# Thanks to the organizers for a fantastic meeting!

# From the organizers

- The aim of CYGNUS 2023 is to bring together experimentalists and theorists interested in developing detectors with the capability of detecting the directions of recoiling particles, especially for low-energy applications.
- The scientific scope of the workshop is broad and will cover applications from across particle physics, astroparticle physics, and nuclear physics.

# Next steps

- CYGNUS 2023 has been very successful in broadening the CYGNUS workshop scope to directional recoil detection
- We would like to take advantage of the building momentum and formalize (slightly) how we work together
- We would like to form a new *CYGNUS Consortium for Directional Recoil Detection*

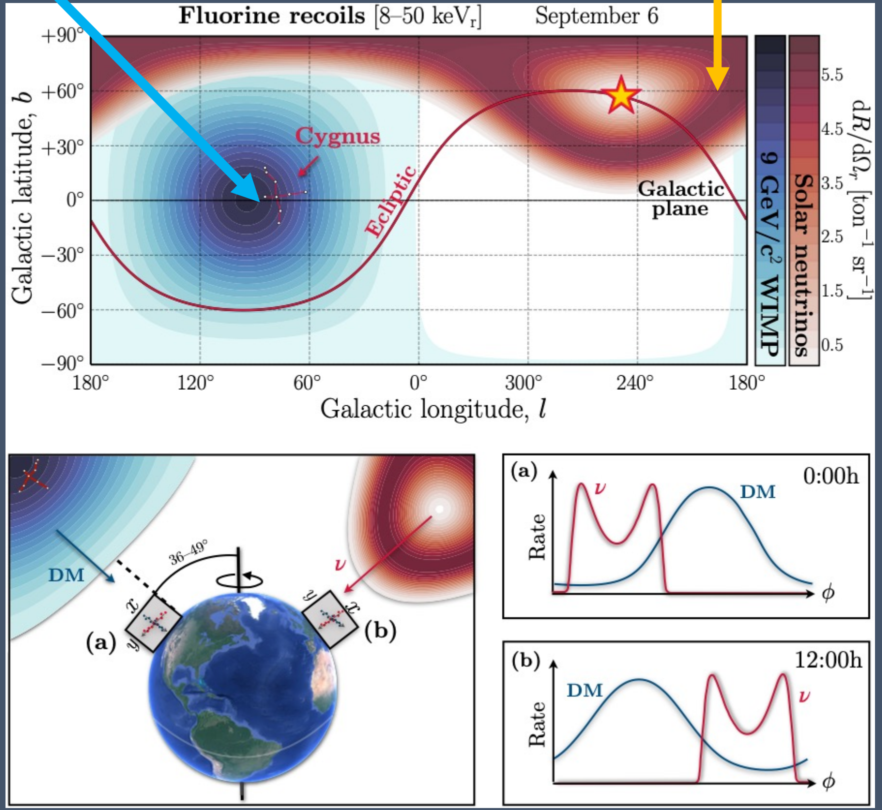
# <=2023: CYGNUS proto-collaboration

- 55 signed members from the US, UK, Japan, Italy, Spain, China
- These 55 folks signed a Memorandum of Understanding (MoU)
- Close collaboration
- Decicated gas and physics meetings
- Interim Steering group:
  - Neil Spooner (Sheffield, UK)
  - Sven Vahsen (Hawaii, USA)
  - Kentaro Miuchi (Kobe, Japan)
  - Elisabetta Baracchini (GSSI/INFN, Italy)
  - Greg Lane (Australian National University)

Recoils from solar neutrinos

Dark Matter recoils

arxiv:2102.04596

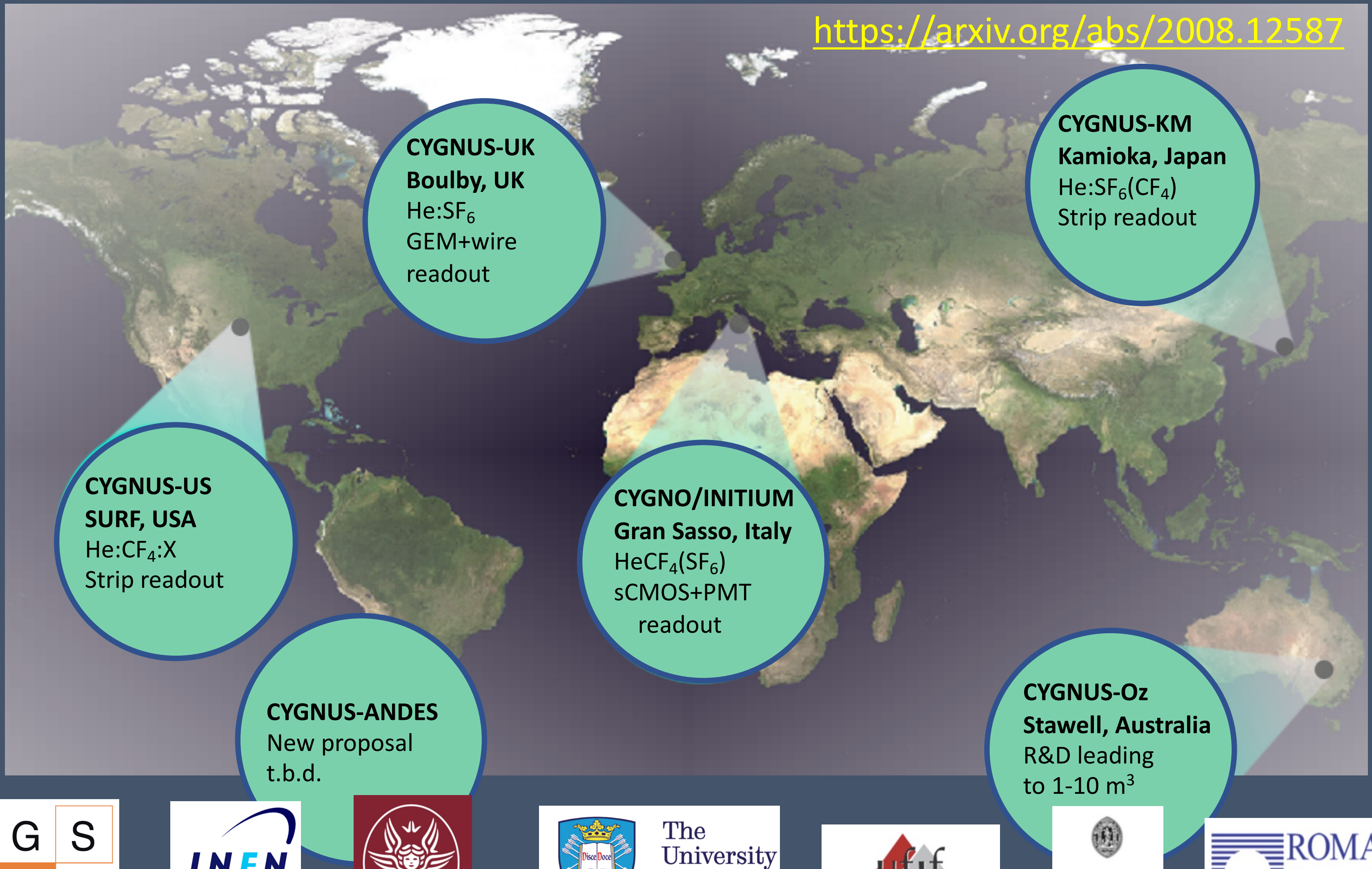



The dark matter wind is expected to come from the constellation Cygnus.

# Long term CYGNUS Vision: Multi-site Galactic Recoil Observatory

## with directional sensitivity to dark matter and neutrinos

https://arxiv.org/abs/2008.12587



# Proposal/Plans going forward (>=2024)

- Expand steering group
  - Neil Spooner (Sheffield, UK)
  - Sven Vahsen (Hawaii, USA)
  - Kentaro Miuchi (Kobe, Japan)
  - Elisabetta Baracchini (GSSI/INFN, Italy)
  - Greg Lane (Australian National University)
  - Ciaran O'Hare (Sydney, Australia)
  - Dinesh Loomba (New Mexico, Hawaii)
- This steering group will work to form the CYGNUS consortium
- CYGNUS consortium *for Directional Recoil Detection* --- broadened scope compared to the CYGNUS proto-collaboration

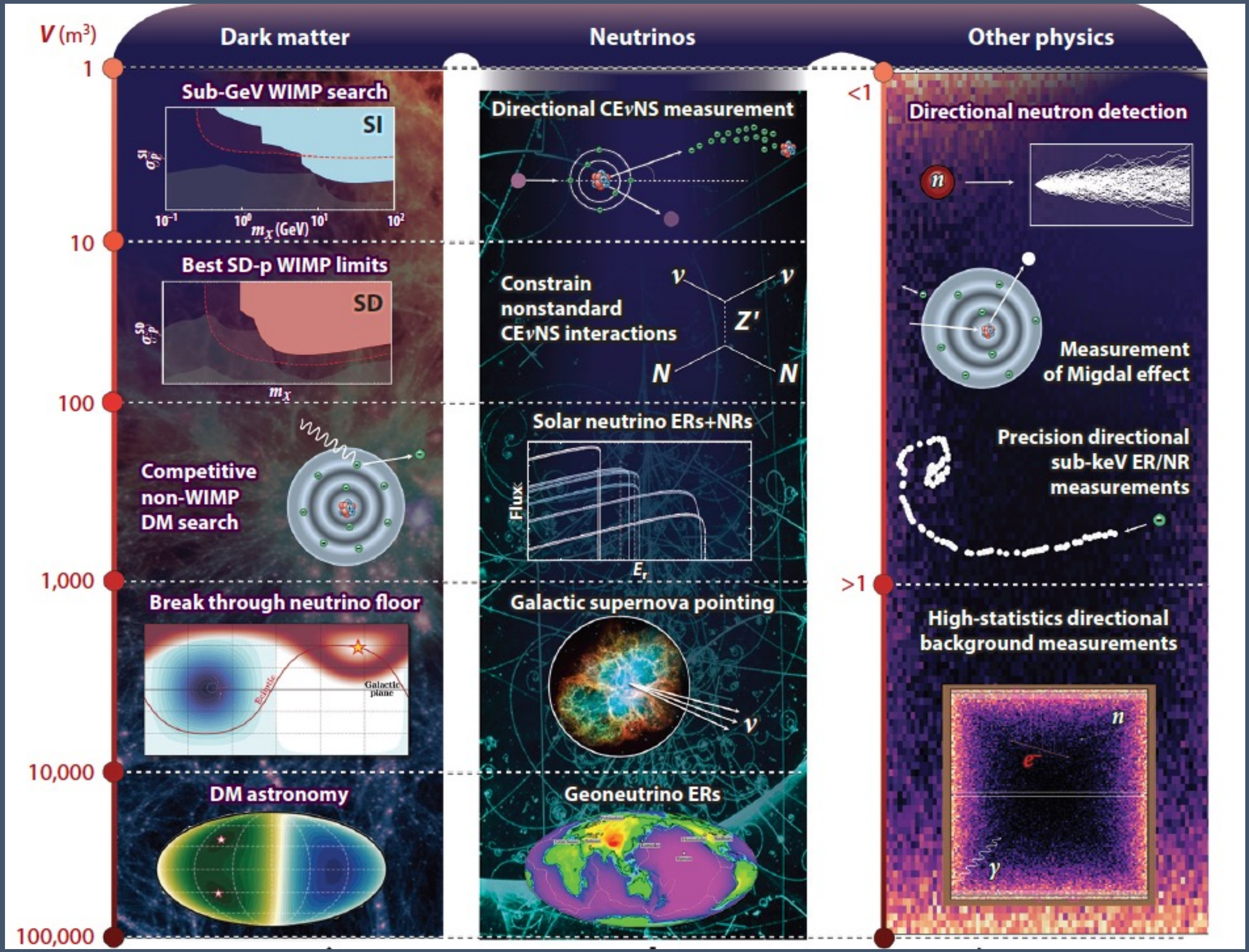
# CYGNUS consortium vision I

- Anyone interested in directional recoil detection is welcome to join
- Individual members sign up so that our membership is clear
- No financial obligations or agreement to data sharing initially, members only agree to their institution's name and logo being used in our talks
- Coordinate detector R&D, theory work, and share software to avoid duplication, thereby maximizing our impact
  - Physics sensitivity studies
  - Technical designs (e.g. gas vessels, shielding)
  - MPGD amplification devices
  - Charge readout
  - Optical readout
  - Simulation and analysis software tools

# CYGNUS consortium vision II

- We eventually envision collaborating on funding proposals for inter-mediate size DM/neutrino demonstration experiments above/below ground
  - Possible example: direction-sensitive CEvNS experiment at SNS Oak Ridge in the USA
- Steering group maintains / organizes infrastructure for joint work
  - Membership directory
  - Web site
  - Mailing lists
  - Expanded range of regular topical meetings
  - Code repository
  - Speakers committee
  - Summary slides and PR material for use in talks
  - CYGNUS international workshop series

- By working together, we stand stronger!



# Comments or suggestions?

# backup

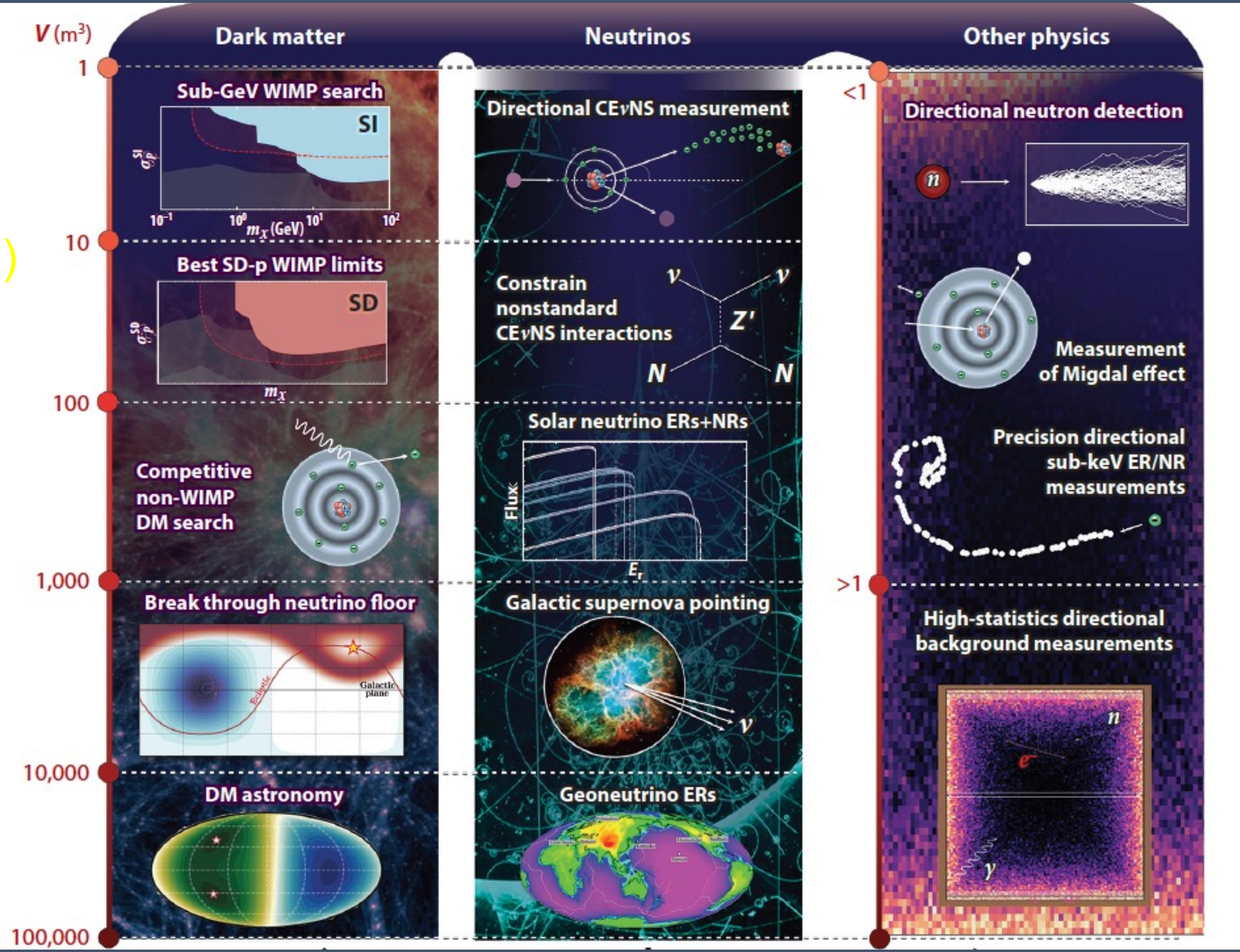
# Opportunities for a 30+ year physics program

arxiv:2102.04596

Approx. volume of gas TPC required.
Expect 10 $m^3$ modules eventually

Exposure, size

- Quenching factor and recoil physics (TUNL)
- Migdal Effect measurement
- Coherent Elastic Neutrino-Nucleus Scattering (CEνNS) at ORNL (SNS) or Fermilab (NuMI and later LBNF)
- Competitive DM limits in SI and SD
- CEνNS and e-recoils from solar neutrinos
- Efficiently penetrating the LDM ν floor
- Observing galactic DM dipole
- Measuring DM particle properties and physics
- Geoneutrinos
- WIMP astronomy




- New physics opportunities for each factor of 10 increase in exposure
- Both guaranteed measurements (yellow text) and novel, exciting searches --- across frontiers!

# Dark Matter via Nuclear Recoils (<2019)

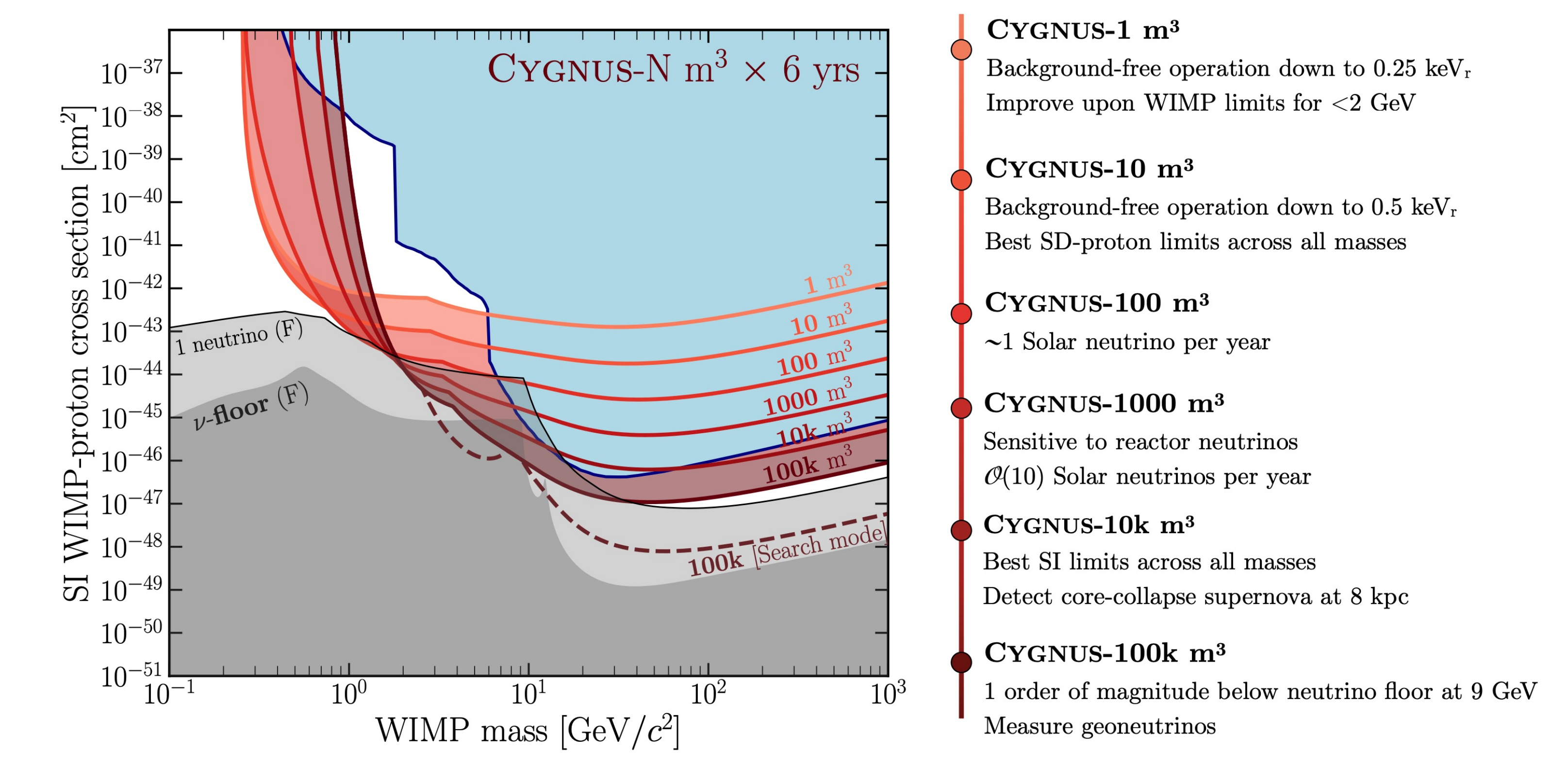



FIG. 34. Summary of the projected SI WIMP 90% CL exclusion limits as a function of the total fiducial volume of the network of detectors comprising the CYGNUS experiment. All experimental exposures are multiplied by a running time of 6 years such that the listed benchmarks are all approximately multiples of 1 ton year (1 ton year corresponds to 1000 $m^3$). We shade in blue the currently excluded limits on the SI WIMP-nucleon cross section as of 2020. The thresholds are increased evenly between 0.25 and 8 $keV_r$ and for each increasing volume to illustrate the range of possible thresholds envisaged for the final experiment. Below the final volume we also extend the reach by including the possibility of a "search mode" experiment which would have 1520 Torr of $SF_6$ (as opposed to 5 Torr), but would have no directional sensitivity.

https://arxiv.org/abs/2008.12587 (2020)

## 2021

ANNUAL REVIEWS

*Annual Review of Nuclear and Particle Science*

Directional Recoil Detection

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"Directional Recoil Detection": Expanded physics program for directional detectors (link)

## 2022

# Recoil imaging for dark matter, neutrinos, and physics beyond the Standard Model

**Snowmass 2021 inter-frontier white paper:**
IF5: Micro-pattern gas detectors
CF1: Particle-like dark matter
NF10: Neutrino detectors

Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

arXiv:2203.05914v3 [physics.ins-det] 17 Jul 2022

**Abstract**

Recoil imaging entails the detection of spatially resolved ionization tracks generated by particle interactions. This is a highly sought-after capability in many classes of detector, with broad applications across particle and astroparticle physics. However, at low energies, where ionization signatures are small in size, recoil imaging only seems to be a practical goal for micro-pattern gas detectors. This white paper outlines the physics case for recoil imaging, and puts forward a decadal plan to advance towards the directional detection of low-energy recoils with sensitivity and resolution close to fundamental performance limits. The science case covered includes: the discovery of dark matter into the neutrino fog, directional detection of sub-MeV solar neutrinos, the precision study of coherent-elastic neutrino-nucleus scattering, the detection of solar axions, the measurement of the Migdal effect, X-ray polarimetry, and several other applied physics goals. We also outline the R&D programs necessary to test concepts that are crucial to advance detector performance towards their fundamental limit: single primary electron sensitivity with full 3D spatial resolution at the ~100 micron-scale. These advancements include: the use of negative ion drift, electron counting with high-definition electronic readout, time projection chambers with optical readout, and the possibility for nuclear recoil tracking in high-density gases such as argon. We also discuss the readout and electronics systems needed to scale-up detectors to the ton-scale and beyond.

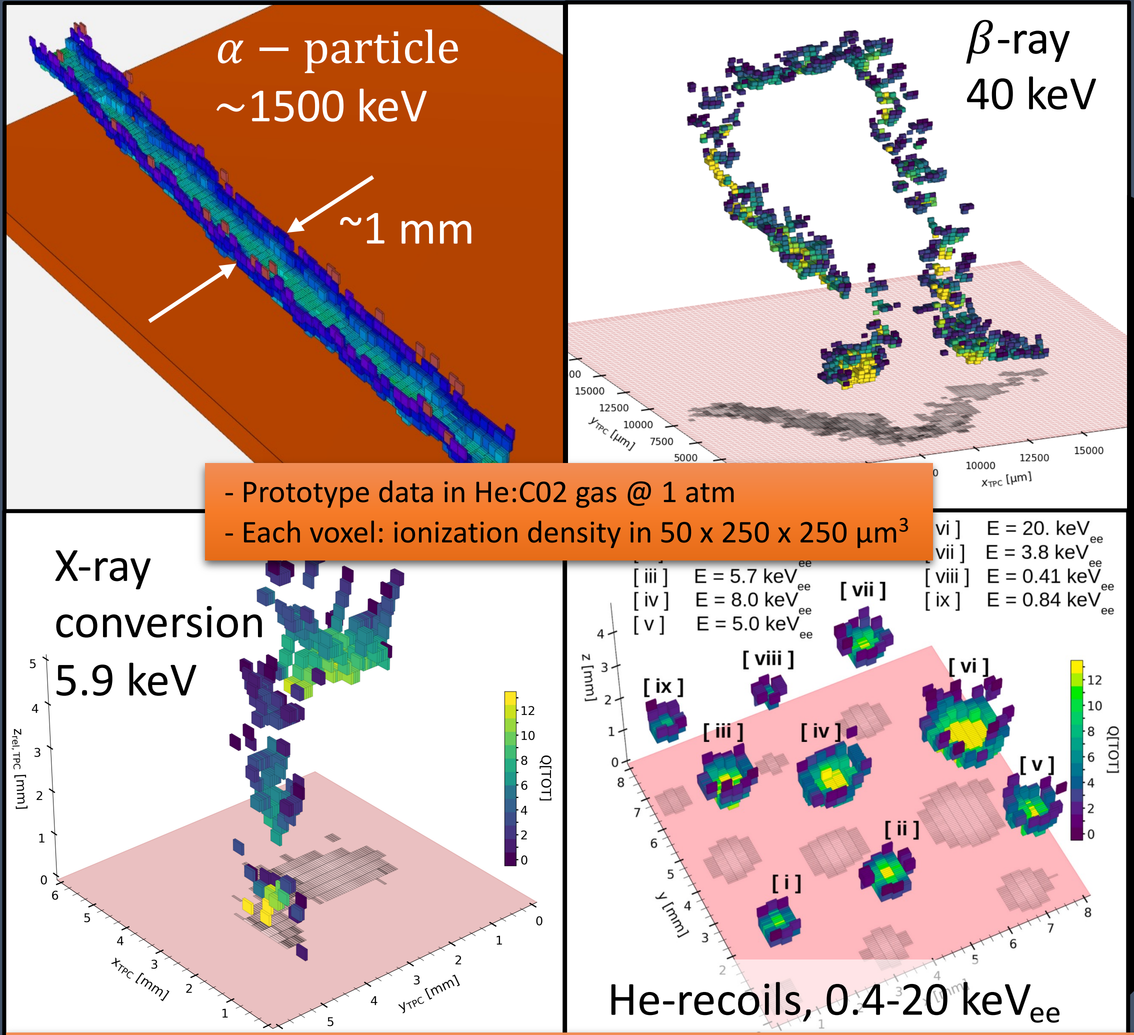
C. A. J. O'Hare (Coordinator)[1,2], D. Loomba (Coordinator)[3], K. Altenmüller[4], H. Álvarez-Pol[5], F. D. Amaro[6], H. M. Araújo[7], D. Aristizabal Sierra[8,9], J. Asaadi[10], D. Attié[11], S. Aune[11], C. Awe[12,13], Y. Ayyad[5], E. Baracchini[14a,14b,14c], P. Barbeau[12,13], J. B. R. Battat[14], N. F. Bell[15], B. Biasuzzi[11], L. J. Bignell[16], C. Boehm[1,2], I. Bolognino[17], F. M. Brunbauer[18], M. Caamaño[5], C. Cabo[5], D. Caratelli[19], J. M. Carmona[4], J. F. Castel[4], S. Cebrián[4], C. Cogollos[20], D. Collison[1], E. Costa[22], T. Dafni[4], F. Dastgiri[16], C. Deaconu[23], V. De Romeri[24], K. Desch[25], G. Dho[26,27], F. Di Giambattista[26,27], D. Díez-Ibáñez[4], G. D'Imperio[15], B. Dutta[28], C. Eldridge[29], S. R. Elliott[3], A. C. Ezeribe[29], A. Fava[19], T. Felkl[30], B. Fernández-Domínguez[5], E. Ferrer Ribas[11], K. J. Flöthner[18, 66], M. Froehlich[16], J. Galán[4], J. Galindo[4], F. García[31], J. A. García Pascual[4], B. P. Gelli[32], M. Ghrear[33], Y. Giomataris[11], K. Gnanvo[34], E. Gramellini[19], G. Grilli Di Cortona[14], R. Hall-Wilton[35], J. Harton[36], S. Hedges[12], S. Higashino[37], G. Hill[17], P. C. Holanda[32], T. Ikeda[38], I. G. Irastorza[4], P. Jackson[17], D. Janssens[18, 68], B. Jones[10], J. Kaminski[39], I. Katsioulas[51], K. Kelly[19], N. Kemmerich[40], E. Kemp[32], H. B. Korandla[33], H. Kraus[41], A. Lackner[30], G. J. Lane[16], P. M. Lewis[39], M. Lisowska[18, 67], G. Luzón[4], W. A. Lynch[29], G. Maccarrone[14], K. J. Mack[42,43], P. A. Majewski[44], R. D. P. Mano[6], C. Margalejo[4], D. Markoff[45,46], T. Marley[7,44], D. J. G. Marques[26,27], R. Massarczyk[47], G. Mazzitelli[14], C. McCabe[48], L. J. McKie[16], A. G. McLean[29], P. C. McNamara[15], Y. Mei[71], A. Messina[49,15], A. F. Mills[3], H. Mirallas[4], K. Miuchi[37], C. M. B. Monteiro[6], M. R. Mosbech[1,2], H. Muller[39], K. D. Nakamura[70], H. Natal da Luz[50], A. Natochii[33], T. Neep[51], J. L. Newstead[15], K. Nikolopoulos[51], L. Obis[4], E. Oliveri[18], G. Orlandini[18, 69], A. Ortiz de Solórzano[4], J. von Oy[39], T. Papaevangelou[11], O. Pérez[4], Y. F. Perez-Gonzalez[52], D. Pfeiffer[53], N. S. Phan[47], S. Piacentini[49,15], E. Picatoste Olloqui[20], D. Pinci[15], S. Popescu[54], A. Prajapati[26,27], F. S. Queiroz[55,56,57], J. L. Raaf[19], F. Resnati[18], L. Ropelewski[18], R. C. Roque[6], E. Ruiz-Choliz[58], A. Rusu[59], J. Ruz[4], J. Samarati[35], E. M. Santos[40], J. M. F. dos Santos[6], F. Sauli[18], L. Scharenberg[18,39], T. Schiffer[39], S. Schmidt[39], K. Scholberg[12,13], M. Schott[58], J. Schueler[33], L. Segui[11], H. Sekiya[60], D. Sengupta[17], Z. Slavkovska[16], D. Snowden-Ifft[61], P. Soffitta[62], N. J. C. Spooner[29], M. van Stenis[18], L. Strigari[28], A. E. Stuchbery[16], X. Sun[72], S. Torelli[26,27], E. G. Tilly[3], A. W. Thomas[17], T. N. Thorpe[33], P. Urquijo[15], A. Utrobičić[18], S. E. Vahsen[33], R. Veenhof[18, 63], J. K. Vogel[64], A. G. Williams[17], M. H. Wood[65], and J. Zettlemoyer[19]

arXiv:2203.05914

"Recoil imaging": Also expanded community (167 physicists)

# Vision or madness? DUNE-scale gas TPC w/ 30 eV threshold

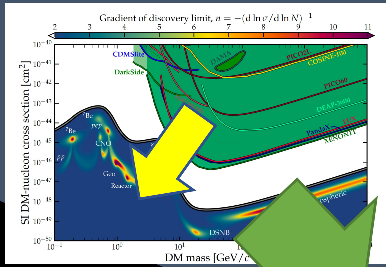
Sven Vahsen (Univ. of Hawaii) for CYGNUS



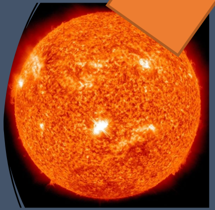

- Prototype data in He:C02 gas @ 1 atm
- Each voxel: ionization density in 50 x 250 x 250 μm$^3$

Topological & directional reconstruction of low-energy nuclear and electronic recoils in gas enables new experiments

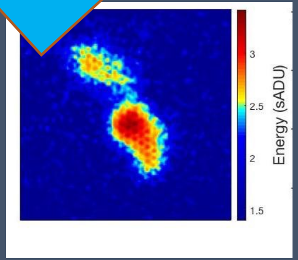
Distinguish dark matter wind from solar-$\upsilon$ → probe $\upsilon$ fog




Search for BSM neutral currents at $\upsilon$ sources



Spectroscopy of Astrophysical neutrinos

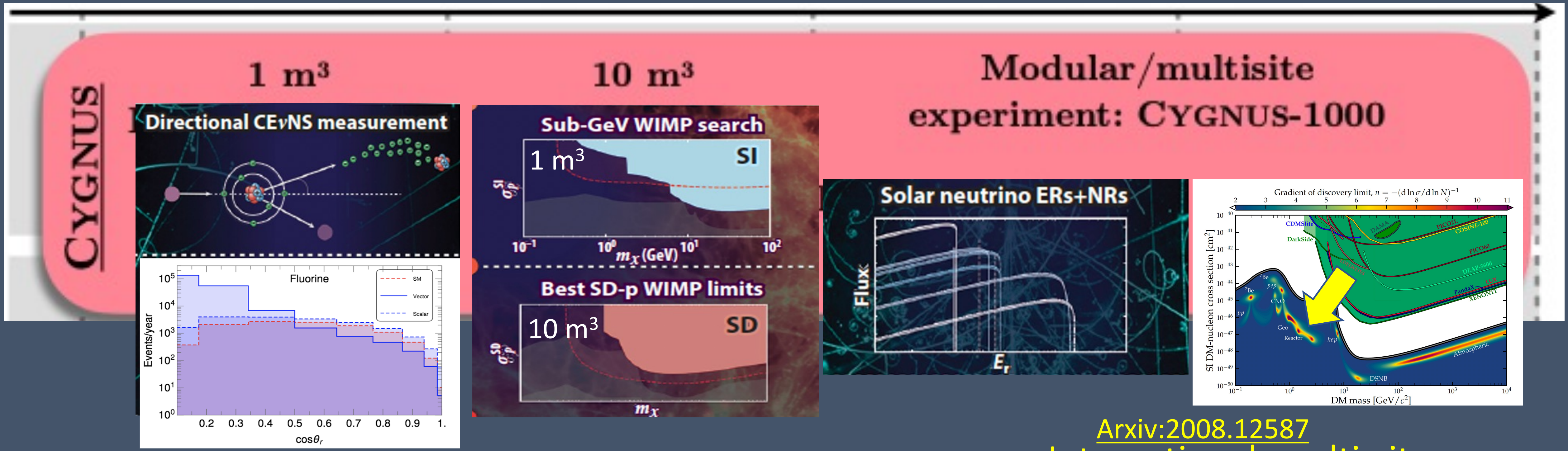



Detect Exotic final states (e.g. Migdal effect)

- Already near the fundamental performance limit – single electron counting in 3d – w/ 100 μm spatial resolution
  - in small detectors using MPGD amplification and pixel ASIC readout
- A DUNE scale experiment with 30 eV energy threshold would be game changing
  - multi-mesh strip micromegas, negative ion drift, and extreme trigger multiplexed readout schemes for cost reduction

# CYGNUS: US Program Vision

time




Arxiv:2008.12587

SNS, Oak Ridge, TN
Directional BSM-search in CEvNS

SURF, Lead, SD
World-leading DM limits

International, multi-site
$1000m^3$ in the U.S.
DM search in the neutrino fog!

- 3 years of R&D to establish electron counting & 1-keV recoil directionality
- Directional BSM search in 1 $m^3$ ν-scattering experiment, aboveground
- Radio-pure 10 $m^3$ experiment, underground (DM)
- Large-scale, underground observatory (solar neutrinos + DM below neutrino floor)

# Final remarks

- CYGNUS workshop has much widened scope this year
  - I only scratched the surface on what can be done with directional reccoil detection
  - I look forward to hearing your latest developments and new, exciting ideas
- We should get more organized
  - R&D collaborations: DRDs (Europe), RDCs (US) now forming. May be an opportunity for more blue sky R&D funding for our field
  - Even so, it may help us formalize the CYGNUS collaboration further
- To make the case for scale-up
  - We need to report clear, practical performance metrics
  - The ultimate performance metric is cost/unit-sensitivity
- Shoot for the stars!
  - Demonstrate 3d electron counting
  - Develop detailed plans for scaling up to DUNE scale: starting with >= 10 $m^3$ designs