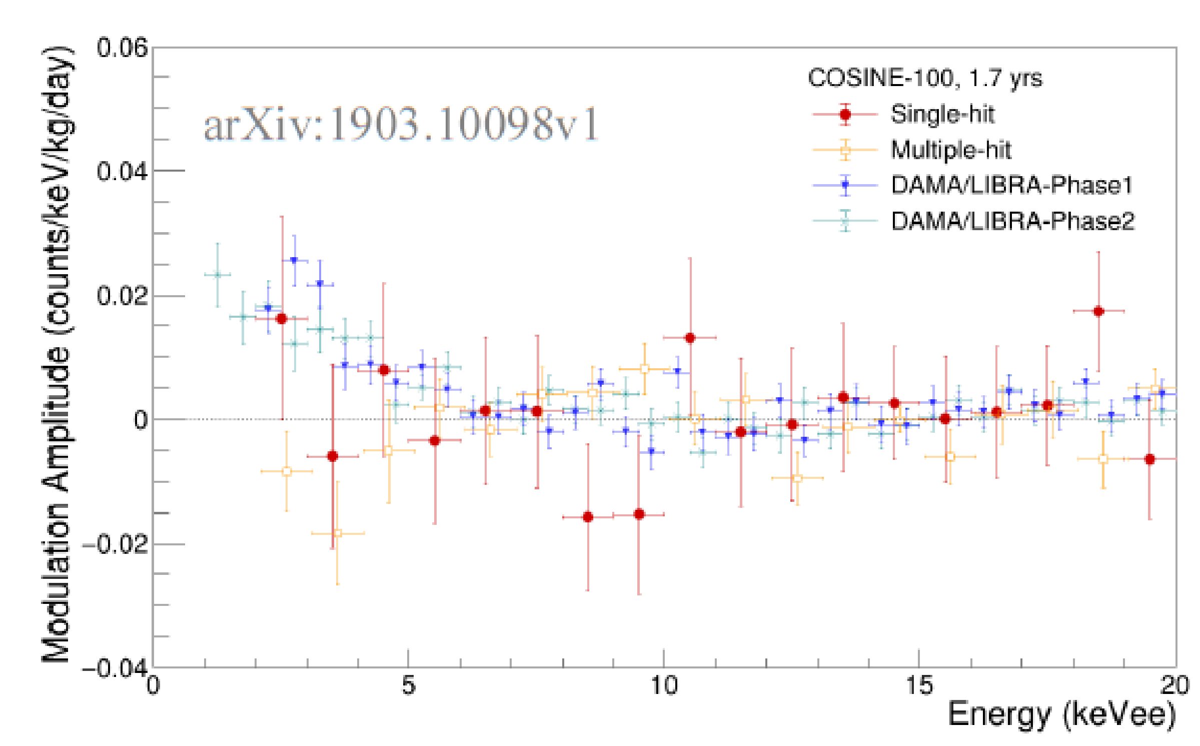
Eur. Phys. J. C (2008) 56: 333–355
DOI 10.1140/epjc/s10052-008-0662-y

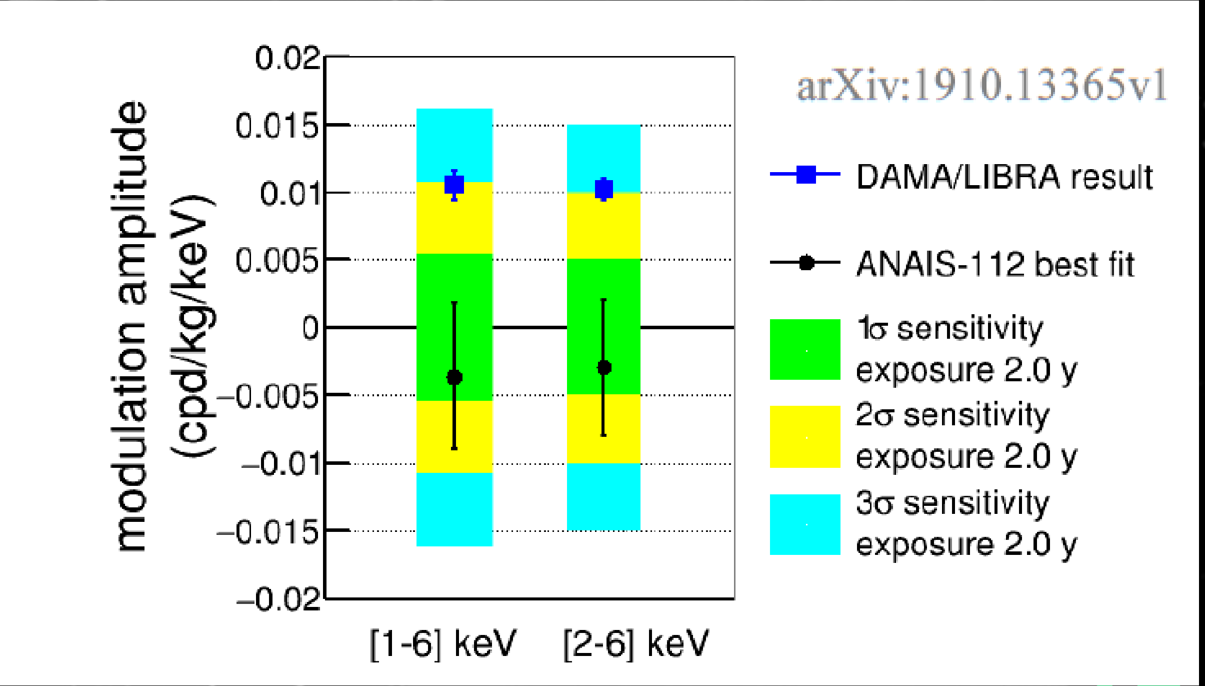


No BG explains this modulation
No natural DM model explains, either…

Kentaro Miuchi

- Other NaI detectors
  - COSINE(106kg), ANAIS (112kg)
    - Annual modulation measurement
    - Consistent with null and DAMA, yet.
  - SABRE
    - North and South
  - PICOLON
    - Pure crystal





Need to be stay tuned.

• Bolometers

• Low energy threshold ⇒ low mass DM

Latest results of CRESST-III's search for sub-GeV/c² dark matter

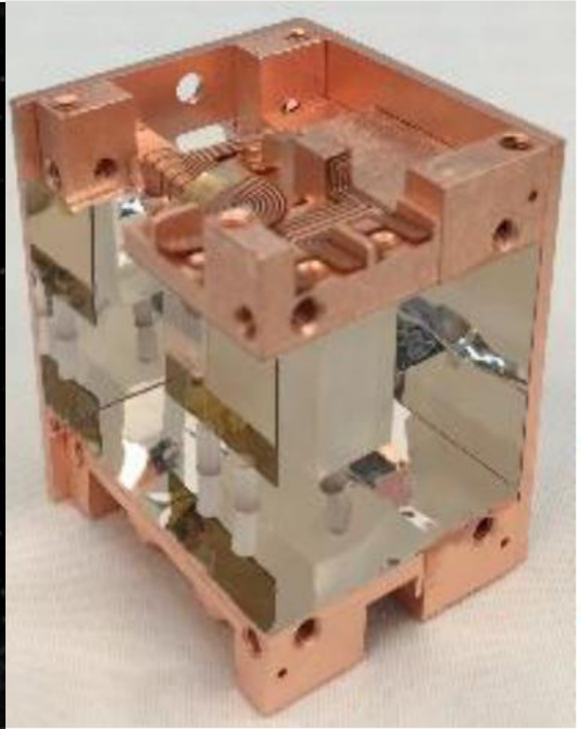
Holger Kluck

on behalf of the CRESST collaboration

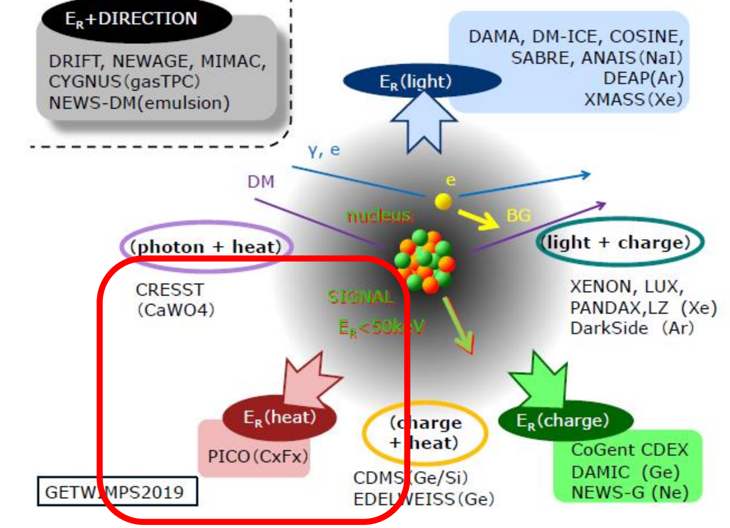
16th International Conference on Topics in Astroparticle and Underground Physics (TAUP2019)

September 10, 2019

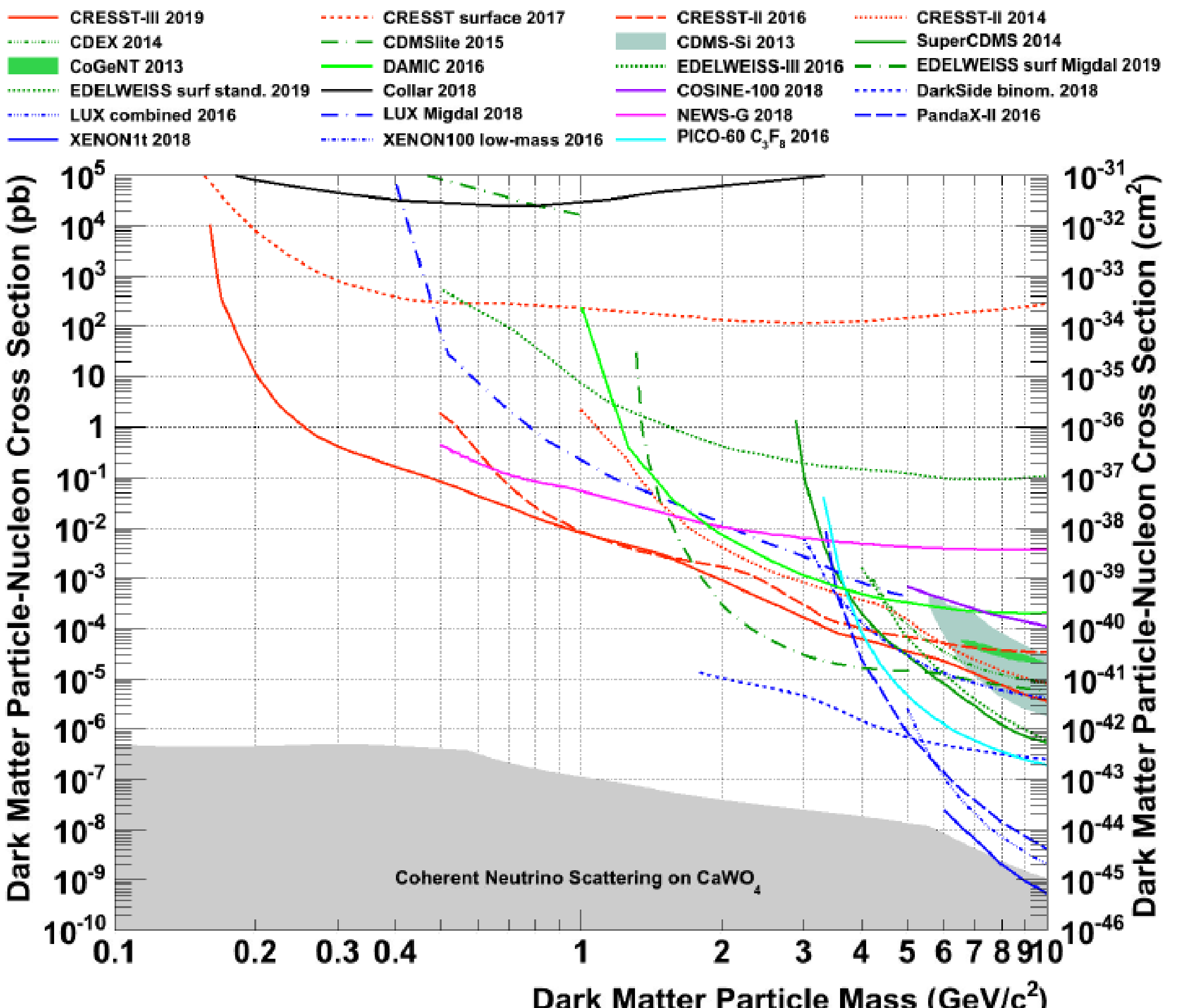
CRESST-III detector



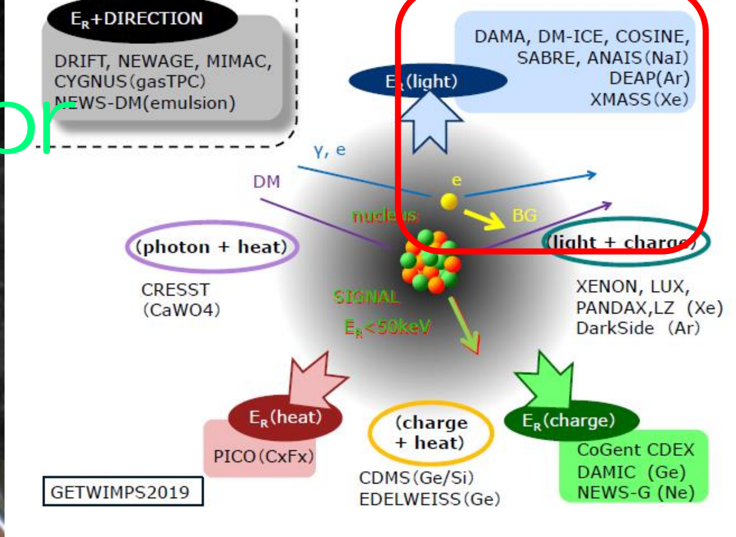
- May 2016:
  10 CRESST-III modules installed
- Jul 2016 – Feb 2018:
  data taking (80% blinded, 20% training set)
- Detector A
  → lowest nuclear recoil threshold so far: 30.1 eV
- Target crystal mass: 23.6g
- Gross exposure: 5.6 kg d
- [arXiv:1904.00498], accepted by Phys.Rev.D
  → this talk

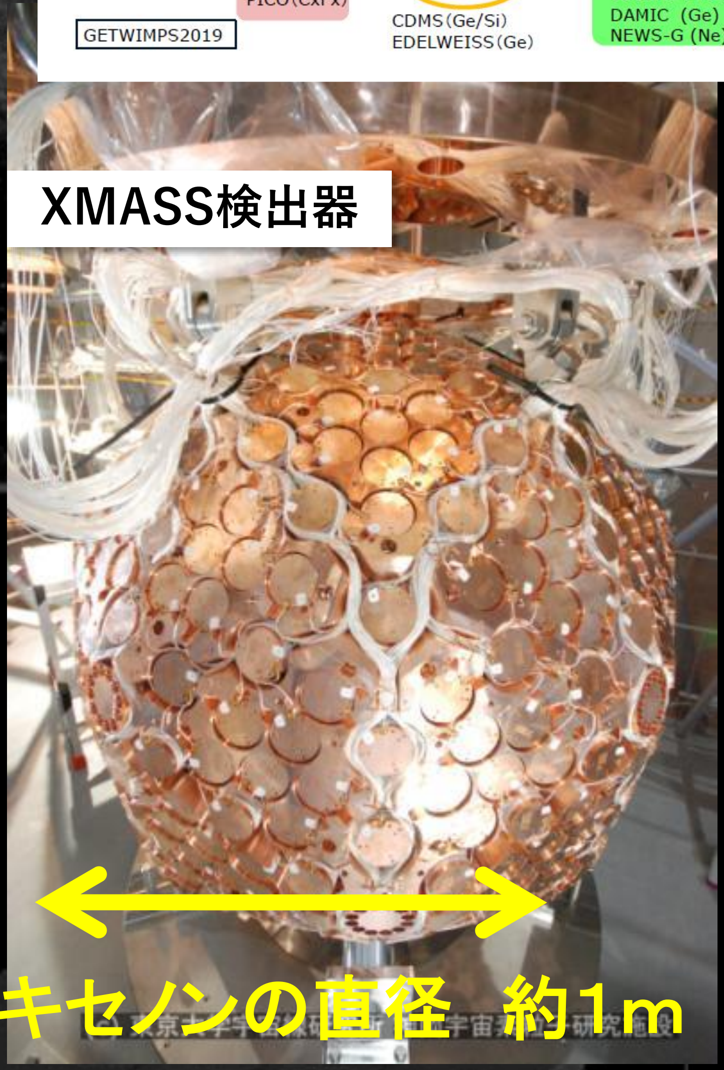


CRESST-III result



- Liq Xenon：1 phase (liquid-only) detector
  - XMASS
    - Observation 2013 Nov.～2019 Mar.
    - 642× PMTs
    - 800kg liquid xenon
  - One of the main results ”fiducial paper”
    - “self-shielding” of liquid xenon





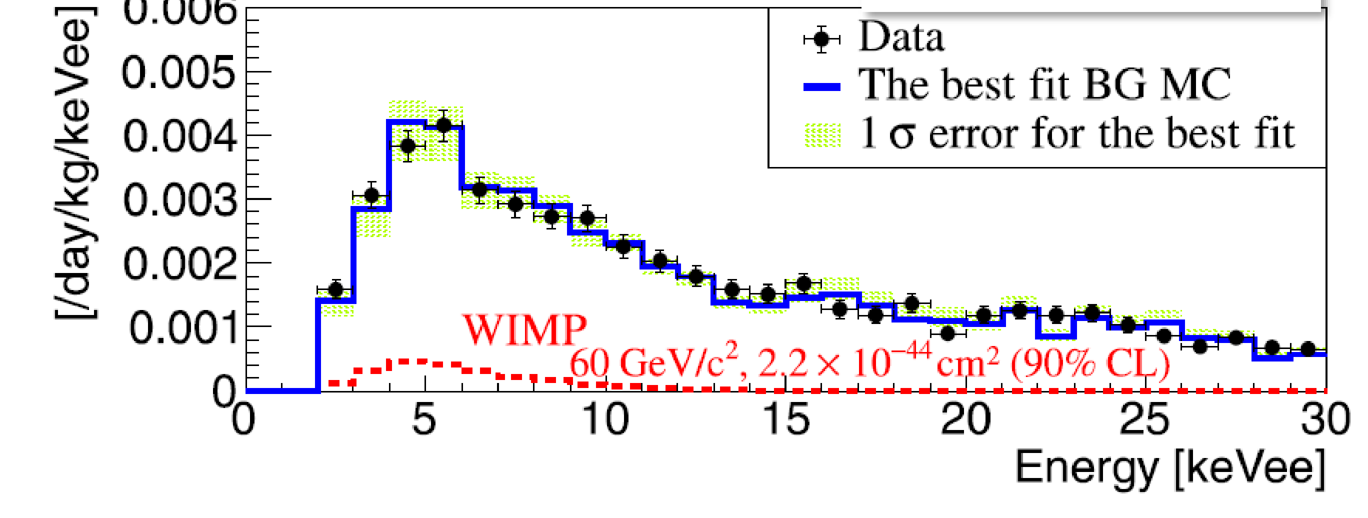
Physics Letters B 789 (2019) 45–53

A direct dark matter search in XMASS-I

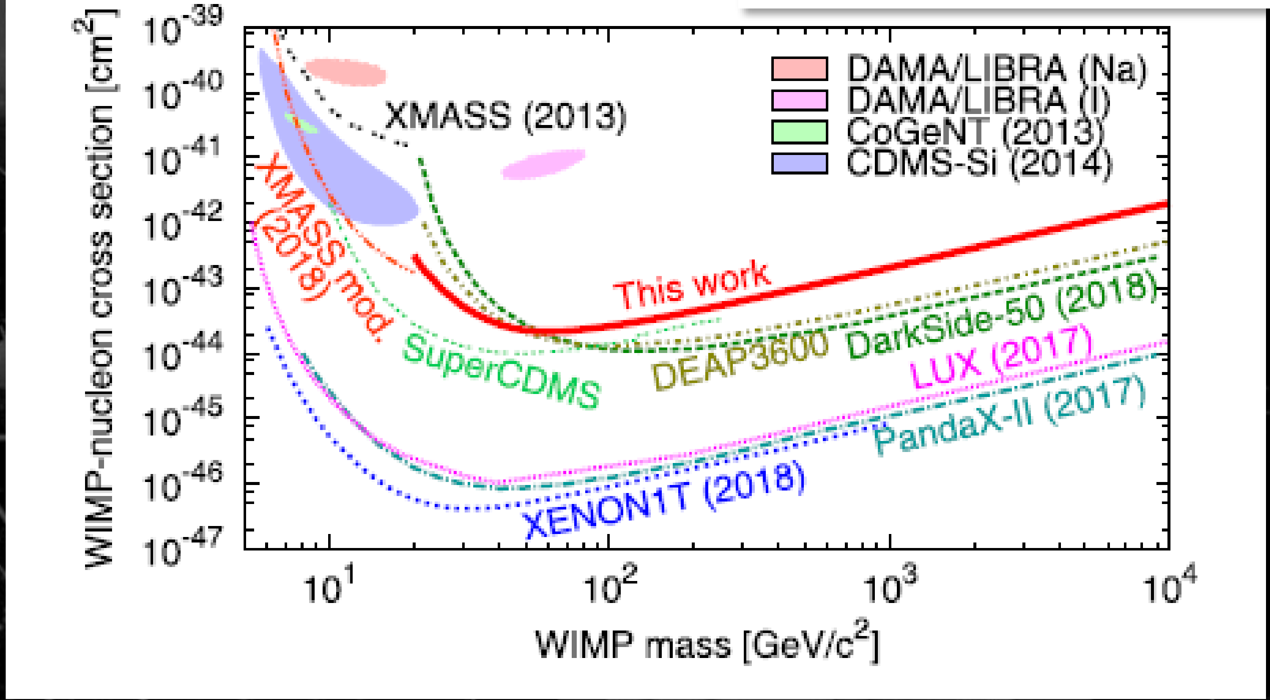
XMASS Collaboration *

- XMASS fiducial paper: limit
  - Fitting the obtained energy spectrum with BG + WIMP
  - Consistent with the BG model

WIMP fit ersults



XMASS DM limits



- Best limit as a 1-phase liq. Xe detector
- （Learned lesson） Reduction of the systematic error is important for an effective BG reduction

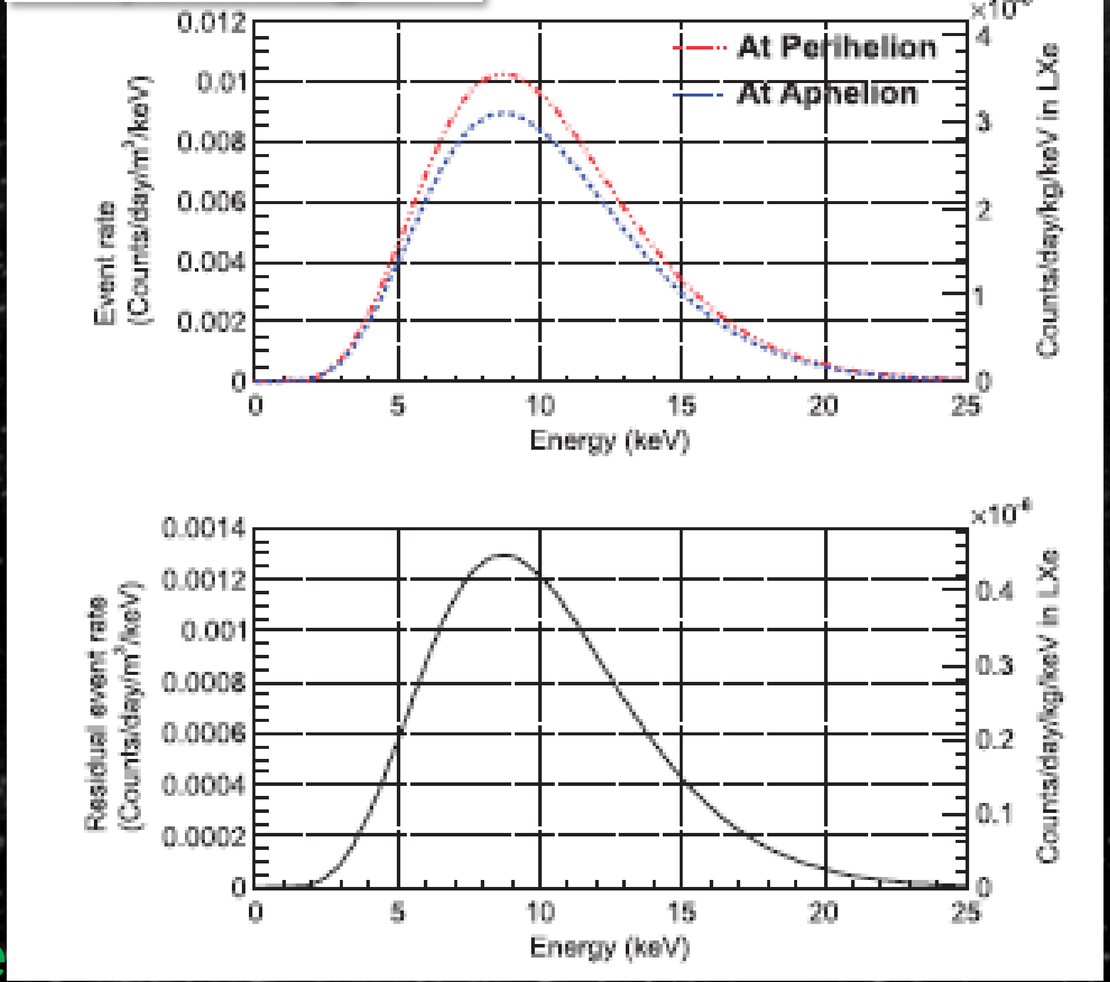
• XMASS other results

- Kaluza-Klein solar AXION
- Extra dimension AXION: mass ~keV
- Thermally produced in the Sun ⇒ gravitationally trapped
  ⇒ decays in the detector

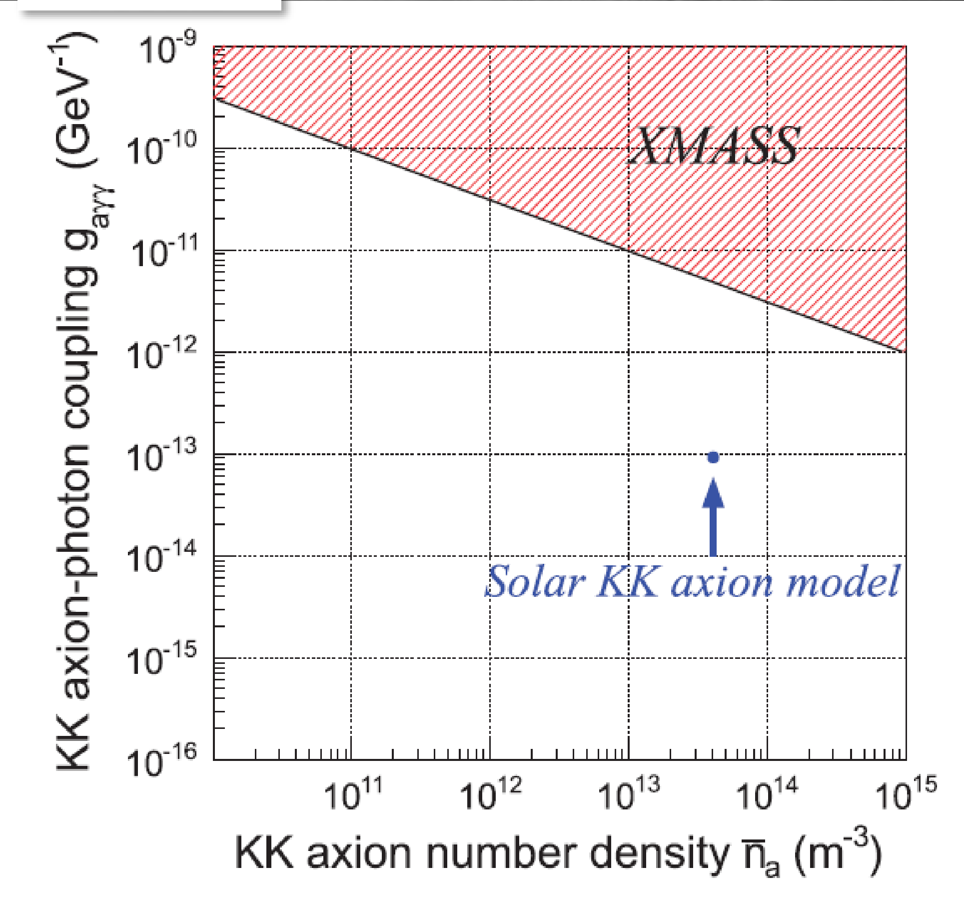
Prog. Theor. Exp. Phys. **2017**, 103C01 (10 pages)

N.Oka *et. al.*

expected signal

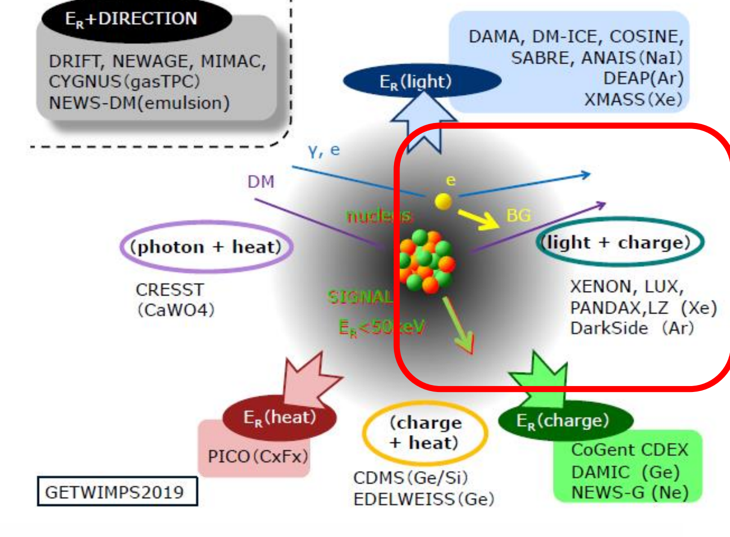


result

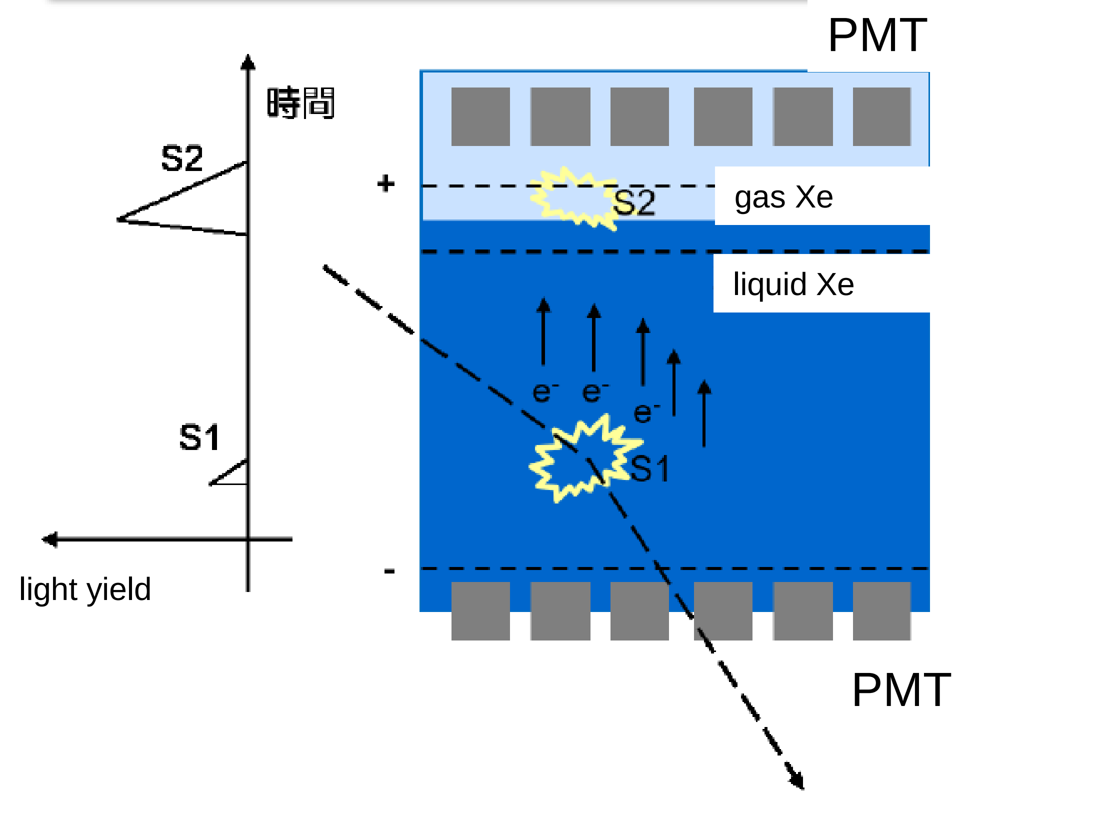


- First experimental limit!

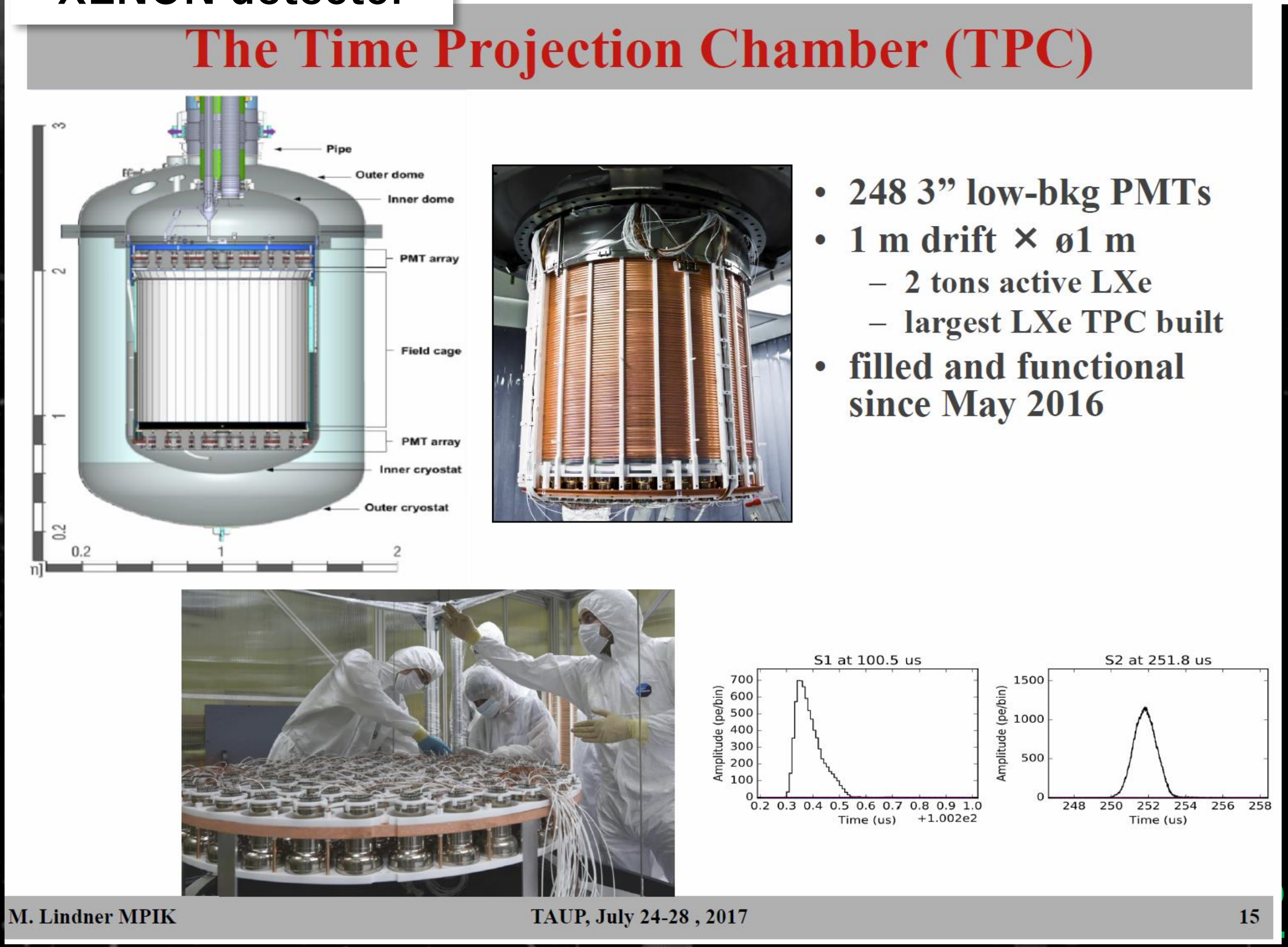
- Liquid xenon：double-phase（liquid+gas)
  - XENON1T, LUX, PandaX-II
  - Several 100kg ～ 1ton
  - Electron background can be discriminated



Double phase detector principle



XENON detector

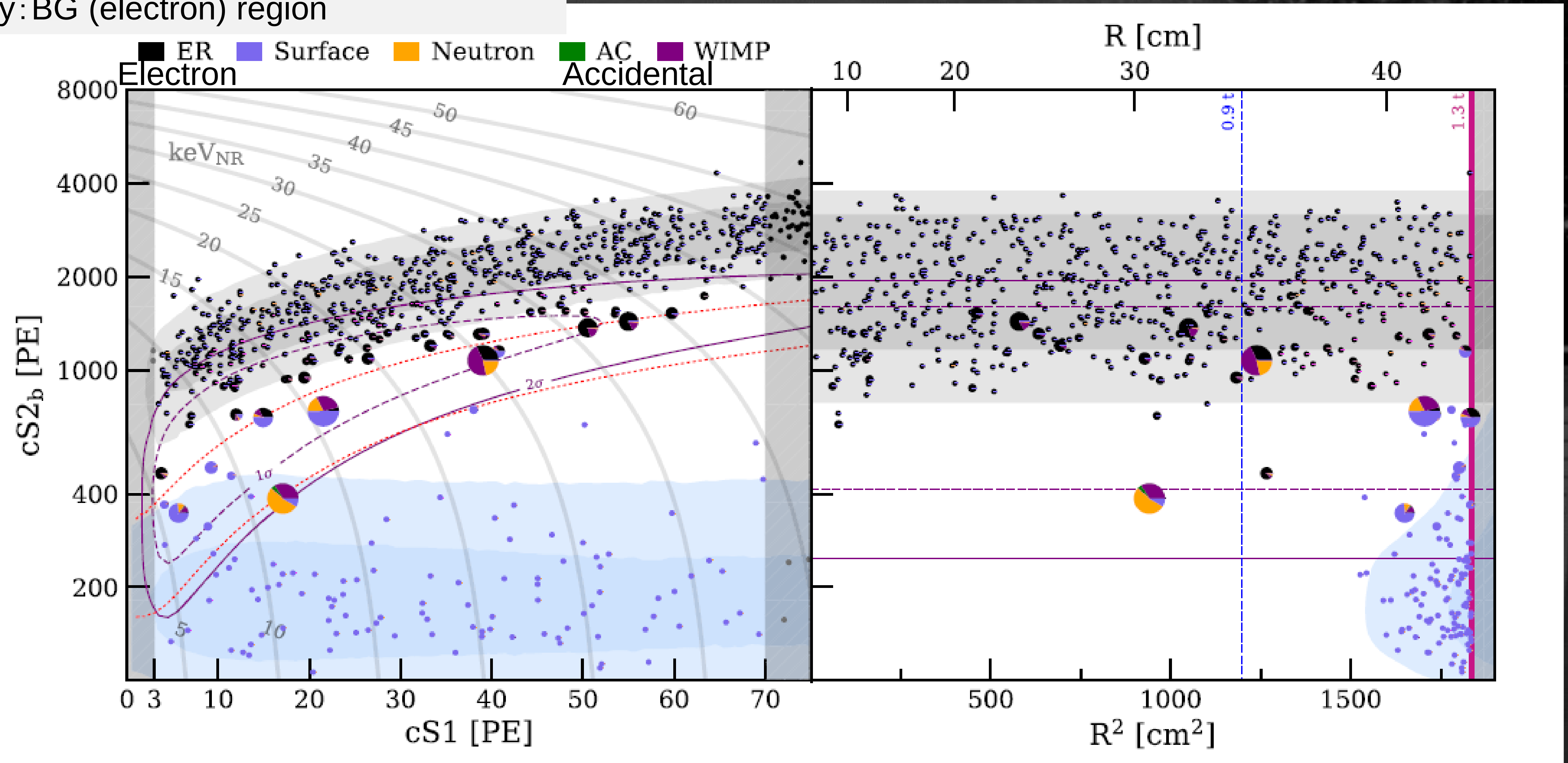


- XENON1T
  - Some events in ROI
  - ER : radon   neutron : neutrons from α particle

Dark Matter Search Results from a One Ton-Year Exposure of XENON1T

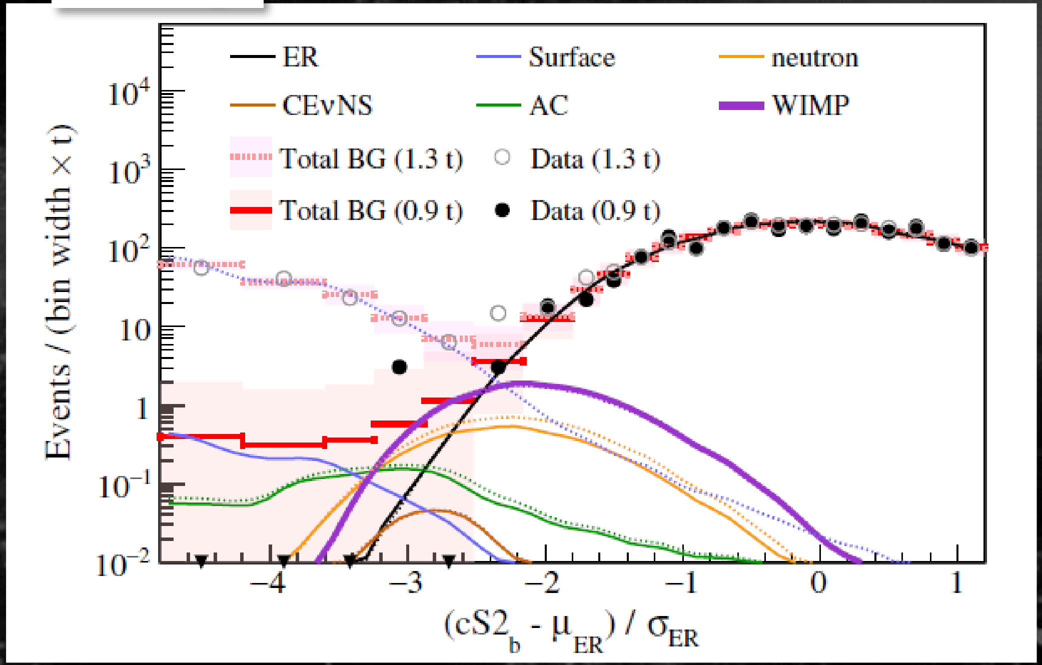
PHYSICAL REVIEW LETTERS **121**, 111302 (2018)

red : nuclear recoil (signal) region
gray : BG (electron) region

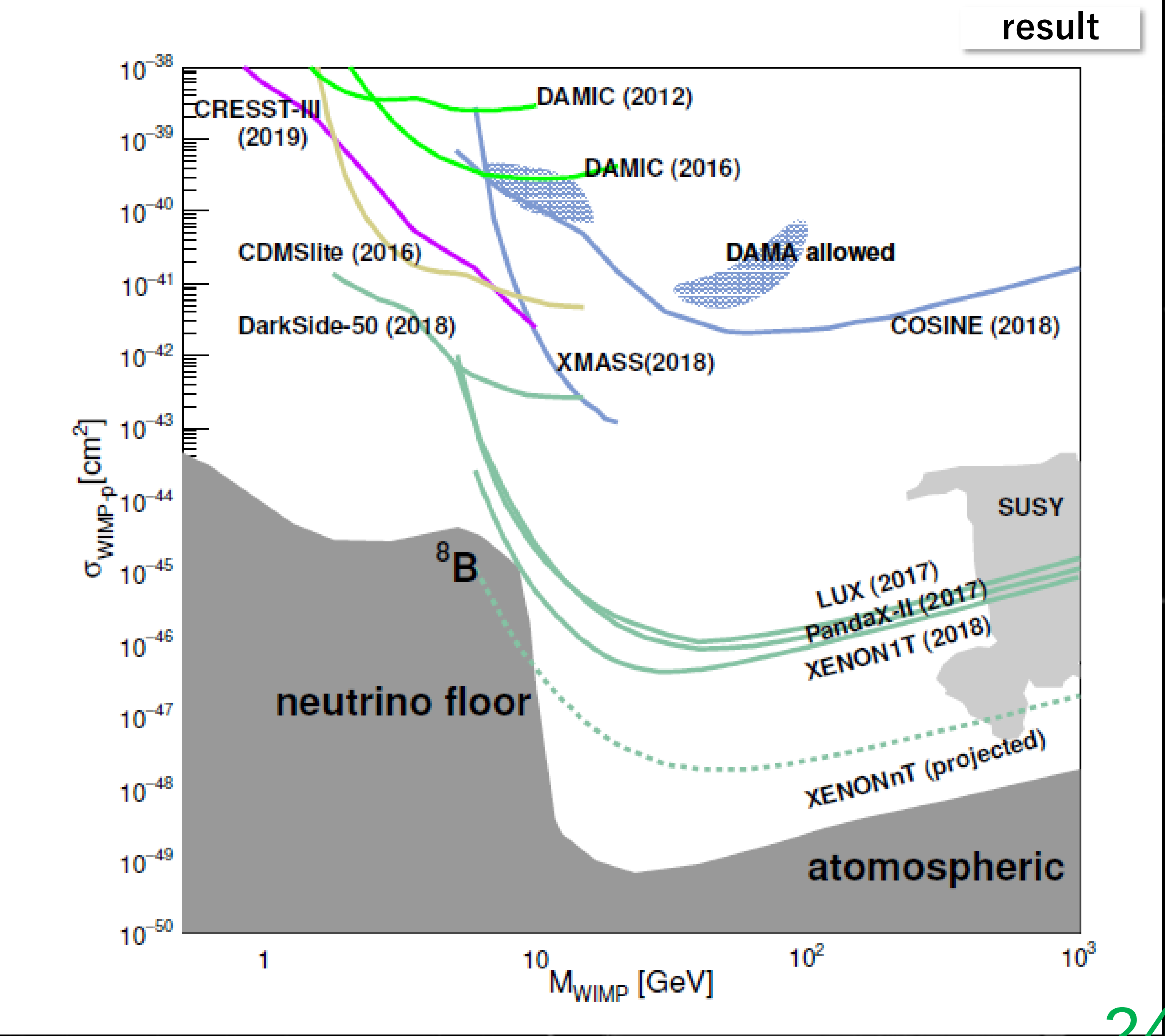


• XENON1T 1ton • year limit

fitting



result

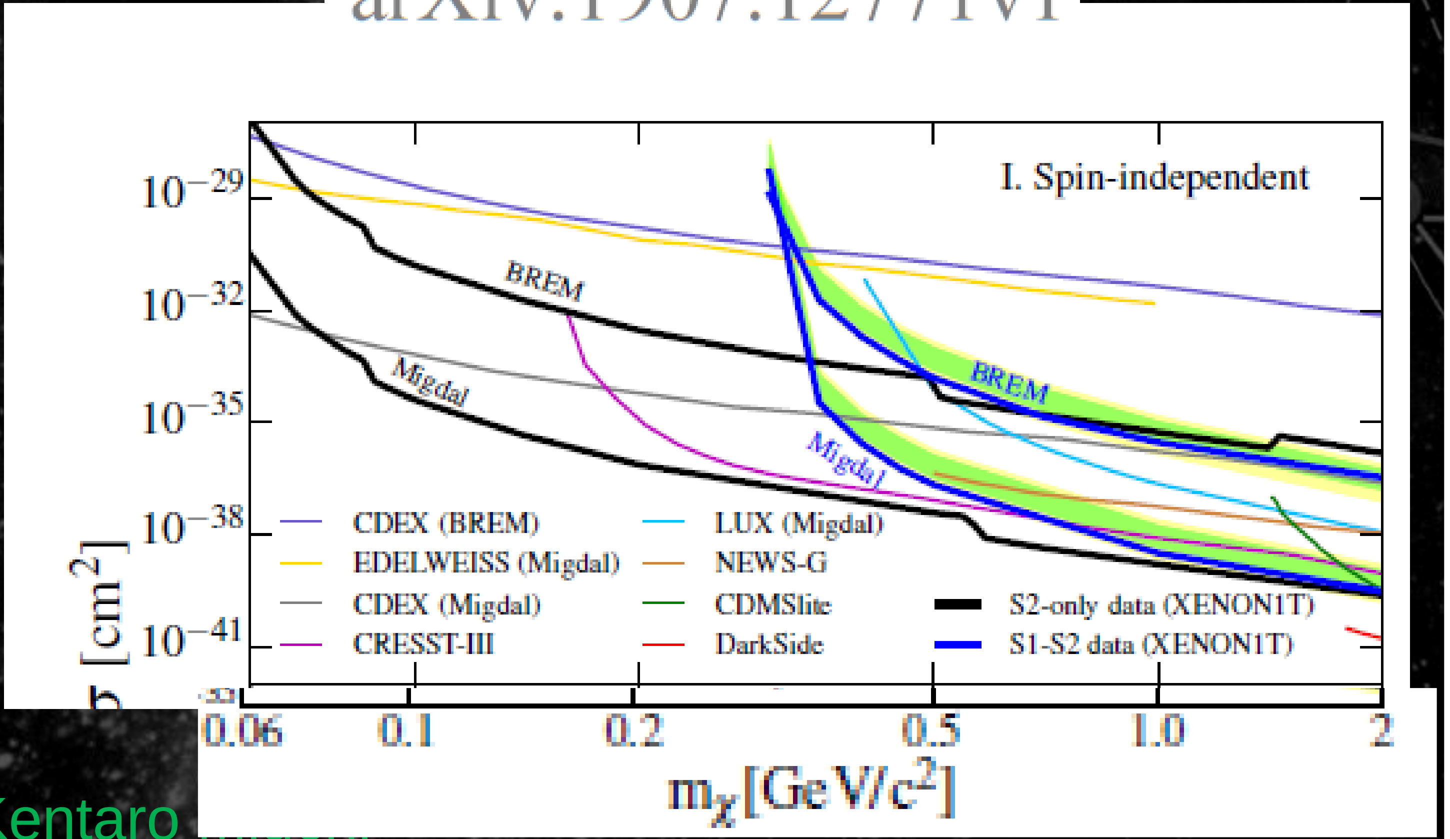


- Leading the direct detection
- SUSY predictions are investigated

• Recent results by liquid xenon detector

- Low mass search with "MIGDAL effect"
- Ordinary nuclear recoil : ionization along the track
- Low energy recoil : ionization efficiency is low
  ⇒ cannot be detected
- Very rare case electrons are emitted

arXiv:1907.12771v1



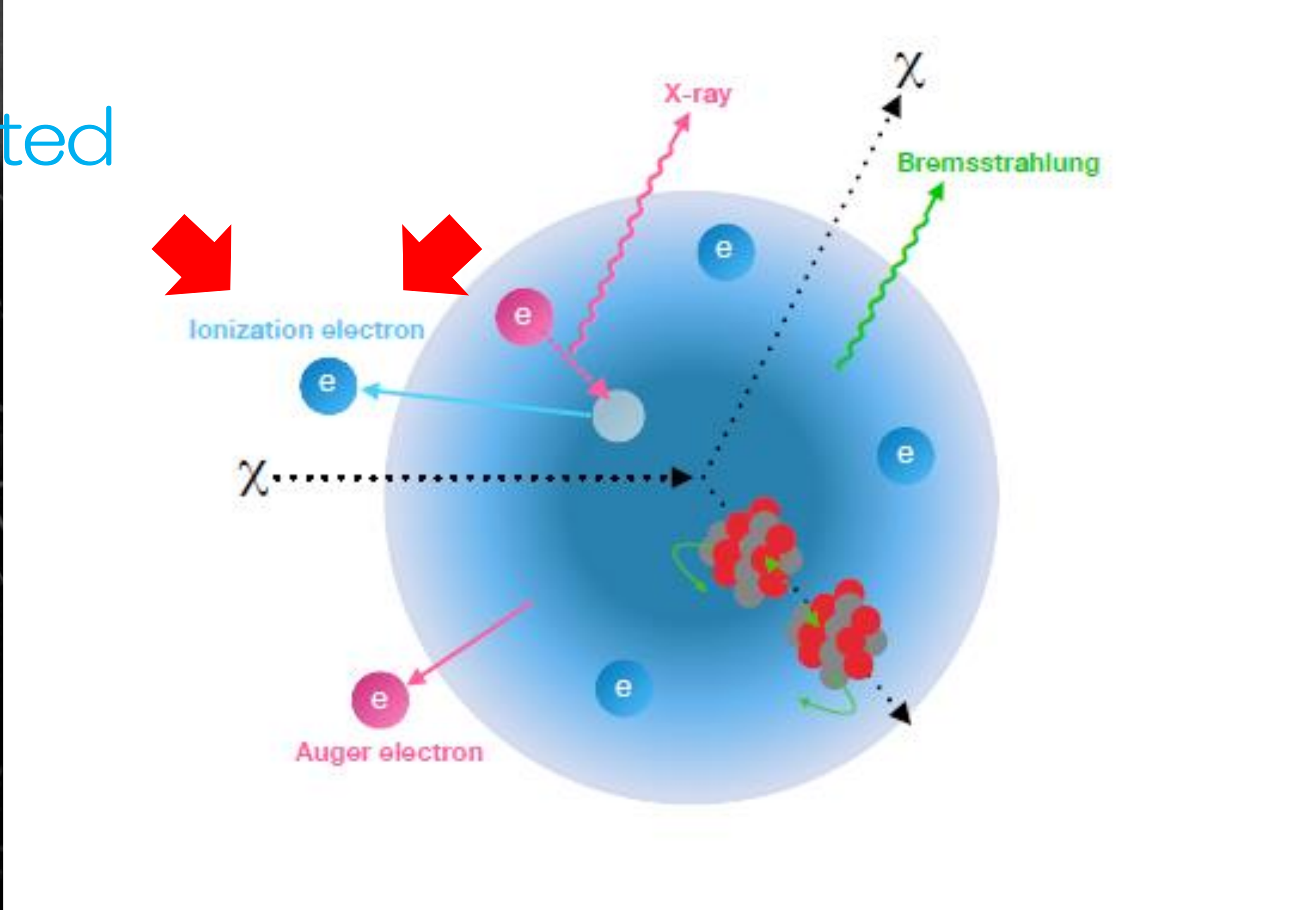
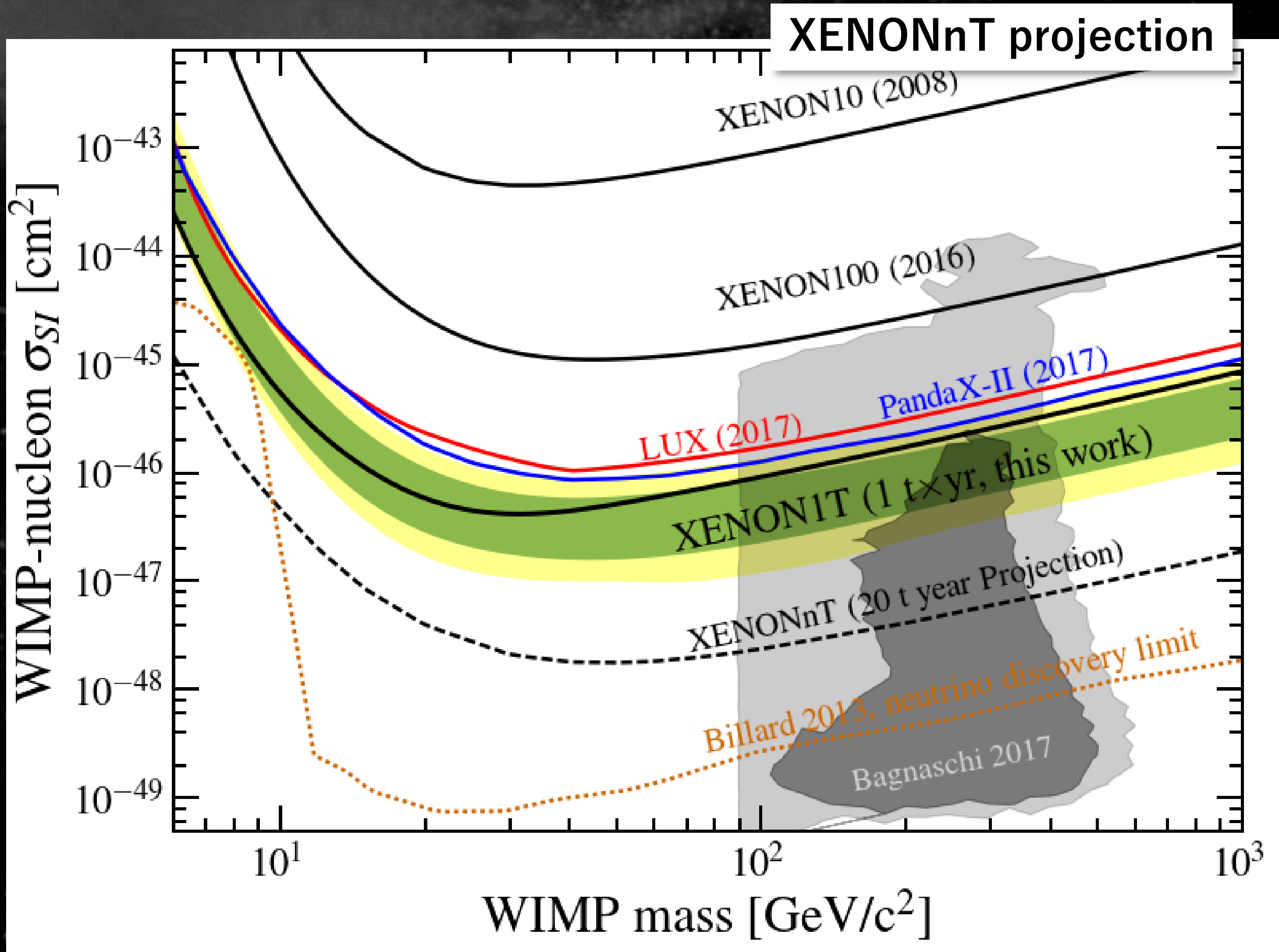


FIG. 1. Illustration of the ER signal production from BREM (green) and Migdal processes (pink) after elastic scattering between DM (χ) and a xenon nucleus.

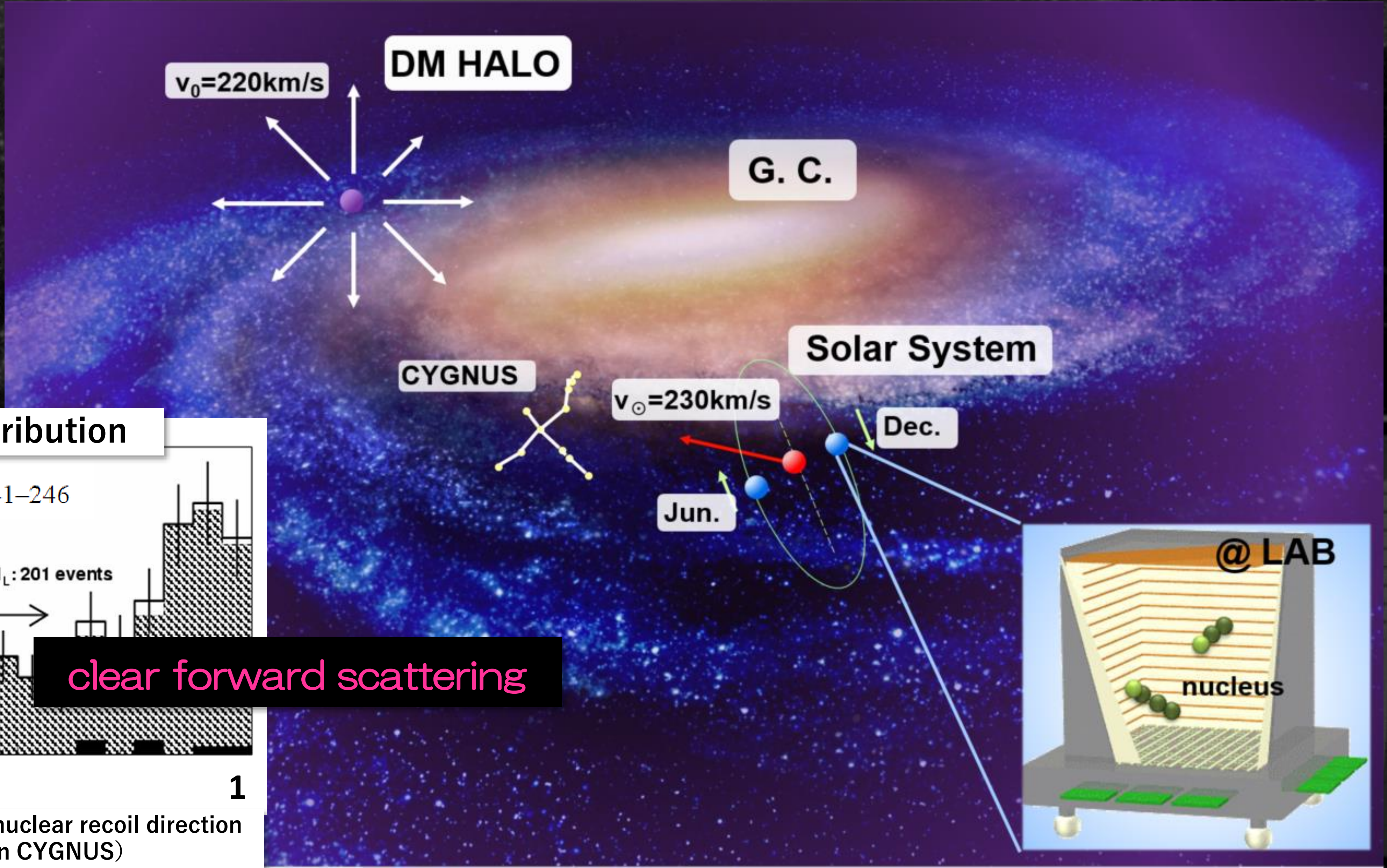

Future

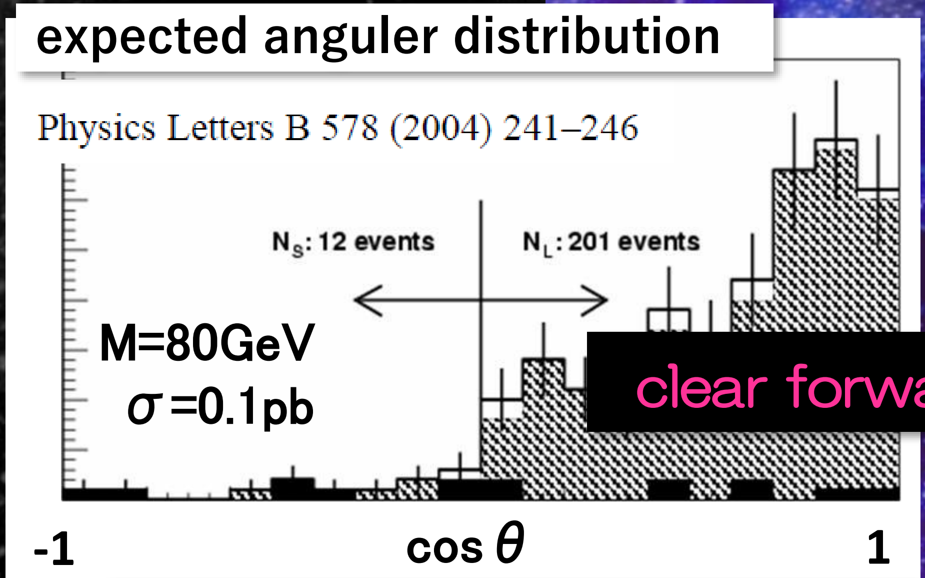
- Upcoming detectors: XENONnT, LZ
  - Fiducial mass: several ton
  - Constructions ongoing: observation 2020～
  - Japanese group （Kobe, Nagoya, Tokyo） joined XENONnT in 2017
  - Goal:　a few ×$10^{-48}$$cm^2$



• Directional search : concept "CYGNUS"

- More robust evidence than annual modulation
- Study the DM nature after discovery



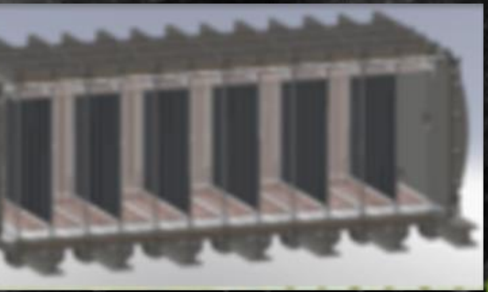


(θ : angle between the nuclear recoil direction and constellation CYGNUS)

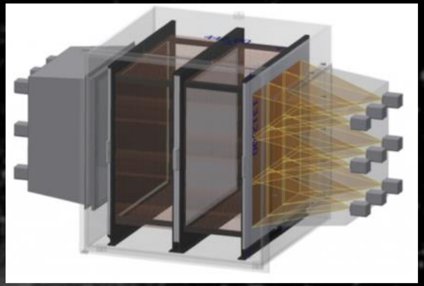
World-wide CYGNUS (ver. TAUP2019)

NEWAGE/CYGNUS-KM
Kamioka, Japan
SF6 / CF4
Strip readout

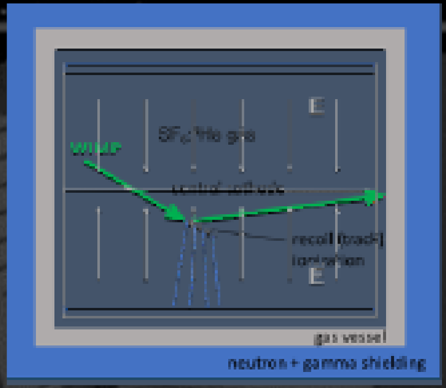
CYGNUS-10
Boulby, UK
$10m^3$ He:SF_6
GEM + wire readout



CYGNO-Initium
Gran Sasso, Italy
He CF_4 (SF_6)
sCMOS+PMT readout



CYGNUS-HD10
SURF, USA
He:CF_4:C_4H_{10}
Strip readout



CYGNUS-OZ
Stawell, Australia
R&D leading to 1 m^3
Long-term plan 10 m^3

multi-site observatory

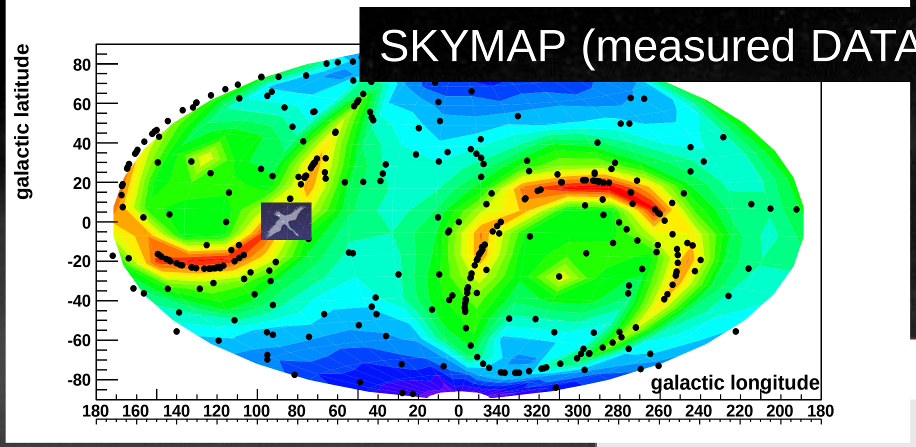
- NEWAGE (Kobe+)
  - 3D tracking
    - μ-PIC
    - SKYMAP
  - CF_4 gas
    - High spatial resolution
    - Spin-Dependent search

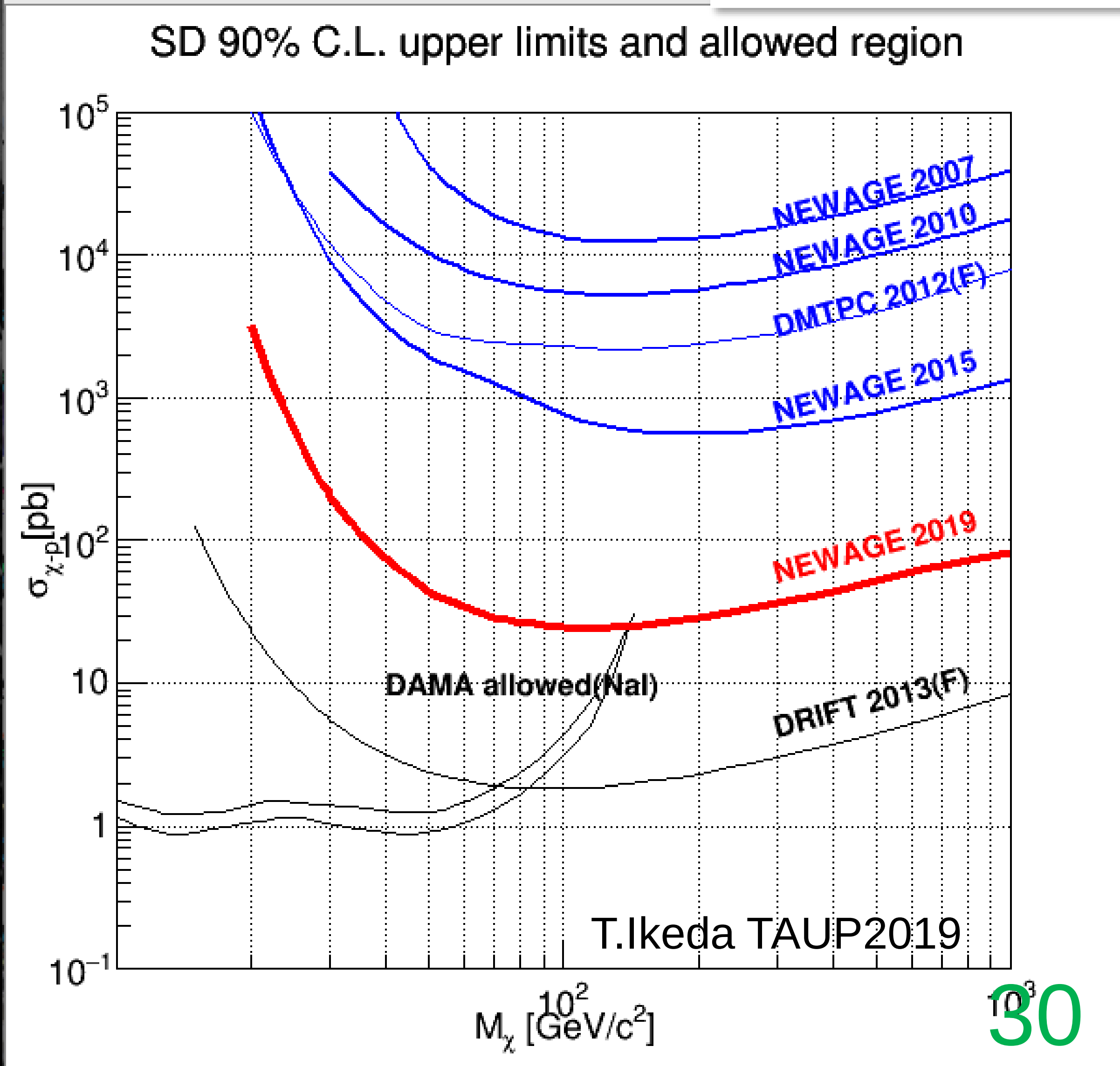
- Proposal

  PLB 578 (2004) 241
- First directional search

  PLB 654 (2007) 58
- Underground measurements

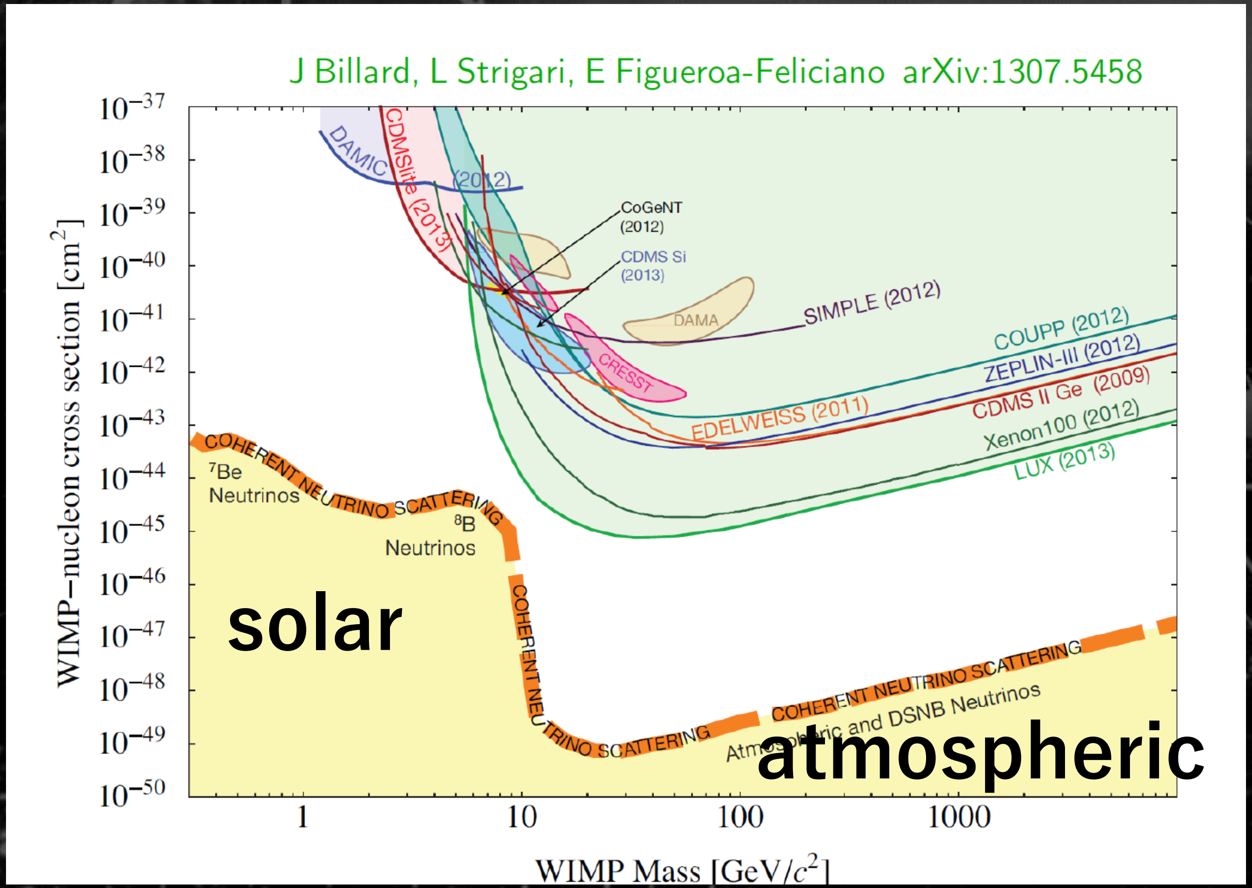
  PLB 686 (2010) 11, PTEP (2015) 043F01S, TAUP2019



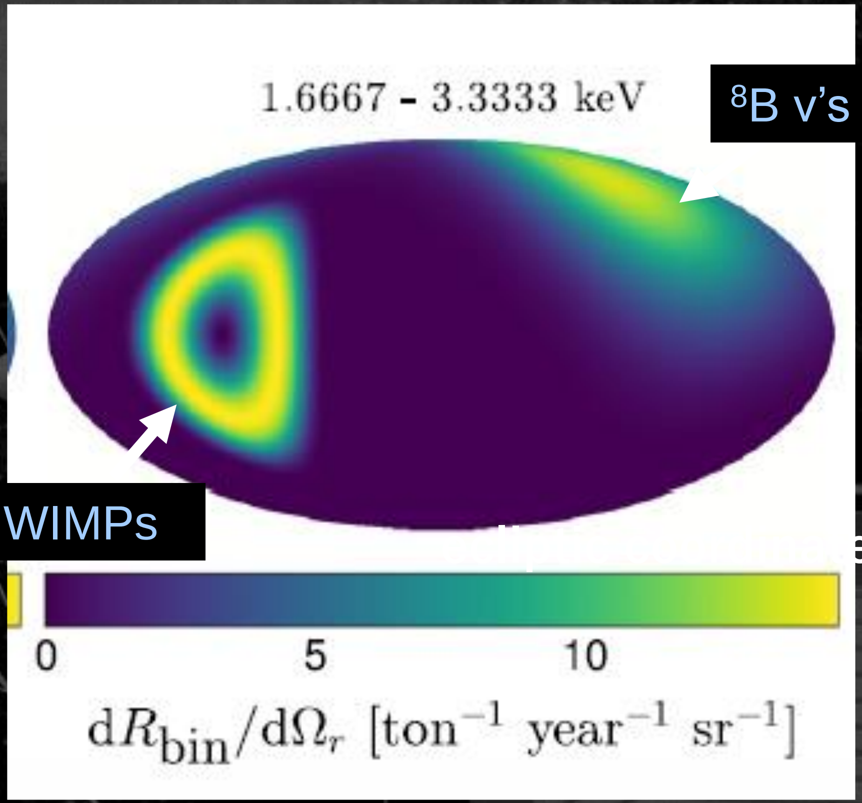


Toward discovery

- Potential to search beyond the "neutrino floor" where large detectors are reaching.



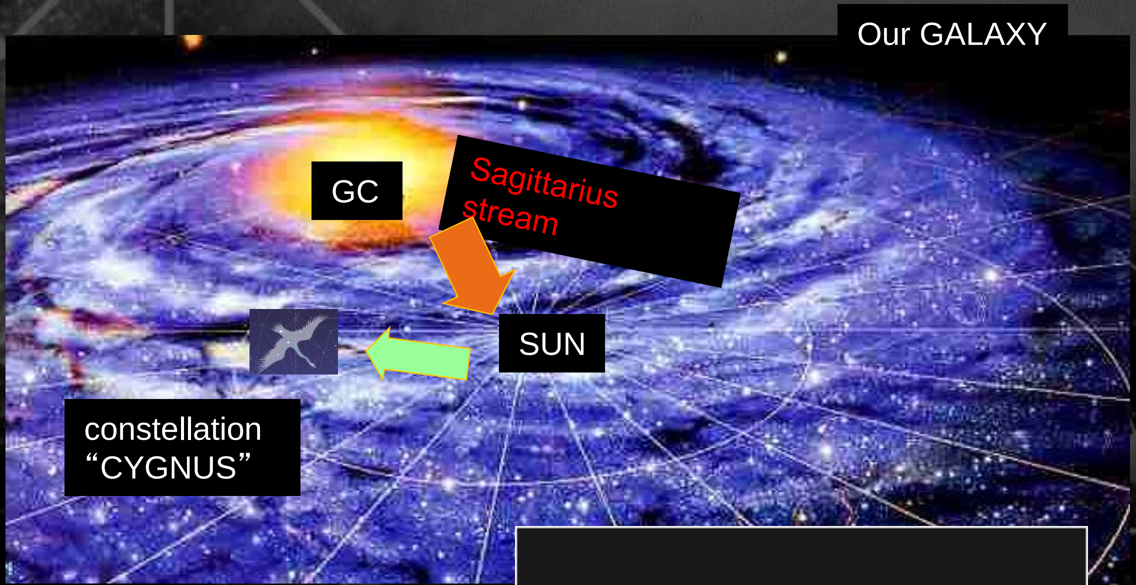
F. Mayet et al. / Physics Reports 627 (2016) 1–49

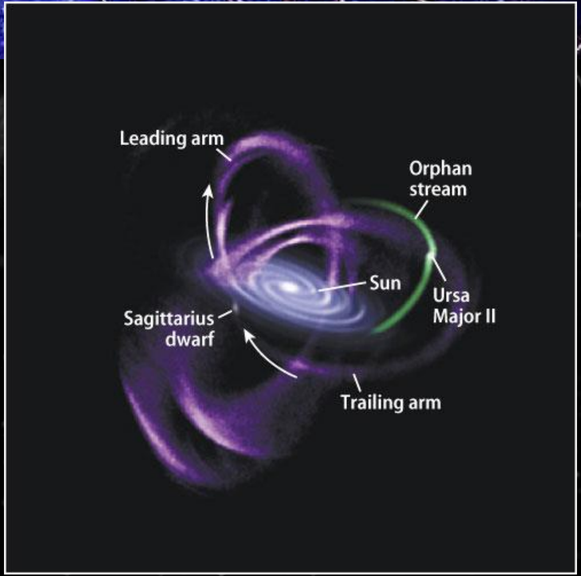


- distinguishable

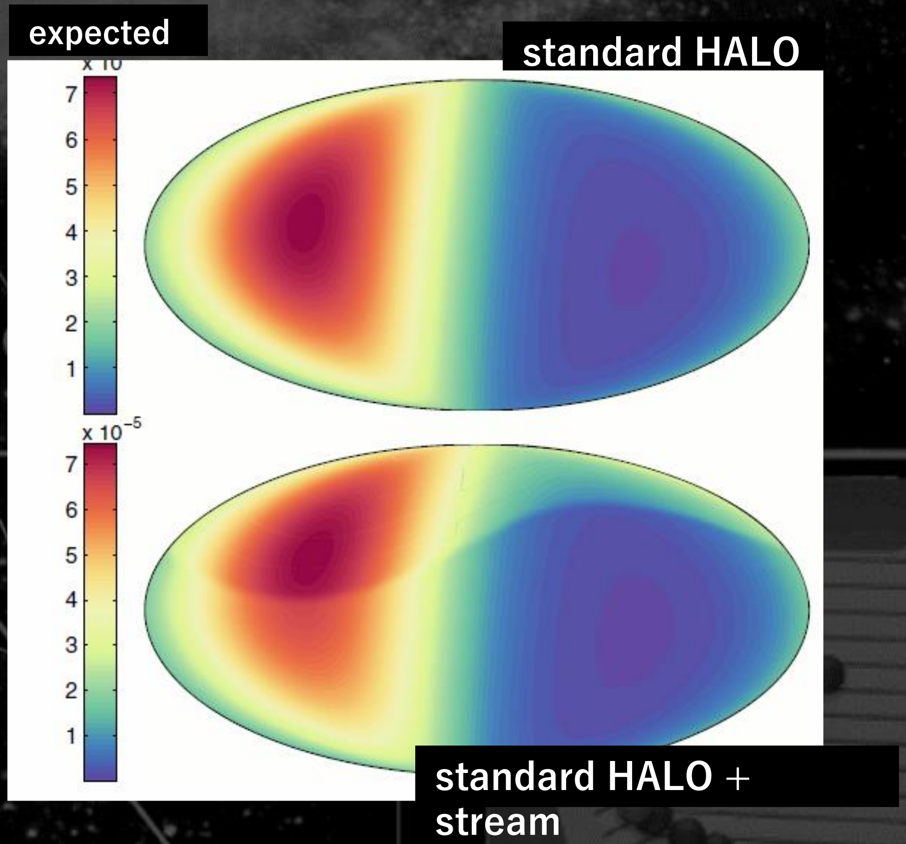
• CYGNUS After Discovery: astronomy/cosmology

- Test the HALO model
- (ex) Sagittarius stream





PHYSICAL REVIEW D **90,** 123511 (2014)

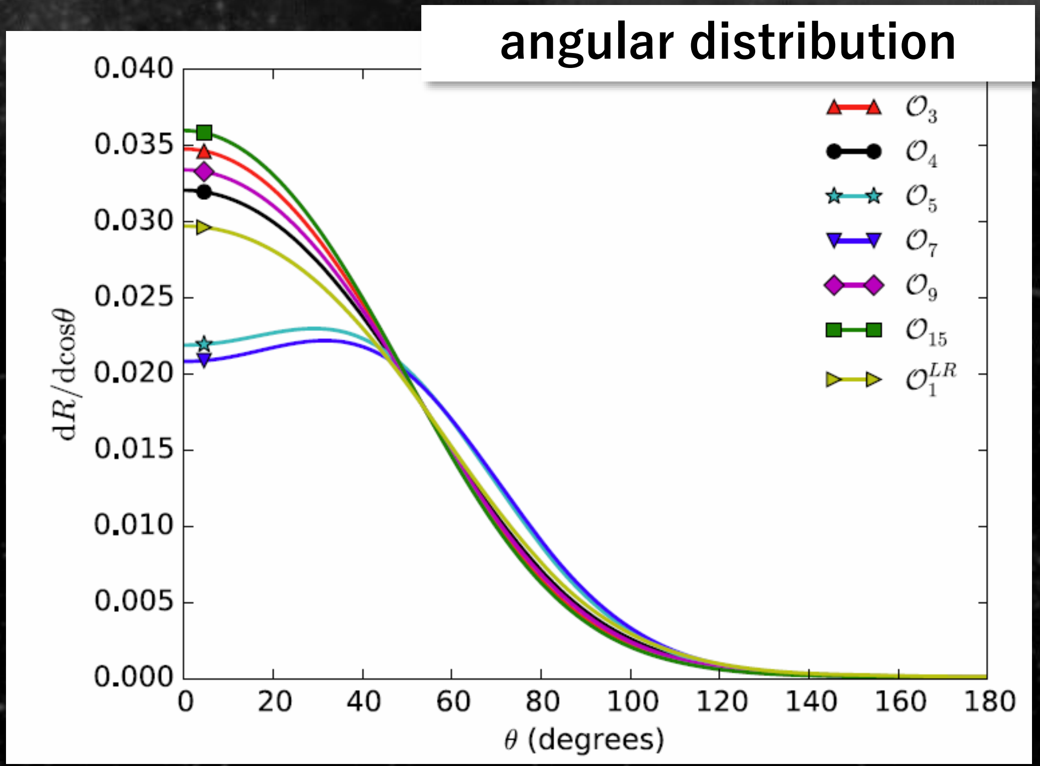


galactic coordinate

- **streams, debris…**

CYGNUS After Discovery : particle physics

- Some interaction provide characteristic angular distributions



PHYSICAL REVIEW D **92**, 023513 (2015)

operator

SI SD

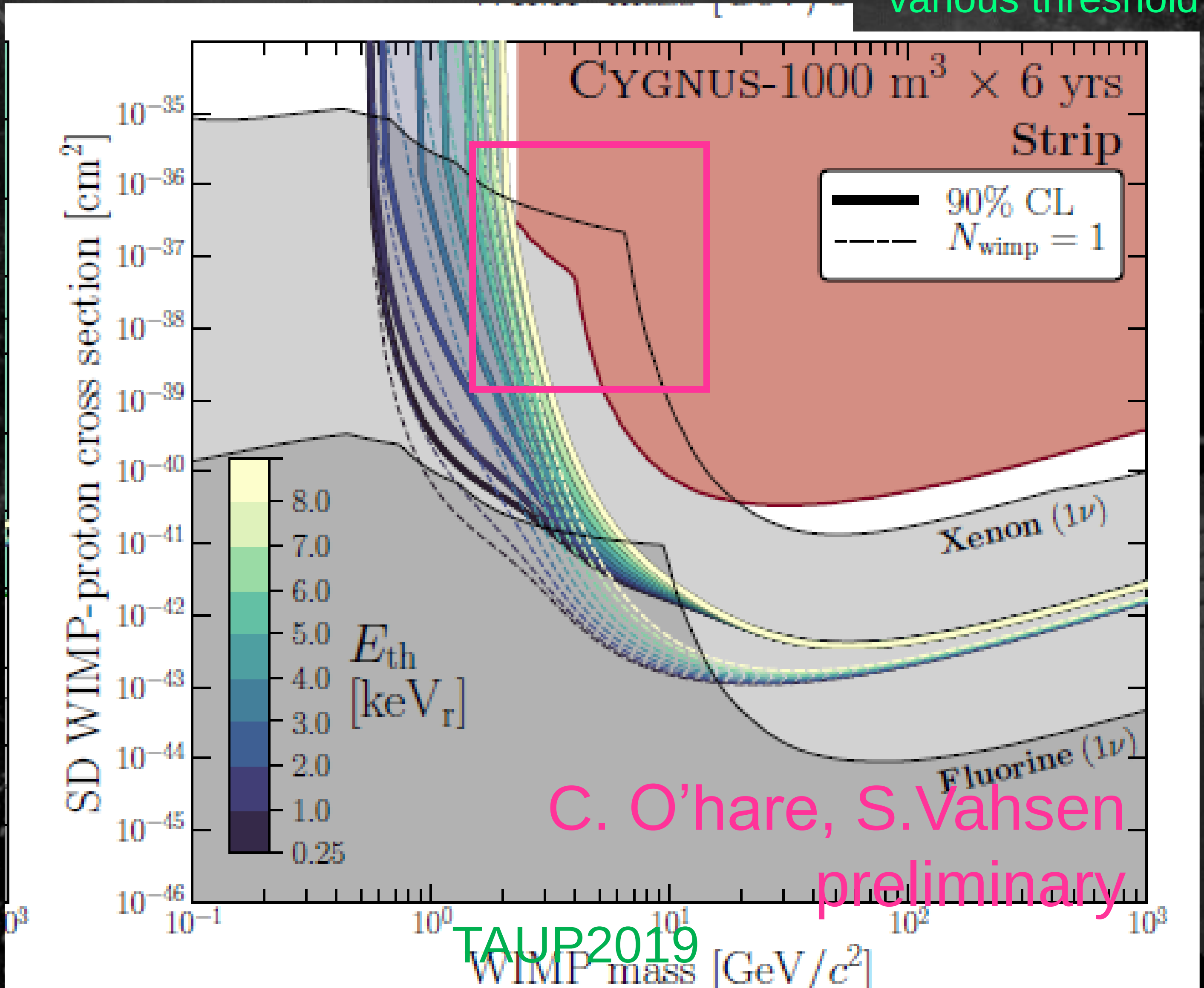
$$
\text{Proportional to}
\begin{cases}
1 & : \mathcal{O}_1, \mathcal{O}_4, \\
v_\perp^2 & : \mathcal{O}_7, \mathcal{O}_8, \\
q^2 & : \mathcal{O}_9, \mathcal{O}_{10}, \mathcal{O}_{11}, \mathcal{O}_{12}, \\
v_\perp^2 q^2 & : \mathcal{O}_5, \mathcal{O}_{13}, \mathcal{O}_{14}, \\
q^4 & : \mathcal{O}_3, \mathcal{O}_6, \\
q^4(q^2 + v_\perp^2) & : \mathcal{O}_{15}, \\
q^{-4} & : \mathcal{O}_1^{\mathrm{LR}}.
\end{cases}
$$

Paper in internal review

• Realistic simulation (strip readout)

1000m^3
strip readout with
various threshold

even 10m^3 detector
(3 order magnitude higher than
the shown curves) can start
exploring Xe neutrino floor



C. O'hare, S.Vahsen
preliminary

SUMMARY

- Dark Matter Direct Detection
  - Hunting in the log-log field
- Large Mass Detectors：Liq Xe
  - Leading the direct search
- Directional Detectors：gas detectors
  - Clear evidence・DM nature study