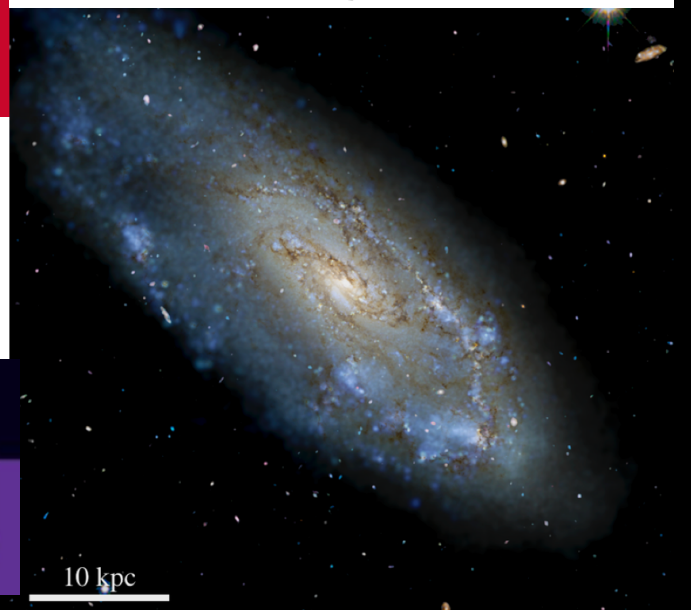
Gusts in the Headwind
Uncertainties in Direct Dark Matter Detection

IDM 2022
14th International Conference on Identification of Dark Matter
18-22 July 2022
Vienna, Austria



Grace E. Lawrence[1,2,3] , Alan R. Duffy[1,2,3], Chris Blake[1], Philip F. Hopkins[4]

[1]Centre for Astrophysics and Supercomputing, Swinburne University of Technology, PO Box 218, Hawthorn VIC

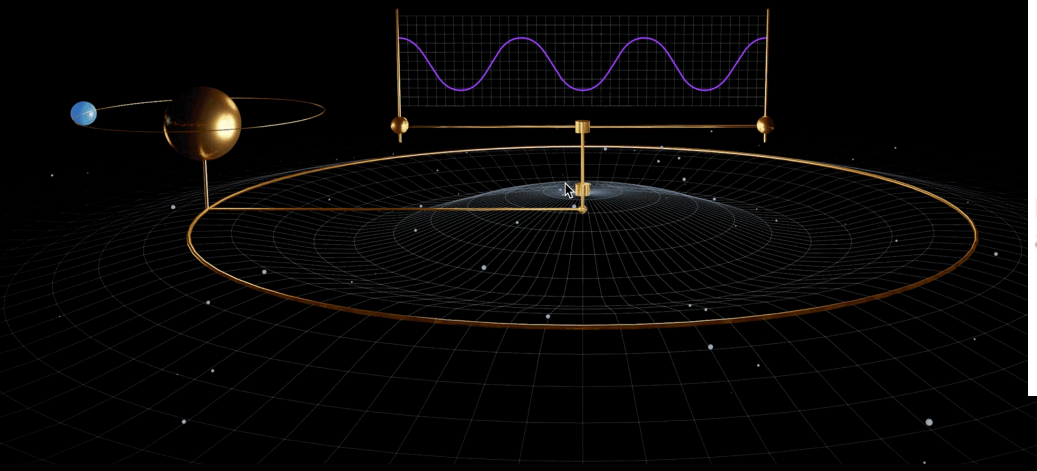
[2]ARC Centre of Excellence for Dark Matter Particle Physics (CDM)

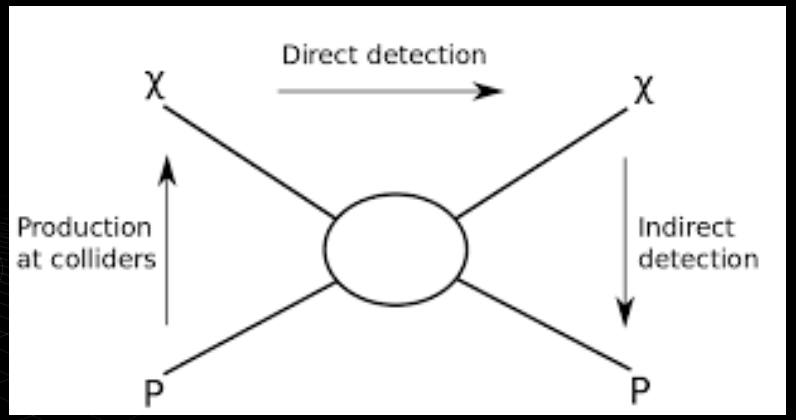
[3]ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D)

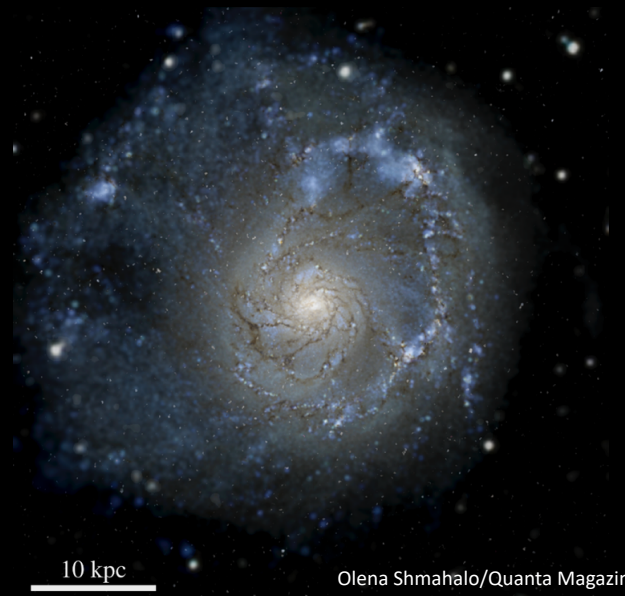
[4]TAPIR, Mailcode 350-17, California Institute of Technology, Pasadena, CA 91125, USA

https://arxiv.org/abs/2207.07644

Assumptions of Direct Dark Matter Detection







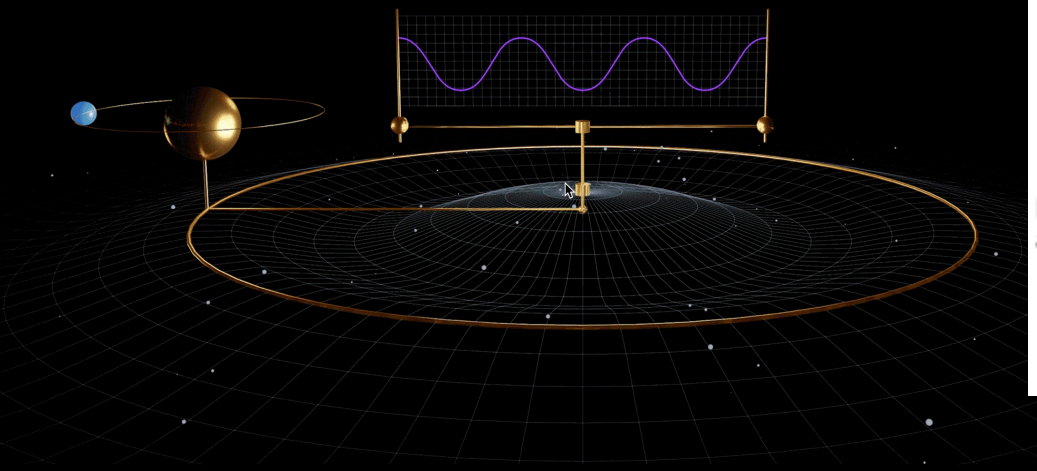
Olena Shmahalo/Quanta Magazine

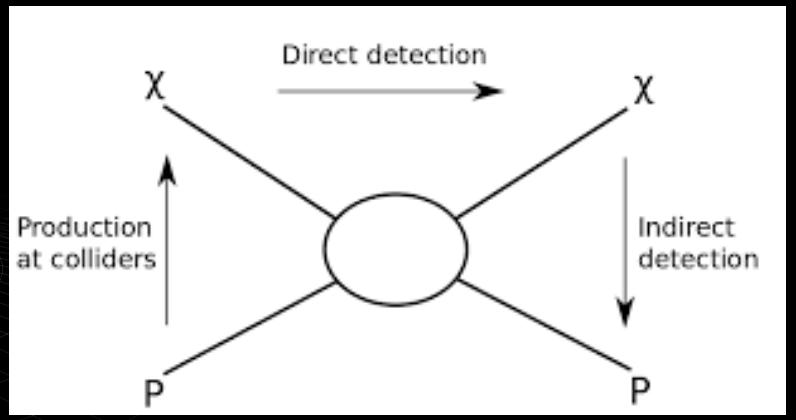
Marrodán Undagoitia, T., & Rauch, L. (2016), Journal of Physics G Nuclear Physics, 43, 013001.

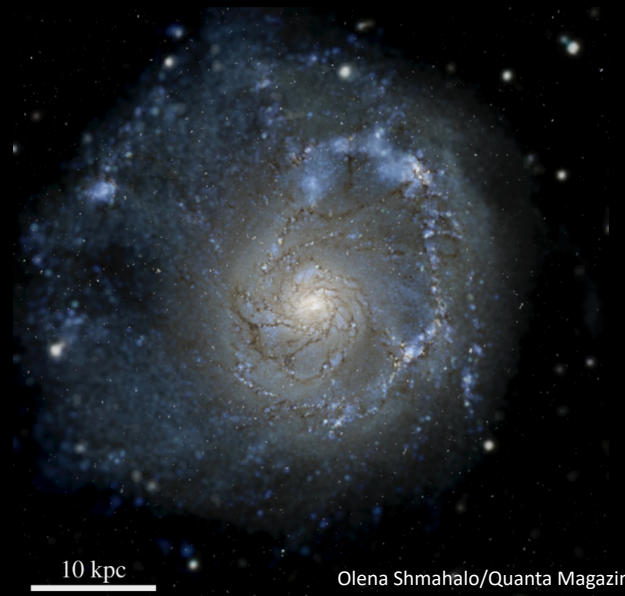
Hopkins, P. F., Wetzel, A., Kereš, D., et al. 2018, MNRAS, 480, 800, doi: 10.1093/mnras/sty1690

Goals of Research

- Use hydrodynamic simulations of Milky Way analogues to inform realistic velocity distributions of dark matter in the solar neighborhood
- Generate bespoke predictions for dark matter direct detectors





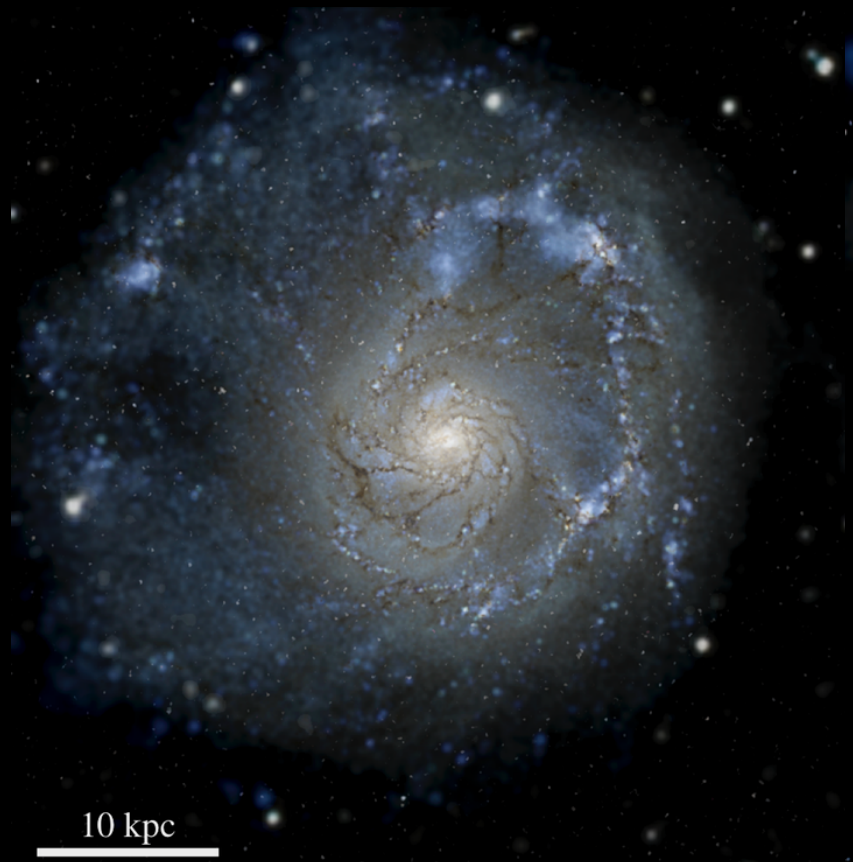


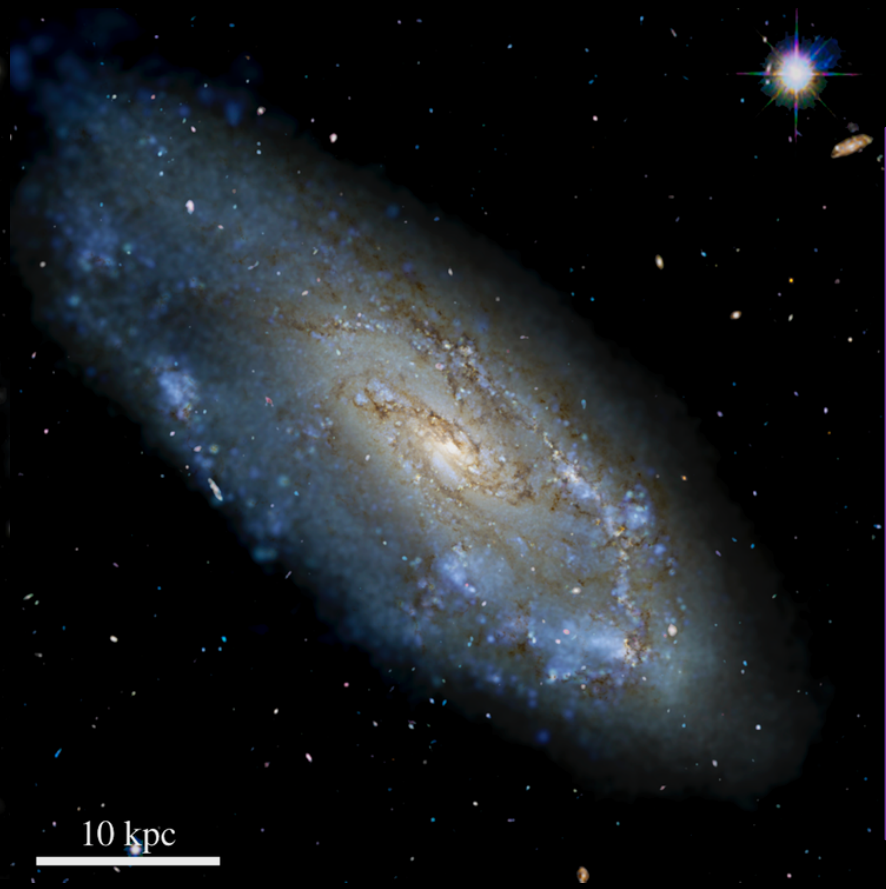
Olena Shmahalo/Quanta Magazine

Marrodán Undagoitia, T., & Rauch, L. (2016), Journal of Physics G Nuclear Physics, 43, 013001.

Hopkins, P. F., Wetzel, A., Kereš, D., et al. 2018, MNRAS, 480, 800, doi: 10.1093/mnras/sty1690

Latte Simulations – m12f





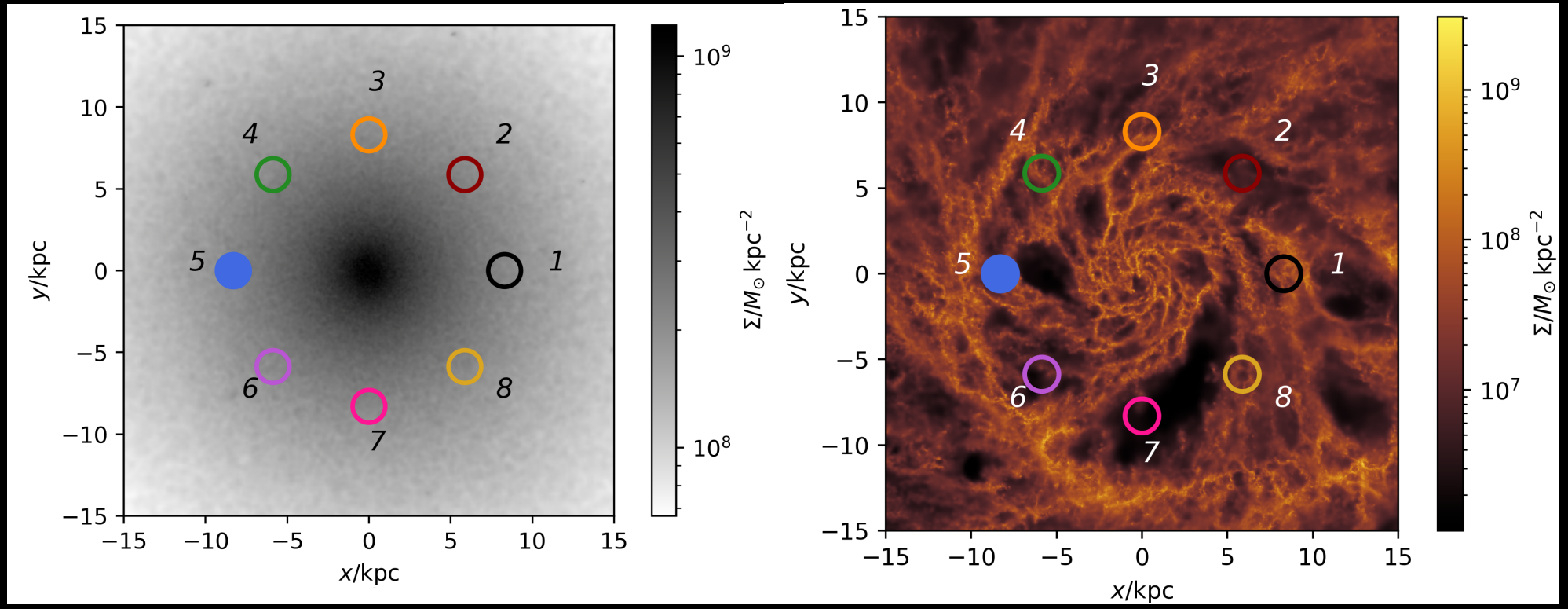
Dark Matter: 40 pc
Stars: 4pc
Gas : 1pc

Hopkins, P. F., Wetzel, A., Kereš, D., et al. 2018, MNRAS, 480, 800, doi: 10.1093/mnras/sty1690

Wetzel, A. R., Hopkins, P. F., Kim, J.-h., et al. 2016, ApJL, 827, L23, doi: 10.3847/2041-8205/827/2/ L23

Wetzel A., et al., 2022, Public data release of the FIRE-2 cosmological zoom- in simulations of galaxy formation, doi:10.48550/ARXIV.2202.06969, https://arxiv.org/abs/2202.06969

Simulation Realization



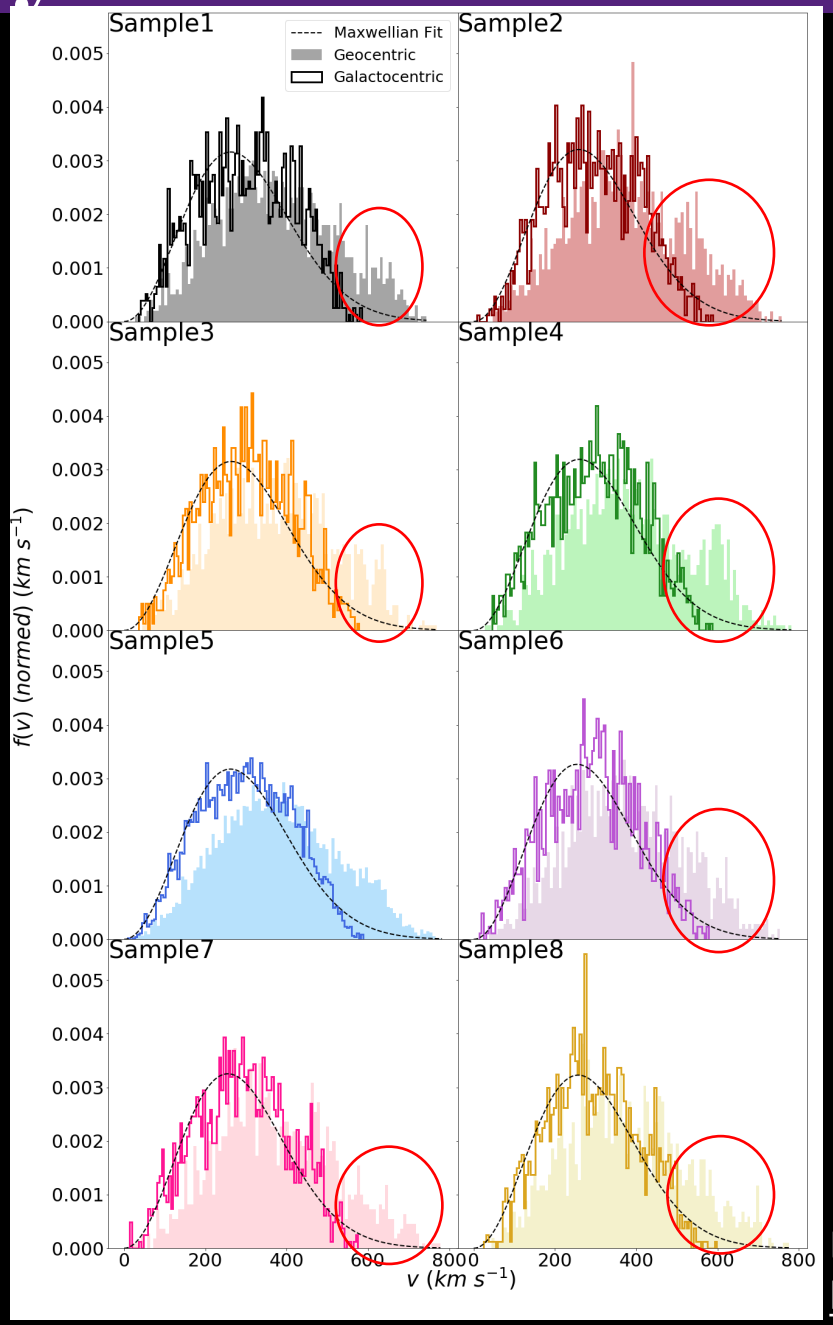
$$Galactocentric \rightarrow Geocentric$$

$$f_{geo}(\vec{v}, t) = f_{gal}(\vec{v} + \vec{v}_{Earth}(t))$$

Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

Geocentric Velocity Distributions

- Realistic velocity distributions show departures from MB
- Rate calculations have strong dependence on geocentric velocity distribution

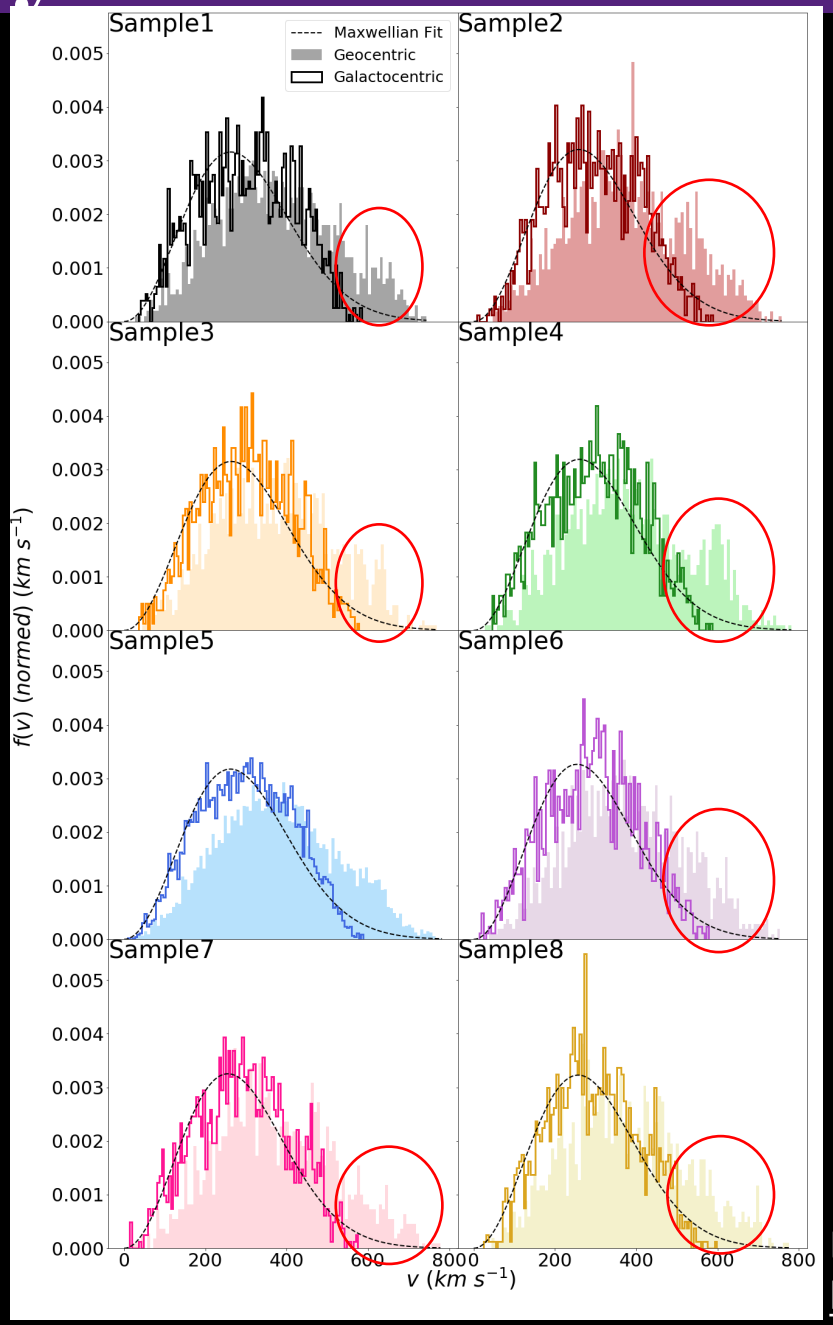


Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

Geocentric Velocity Distributions

- Realistic velocity distributions show departures from MB
- Rate calculations have strong dependence on geocentric velocity distribution

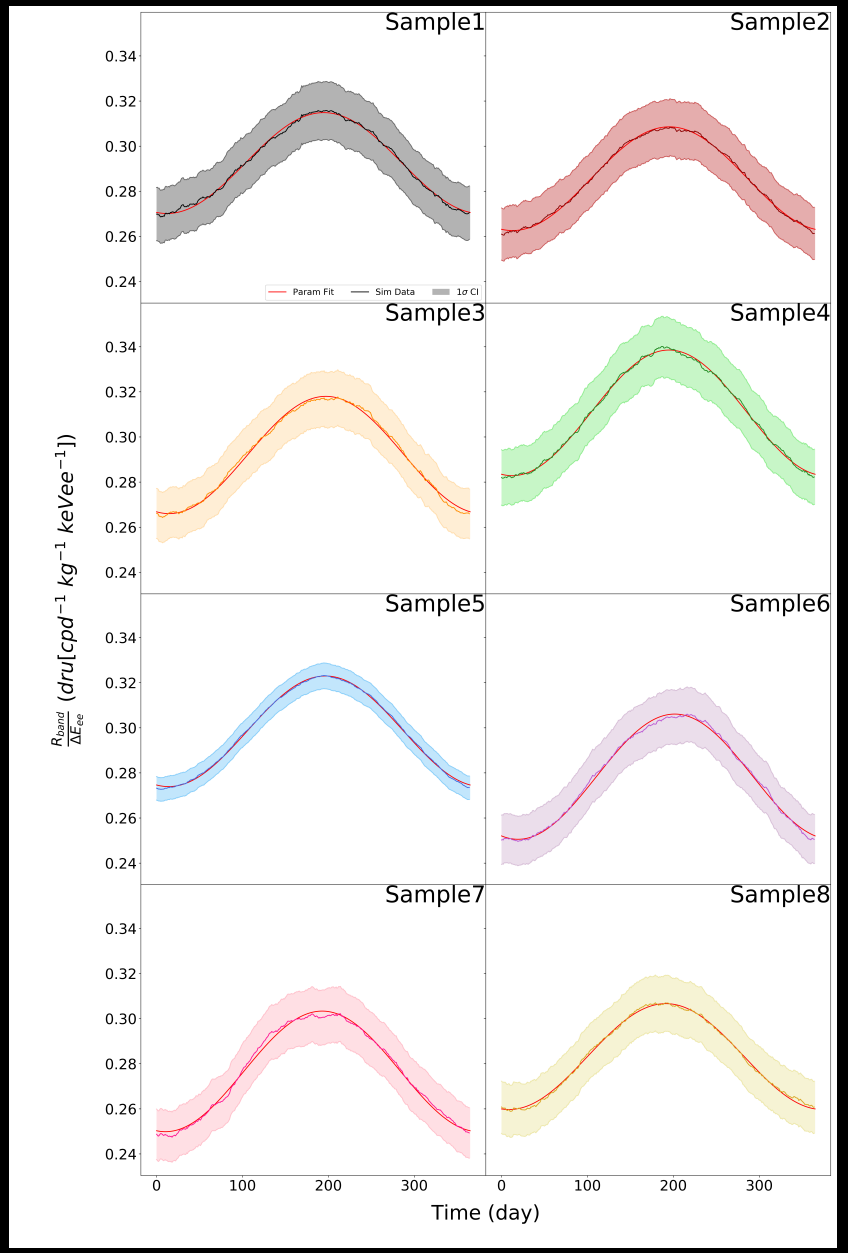
$$\frac{dR}{dE}_{observed} = R_0 S(E) F^2(E) I$$



Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

Annual Modulation

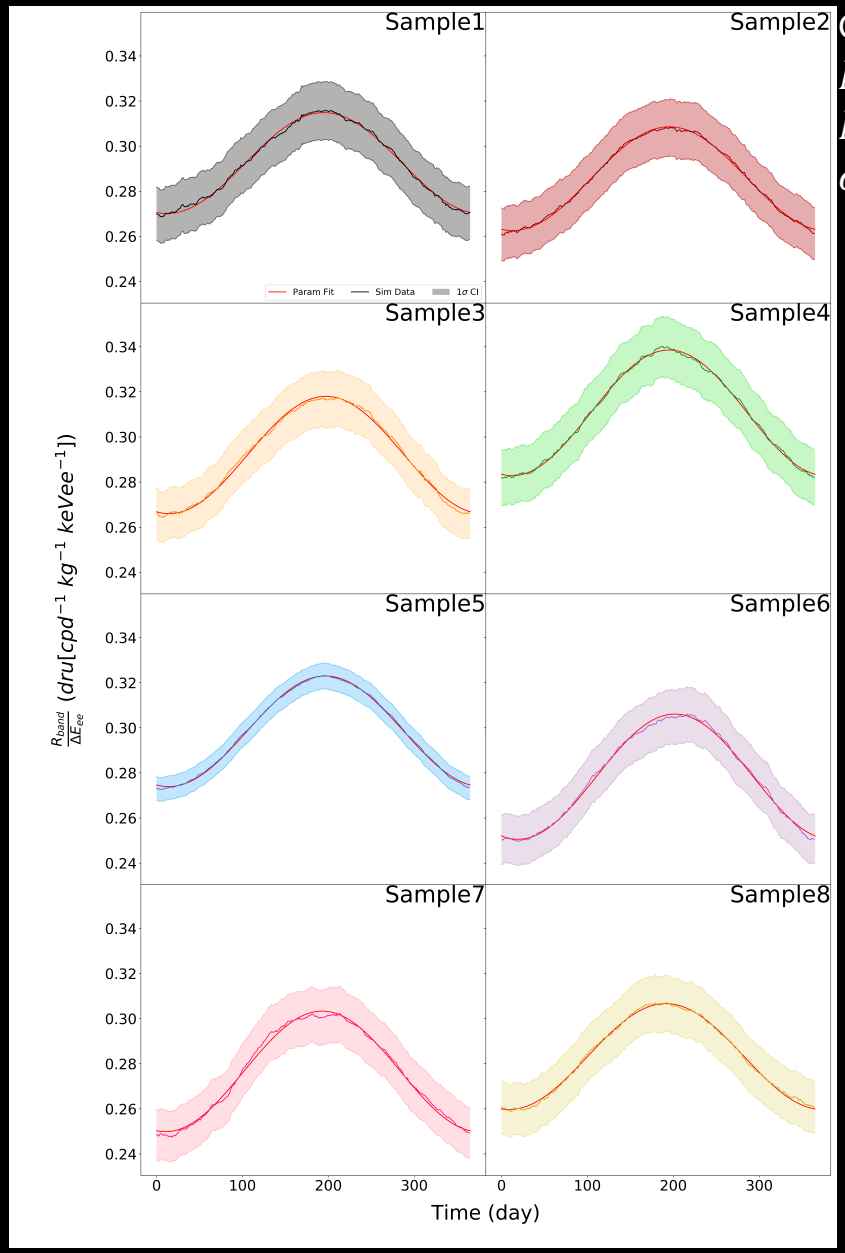
Germanium Detector
M_T = 70amu
M_{DM} = 15GeV
$\sigma_v = 1.3e^{-41} cm^2$



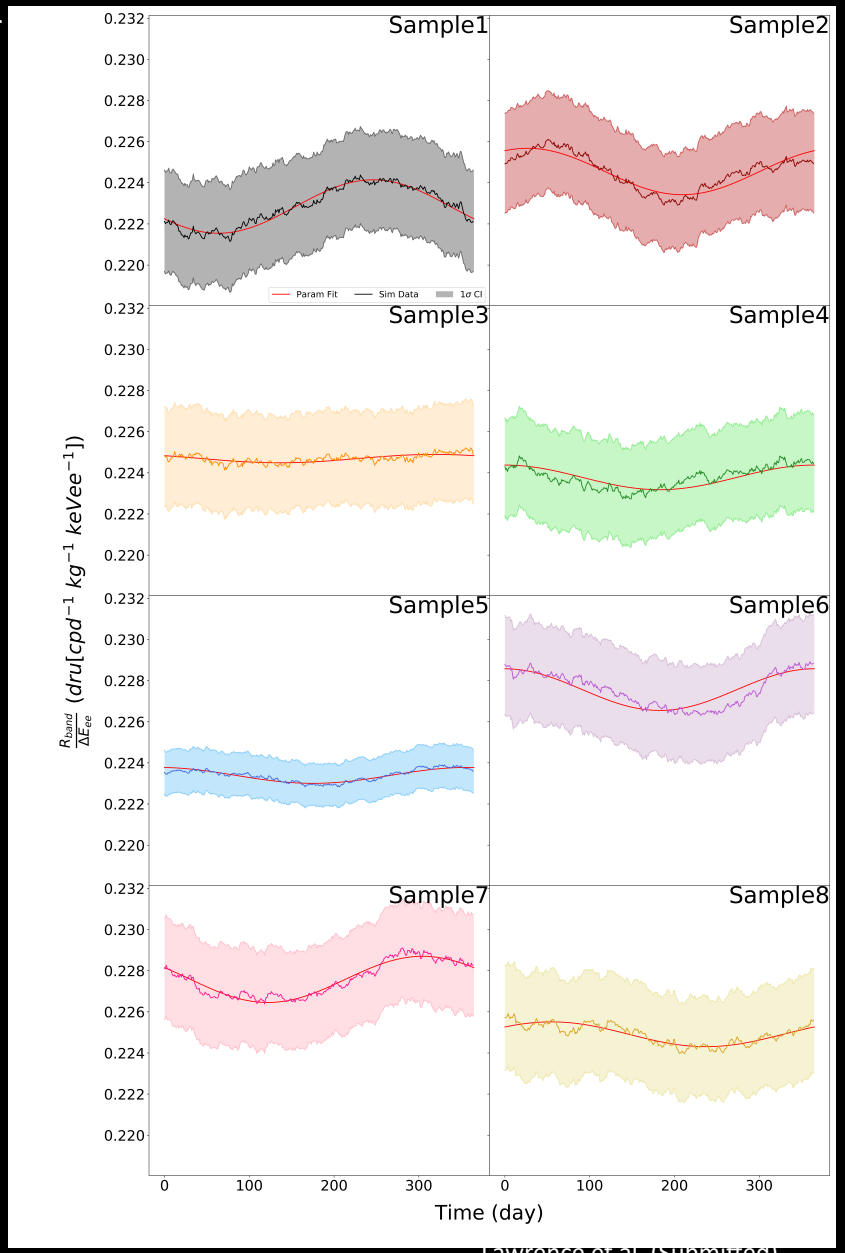
Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

Annual Modulation

Germanium Detector
M_T = 70amu
M_{DM} = 15GeV
$\sigma_v = 1.3e^{-41} cm^2$



Germanium Detector
M_T = 70amu
M_{DM} = 60GeV
$\sigma_v = 5.5e^{-42} cm^2$



Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

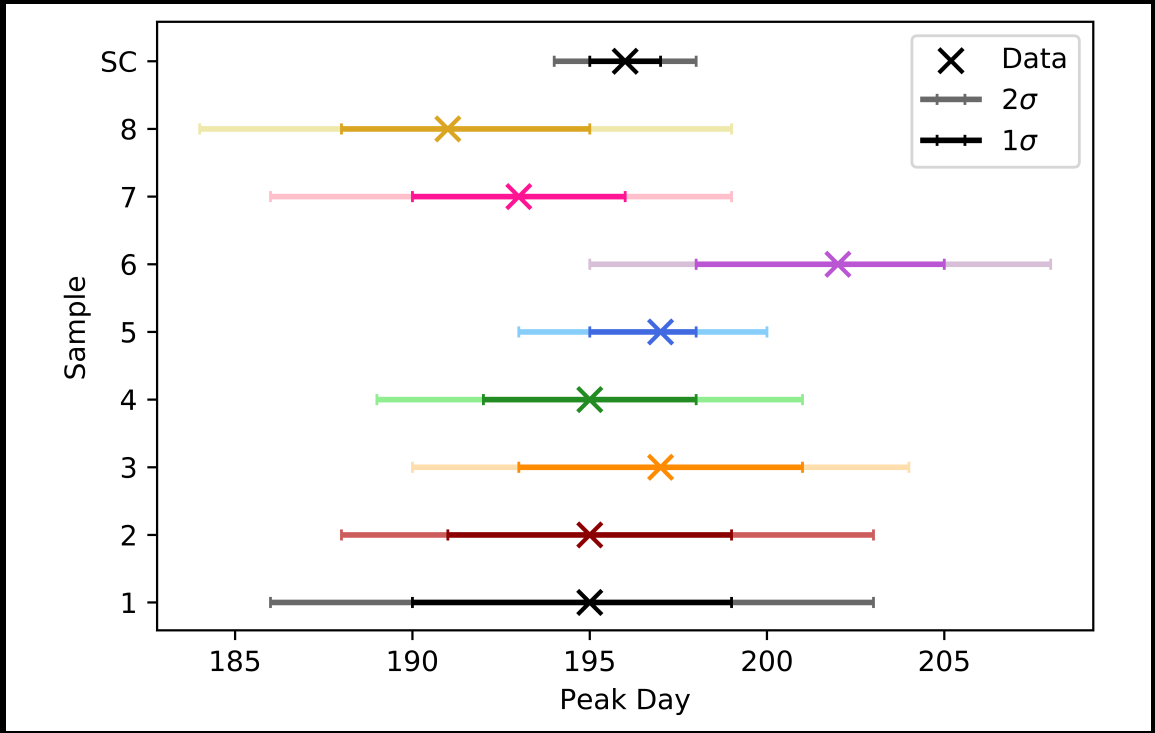
Peak Day

Germanium Detector

M_T = 70amu

M_{DM} = 15GeV

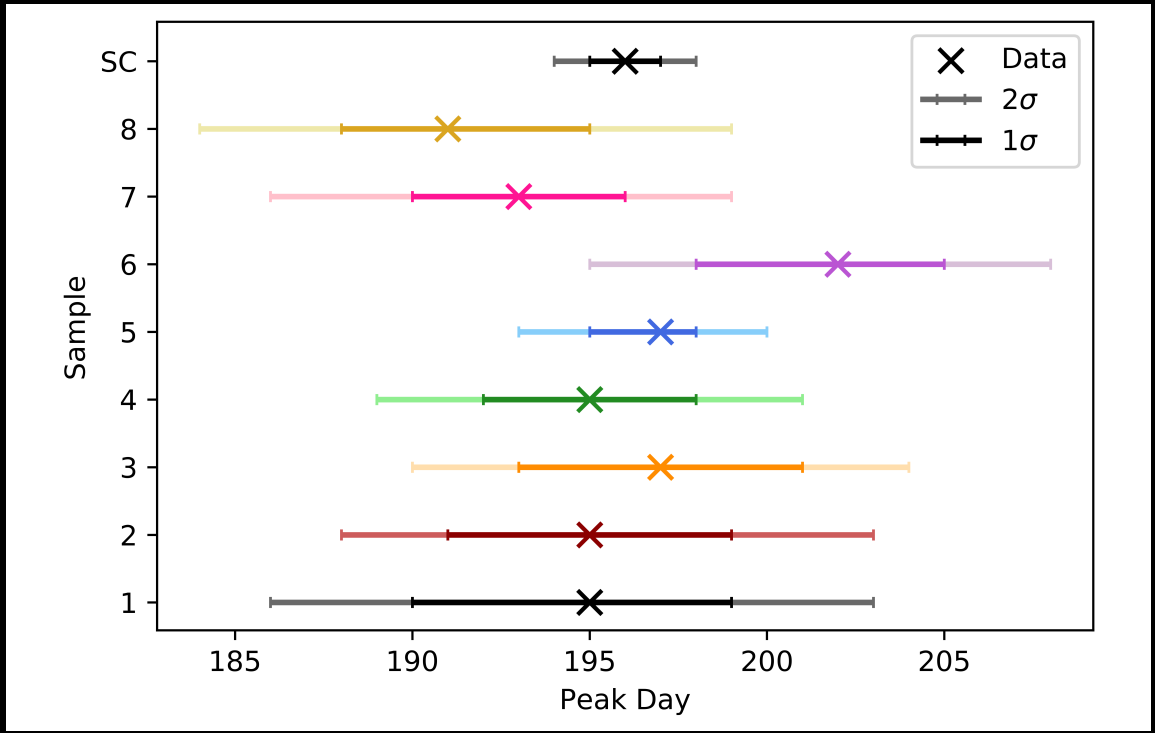
$\sigma_v = 1.3e^{-41} cm^2$



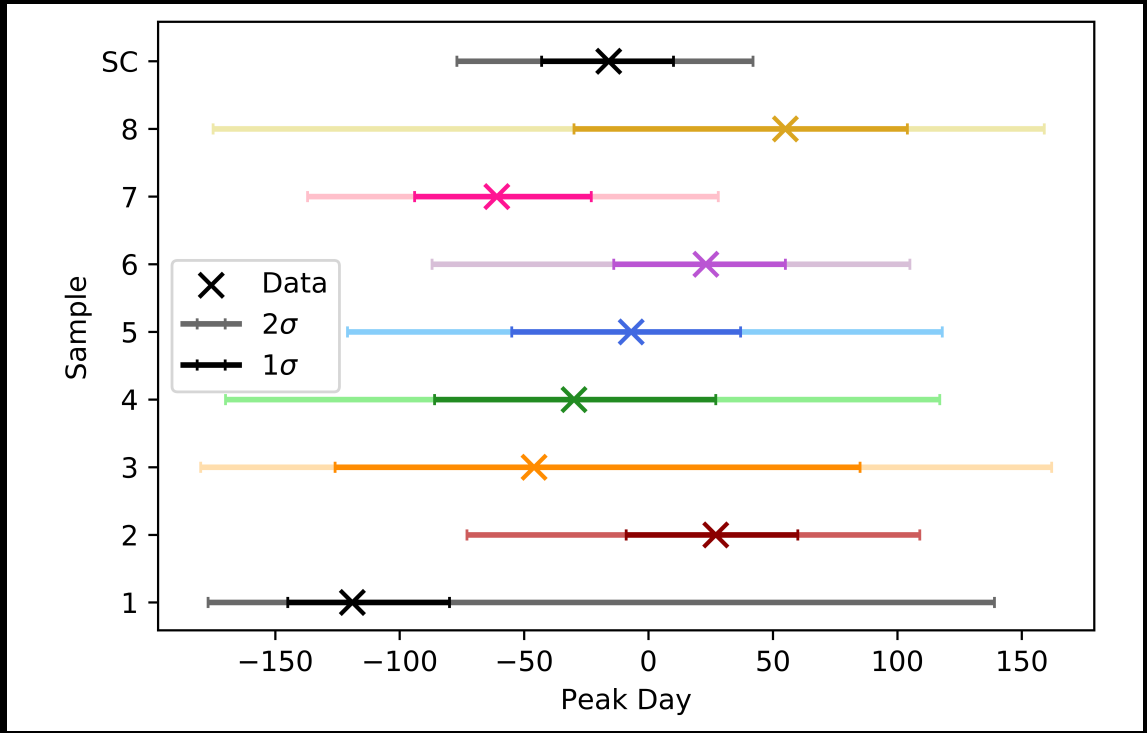
Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

Peak Day

Germanium Detector
M_T = 70amu
M_{DM} = 15GeV
$\sigma_v = 1.3e^{-41} cm^2$

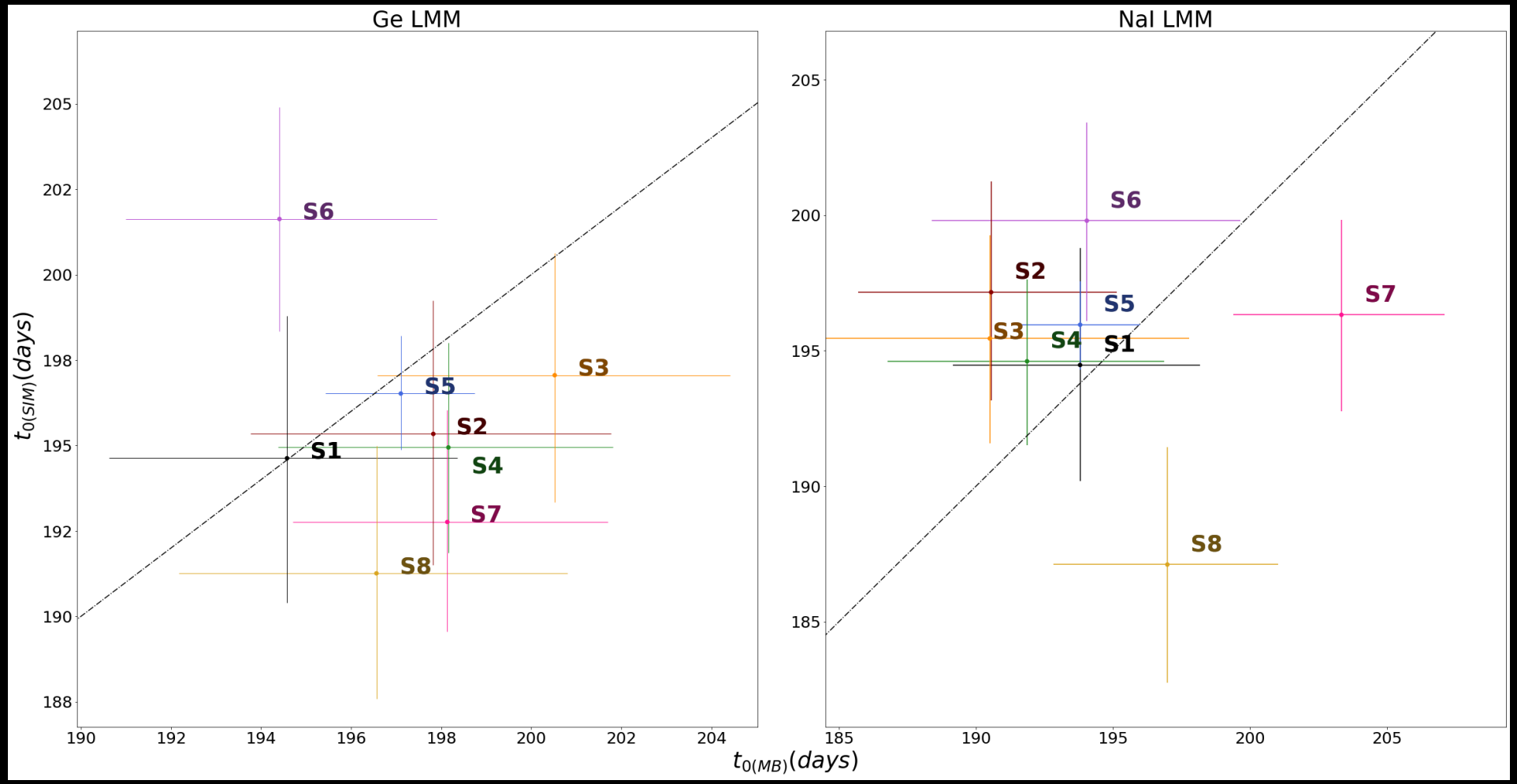


Germanium Detector
M_T = 70amu
M_{DM} = 60GeV
$\sigma_v = 5.5e^{-42} cm^2$



Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

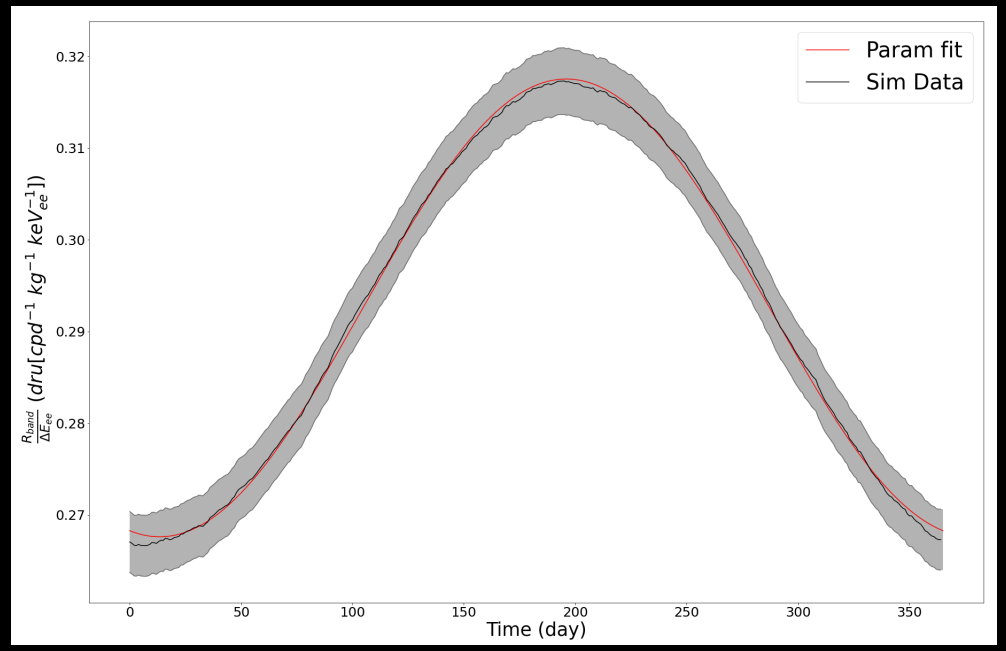
Model Comparison



Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

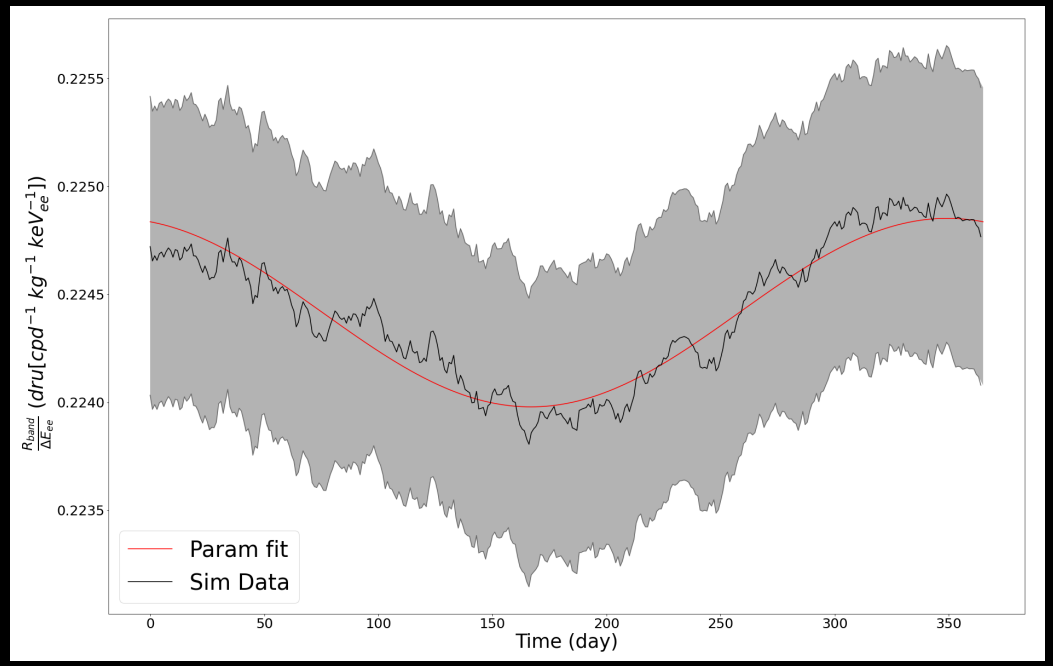
Turn Over Energy - Q_c

Low Mass



180^o

High Mass

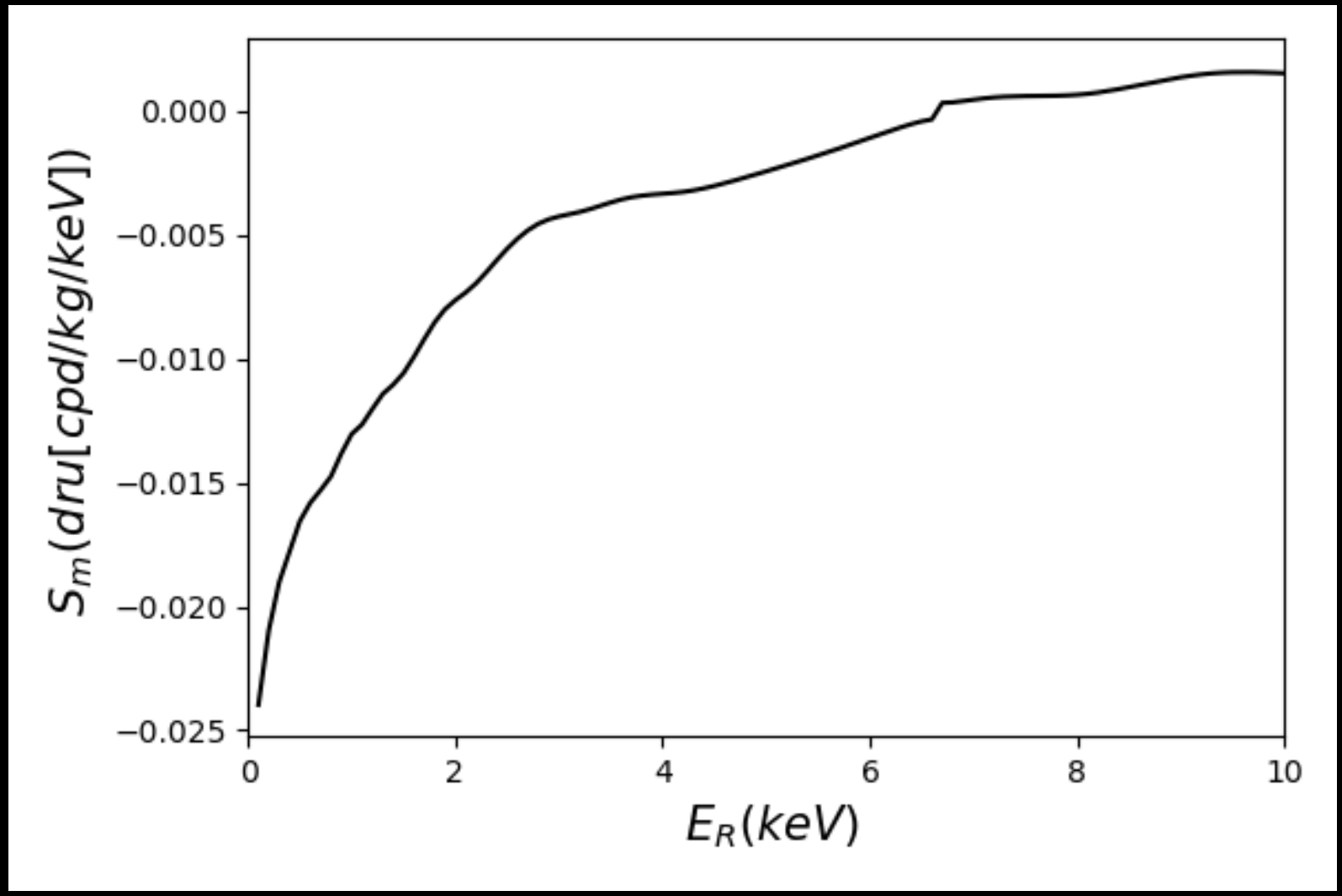


The modulation is fixed for a given minimum velocity, regardless of M_{DM}, but it's not fixed for a given recoil energy

Lawrence et al. (Submitted)
https://arxiv.org/abs/2207.07644

Turn Over Energy - Q_c

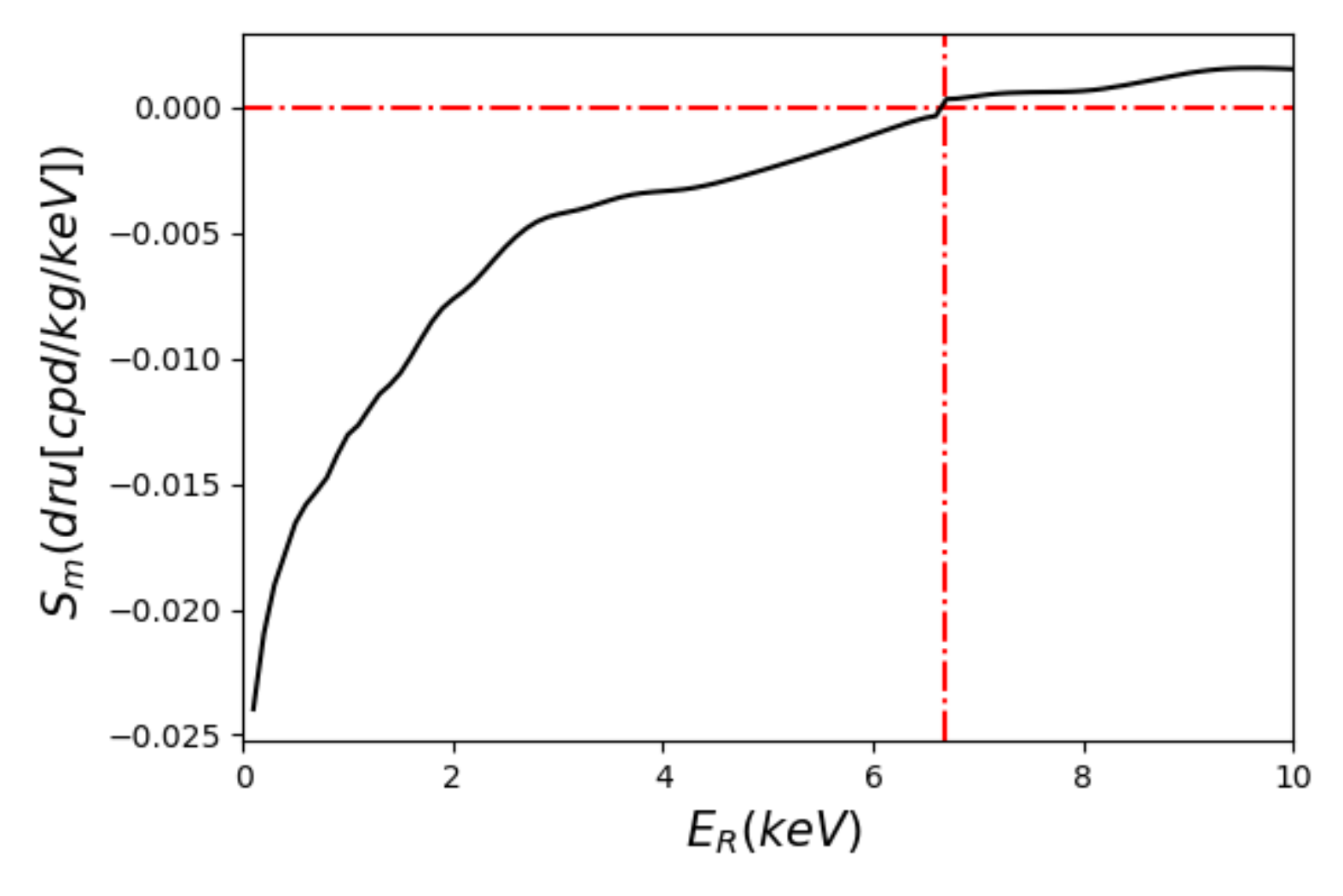
Germanium Detector
M_T = 70amu
M_{DM} = 15GeV
$\sigma_v = 1.3e^{-41}cm^2$



Lawrence et al. (in prep)

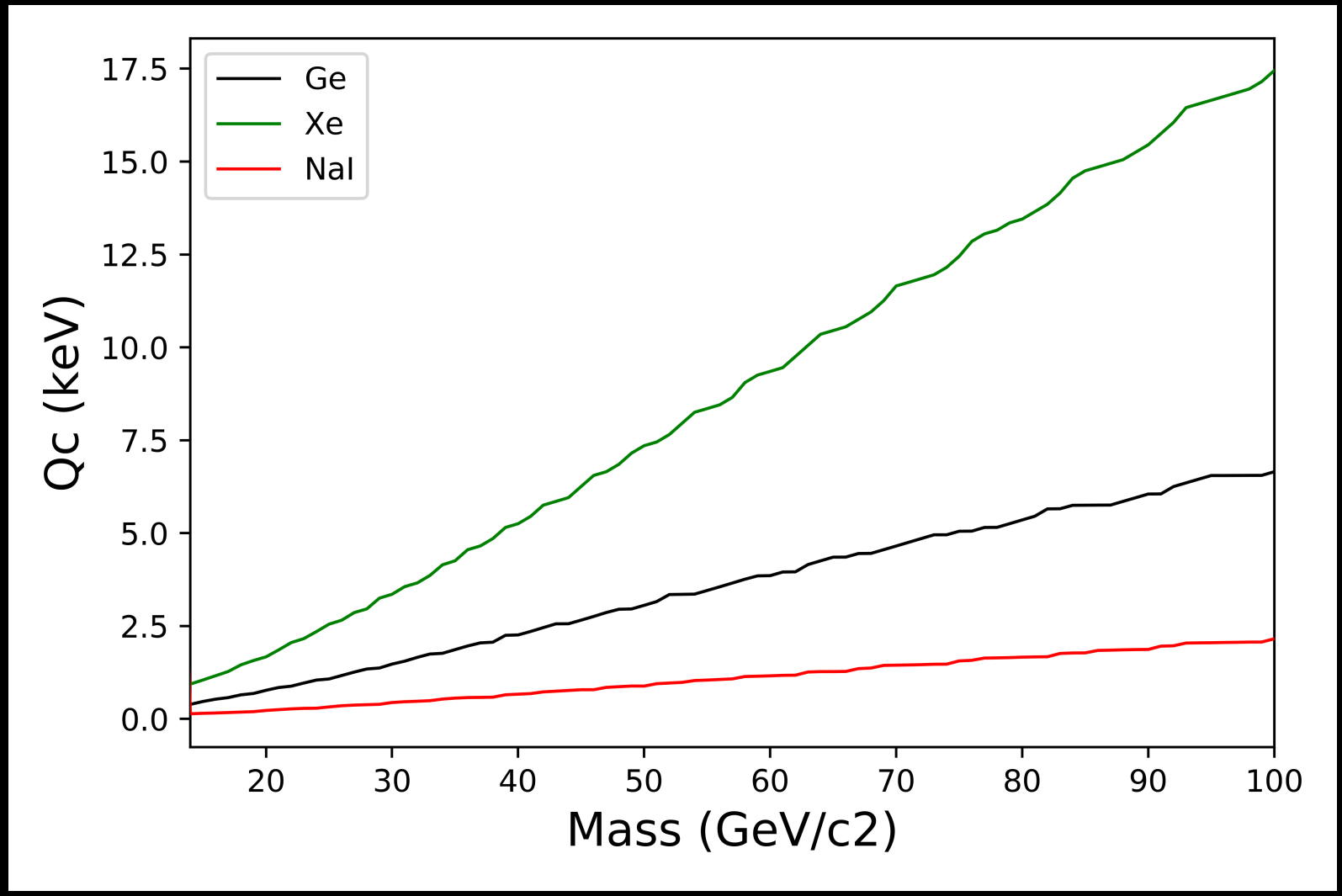
Turn Over Energy - Q_c

Germanium Detector
M_T = 70amu
M_{DM} = 15GeV
$\sigma_v = 1.3e^{-41}cm^2$



Lawrence et al. (in prep)

Q_c vs M_{DM}



Lawrence et al. (in prep)

Dark MaRK – Dark Matter Rate Kalculator

Grace-Lawrence / Dark-MaRK Public

Unwatch 3 | Star 1 | Fork 0

Code | Issues | Pull requests | Actions | Projects | Wiki | Security | Insights | Settings

main | 2 branches | 0 tags | Go to file | Add file | Code

Grace-Lawrence Reset outputs for example notebook. 3ae7caa 14 days ago 60 commits

Examples	Reset outputs for example notebook.	14 days ago
darkmark	Fixed typos.	19 days ago
docs	Fixed typos in documentation.	15 days ago
.gitignore	Initial commit	2 months ago
LICENSE	Initial commit	2 months ago
MANIFEST.in	Addition of auxillary setup files	2 months ago
README.rst	Update README.rst	19 days ago
requirements.txt	Updated requirements and setup files for package	2 months ago
requirements_dev.txt	Updated requirements_dev.txt which have the requirements for runni...	19 days ago
requirements_extras.txt	Added requirements_extra text for packages required for only specifi...	2 months ago
setup.cfg	Addition of auxillary setup files	2 months ago
setup.py	Updated requirements and setup files for package	2 months ago

README.rst

Dark-MaRK is an open source Python 3 package designed to generate bespoke predictions for dark matter direct detectors. *Dark-MaRK* allows users to vary three key aspects of dark matter direct detection - the detector model, the dark matter model, and the halo model of the galaxy.

About

Dark Matter Rate Kalculator

Readme

BSD-3-Clause License

Releases

No releases published
Create a new release

Packages

No packages published
Publish your first package

Contributors 2

Grace-Lawrence Grace Lawrence

astroduff A R Duffy

Languages

Python 100.0%

Lawrence et al., Submitted

MNRAS 000, 1–22 (2022) Preprint 18 July 2022 Compiled using MNRAS LATEX style file v3.0

Gusts in the Headwind: Uncertainties in Direct Dark Matter Detection

Grace E. Lawrence,[1,2,3]★ Alan R. Duffy,[1,2,3] Chris A. Blake,[1] Philip F. Hopkins[4]
[1]Centre for Astrophysics and Supercomputing, Swinburne University of Technology, PO Box 218, Hawthorn VIC 3122, Australia
[2]ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D)
[3]ARC Centre of Excellence for Dark Matter Particle Physics (CDM)
[4]TAPIR, Mailcode 350-17, California Institute of Technology, Pasadena, CA 91125, USA

18 July 2022

ABSTRACT

We use high-resolution, hydrodynamic, galaxy simulations from the Latte suite of FIRE-2 simulations to investigate the inherent variation of dark matter in sub-sampled regions around the Solar Circle of a Milky Way-type analogue galaxy and its impact on direct dark matter detection. These simulations show that the baryonic backreaction, as well as the assembly history of substructures, has lasting impacts on the dark matter's spatial and velocity distributions. These are experienced as 'gusts' of dark matter wind around the Solar Circle, potentially complicating interpretations of direct detection experiments on Earth. We find that the velocity distribution function in the galactocentric frame shows strong deviations from the Maxwell Boltzmann form typically assumed in the fiducial Standard Halo Model, indicating the presence of high-velocity substructures. By introducing a new numerical integration technique which removes any dependencies on the Standard Halo Model, we generate event-rate predictions for both single-element Germanium and compound Sodium Iodide detectors, and explore how the variability of dark matter around the Solar Circle influences annual modulation signal predictions. We find that these velocity substructures contribute additional astrophysical uncertainty to the interpretation of event rates, although their impact on summary statistics such as the peak day of annual modulation is generally low.

Key words: (cosmology:) dark matter – astroparticle physics – hydrodynamics – scattering – Galaxy:general – software: simulations

https://arxiv.org/abs/2207.07644

Conclusions

- All VDFs demonstrate significant deviations from the fiducial Maxwell Boltzmann fit, demonstrating the inherent fluctuations in the dark matter field.

- Consequent annual modulation signals demonstrate that high energy structure effects from VDFs do not persist.

- Model tests imply the Standard Halo Model is an appropriate approximation.

- The critical turnover energy can be used by direct detection experiments as a tool for constraining WIMP mass

https://arxiv.org/abs/2207.07644