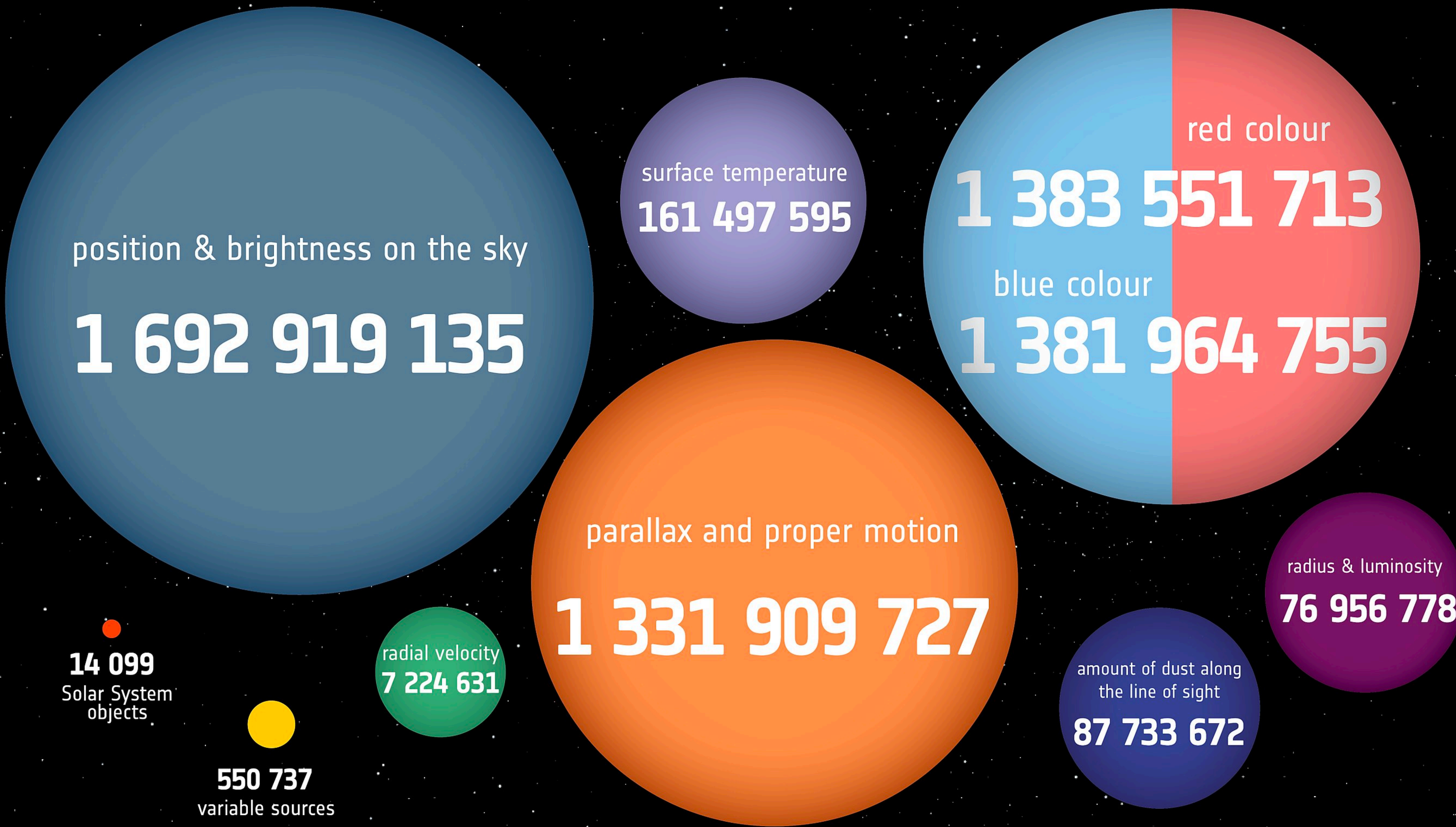
Recent papers on *Gaia* and dark matter detection

Ciaran O'Hare, U. Sydney, COE journal club, August 2020

→ HOW MANY STARS WILL THERE BE IN THE SECOND GAIA DATA RELEASE?



www.esa.int

The second data release of ESA's Gaia mission is scheduled for publication on 25 April 2018.

European Space Agency

Gaia astrometric solution

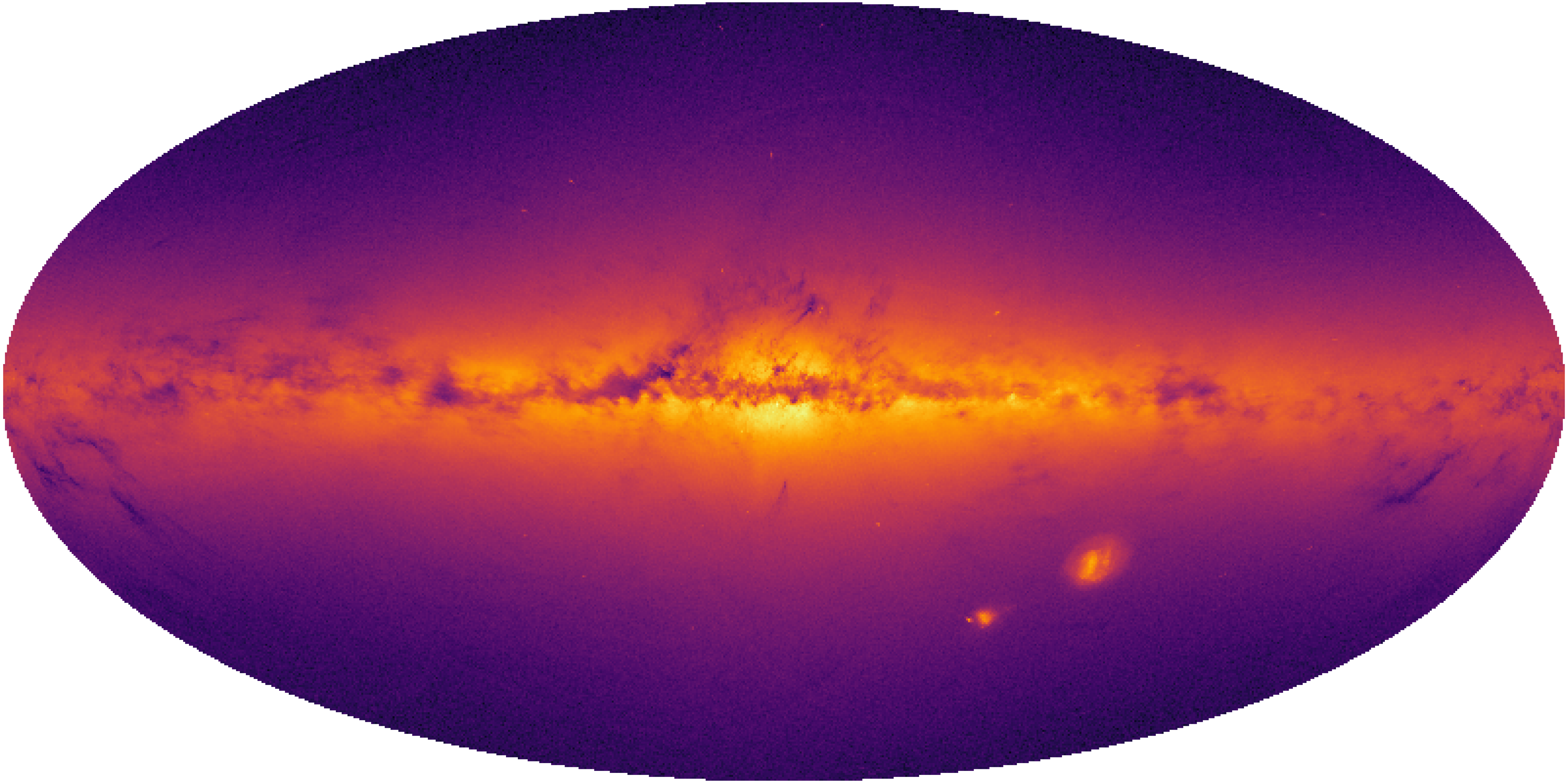
The goal is to have stars located in 6D: (x,y,z,vx,vy,vz)

- Right ascension (ra) and Declination (dec) → position on sky
- Proper motion (pmra, pmdec) → motion on sky
- Parallax [mas] ~ 1/distance[kpc] (works at small distances, other methods needed at large distances)
- Radial velocity (rv) = line of sight velocity (need spectra)

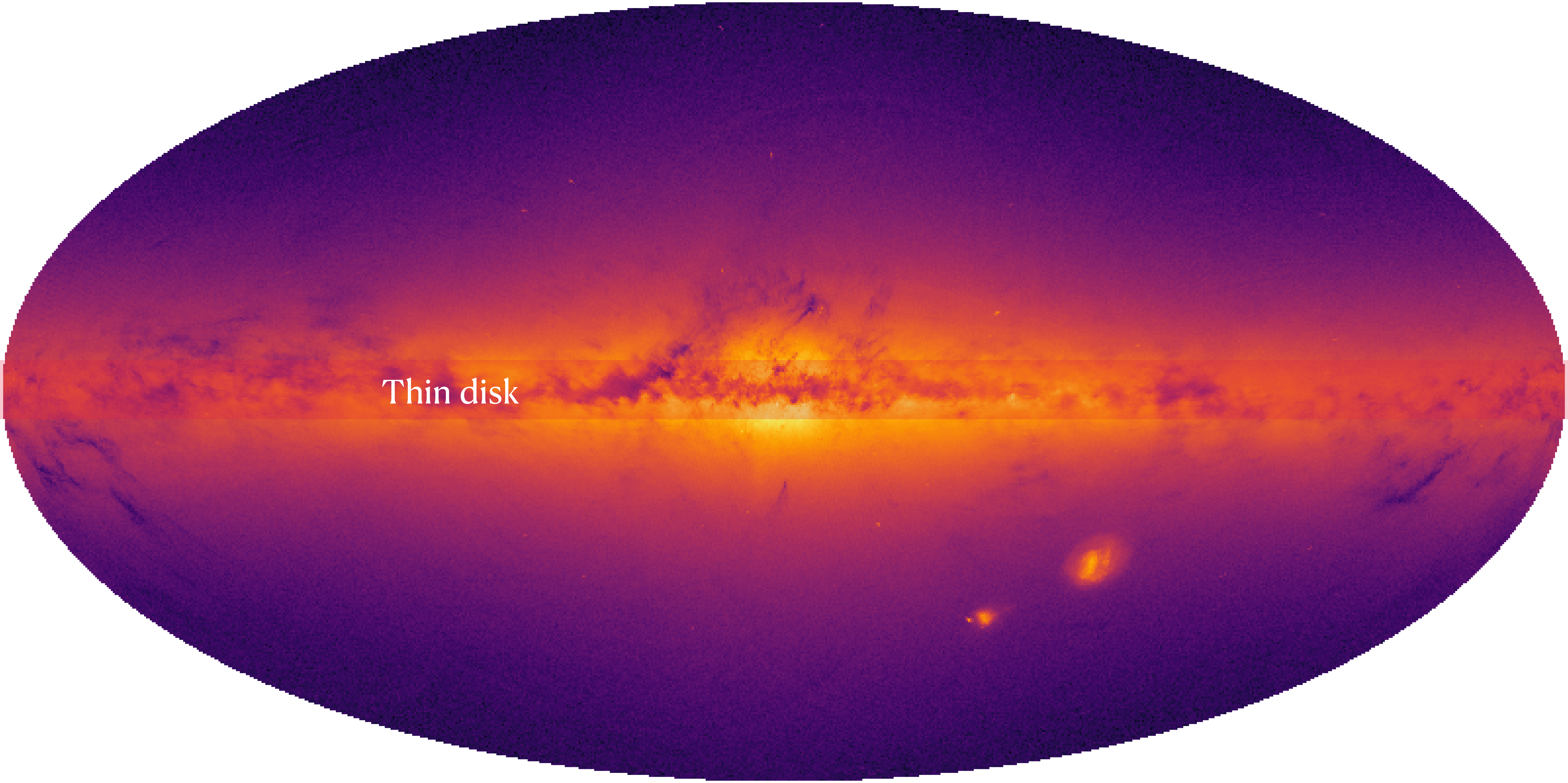
(ra,dec,parallax) → (x,y,z)

(pmra,pmdec,rv) → (v_x, v_y, v_z)

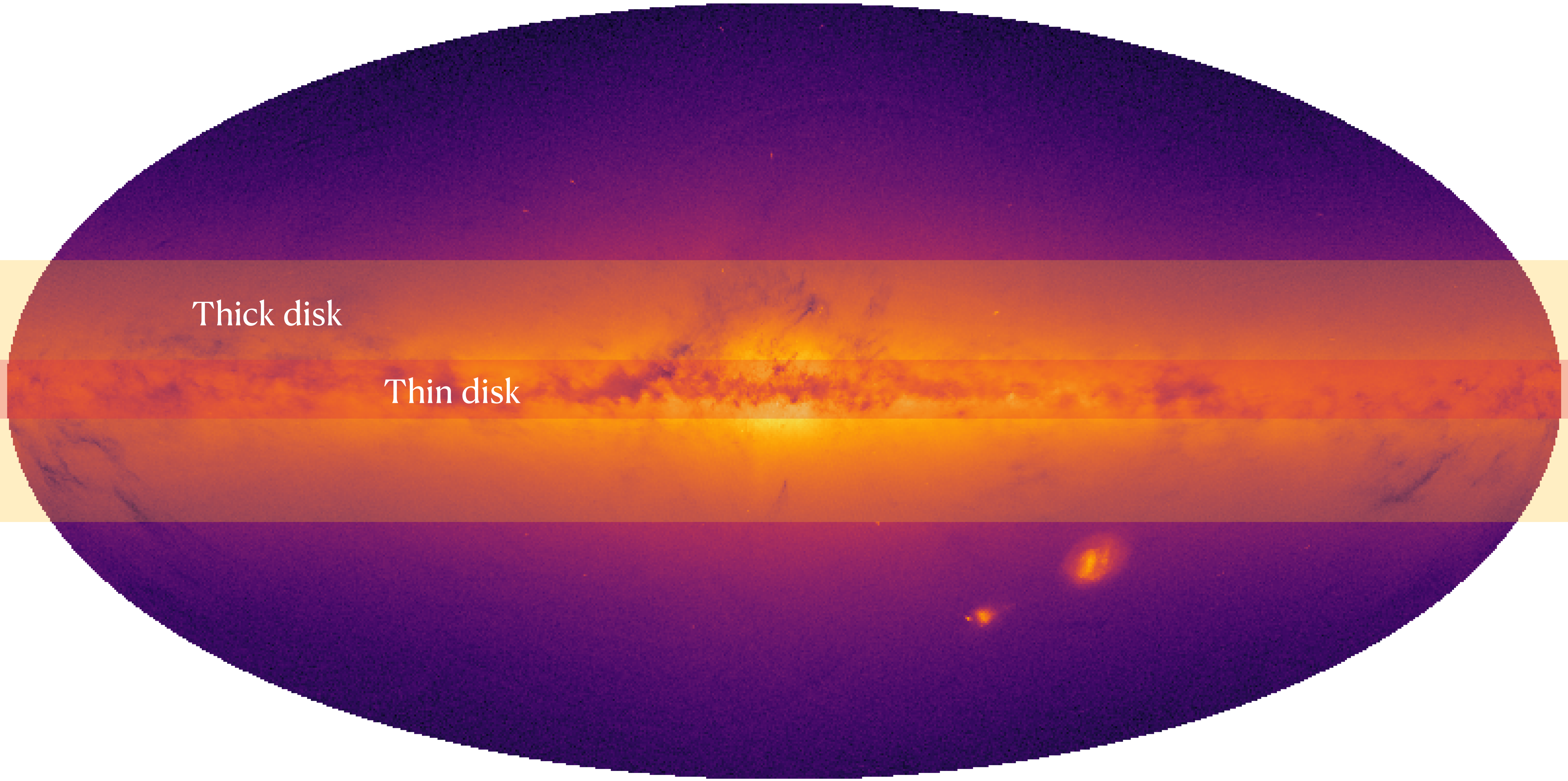
Structure of the Milky Way



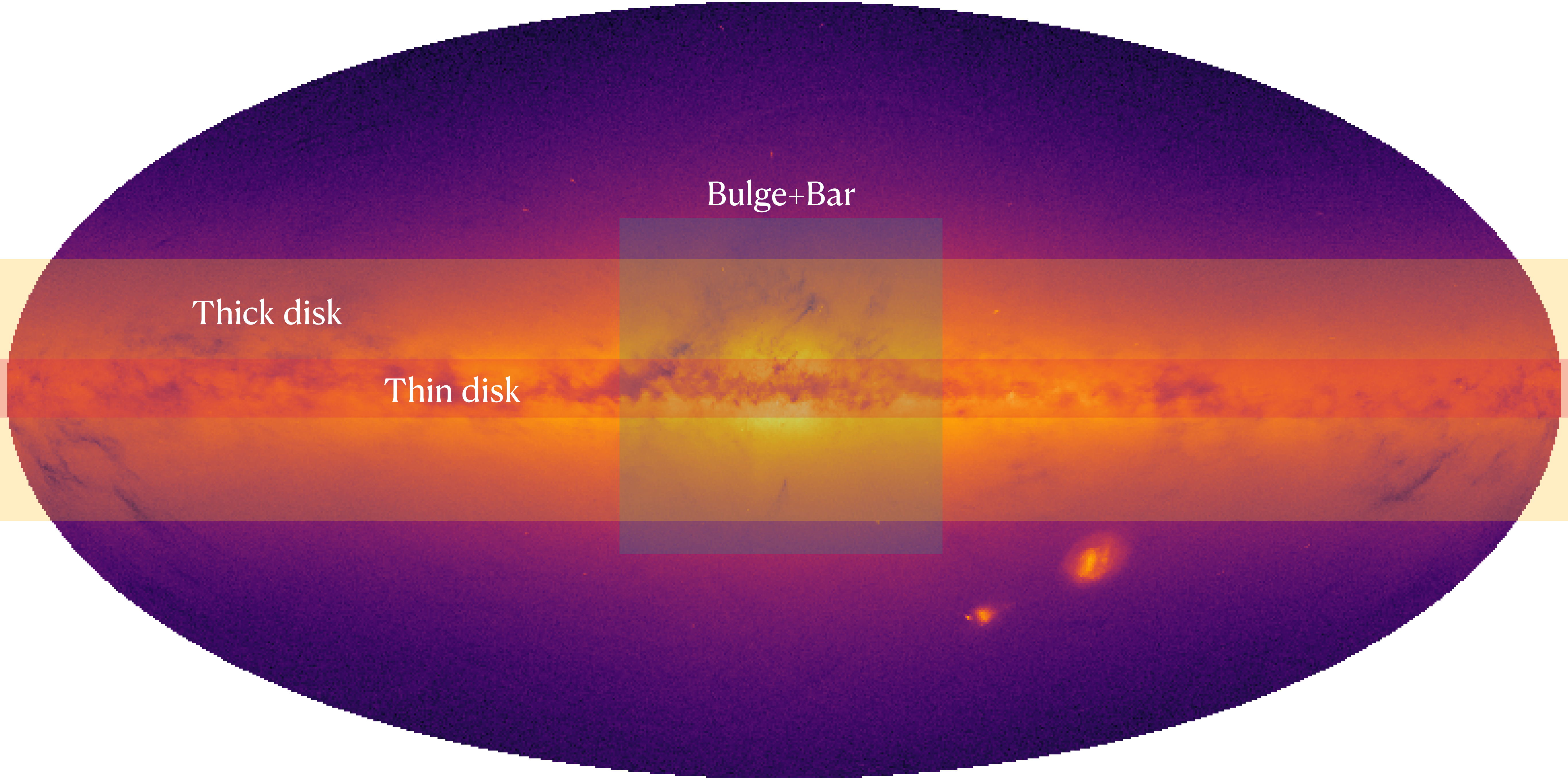
Structure of the Milky Way



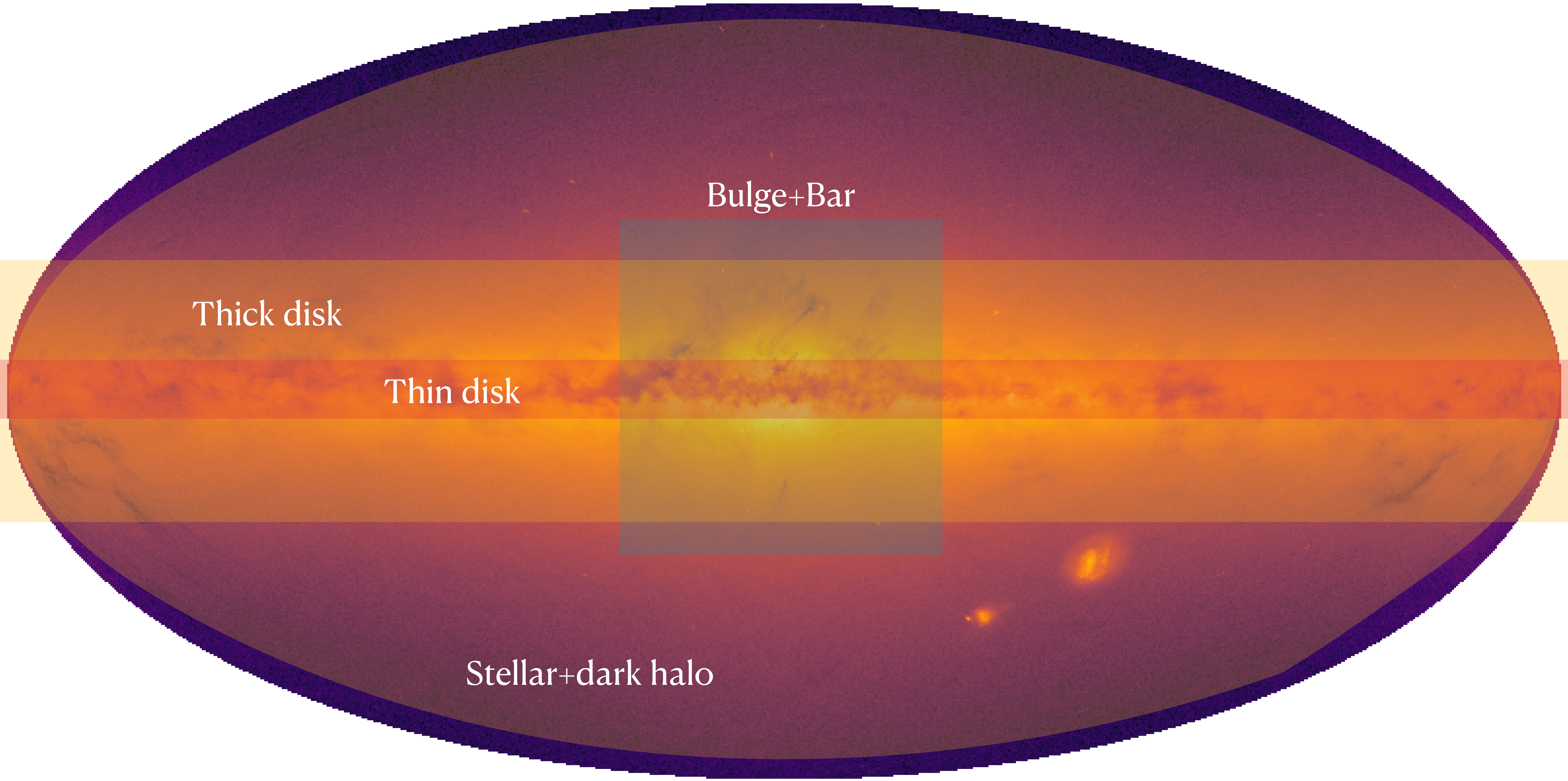
Structure of the Milky Way



Structure of the Milky Way



Structure of the Milky Way



Local DM Density

WIMP expts assume 0.3 GeV/cm3
Axion expts assume 0.4 GeV/cm3

$$\frac{\mathrm{d}R}{\mathrm{d}E_r}(E_r, t) = \frac{\rho_0}{m_\chi m_A} \int_{v>v_{\min}} v f(\mathbf{v}, t) \frac{\mathrm{d}\sigma}{\mathrm{d}E_r}(E_r, v) \mathrm{d}^3 v$$

Local DM velocity distribution

Usually assume SHM
→ Gaussian velocity distribution

Local DM Density

See 1910.14366 for summary of post-Gaia progress

Many ways to measure this locally
Just rescales the rate, so of low priority (prior to some detection)

$$\frac{\mathrm{d}R}{\mathrm{d}E_r}(E_r,t) = \frac{\rho_0}{m_\chi m_A}\int_{v>v_{\min}} v f(\mathbf{v},t)\frac{\mathrm{d}\sigma}{\mathrm{d}E_r}(E_r,v)\mathrm{d}^3v$$

Local DM velocity distribution

Pre-Gaia, no way to infer this apart from simulations
A major uncertainty for DM limits

Simulate MW analogues

- Infer range of possible DM velocity distributions from similar halos
- Impact of baryonic physics?

Compute DM detection signals

- Effects of *f(v)* on particle inference/exclusion limits
- Can DM experiments tell the difference between halo models?

Gaia and direct detection

Observe the MW halo with *Gaia*

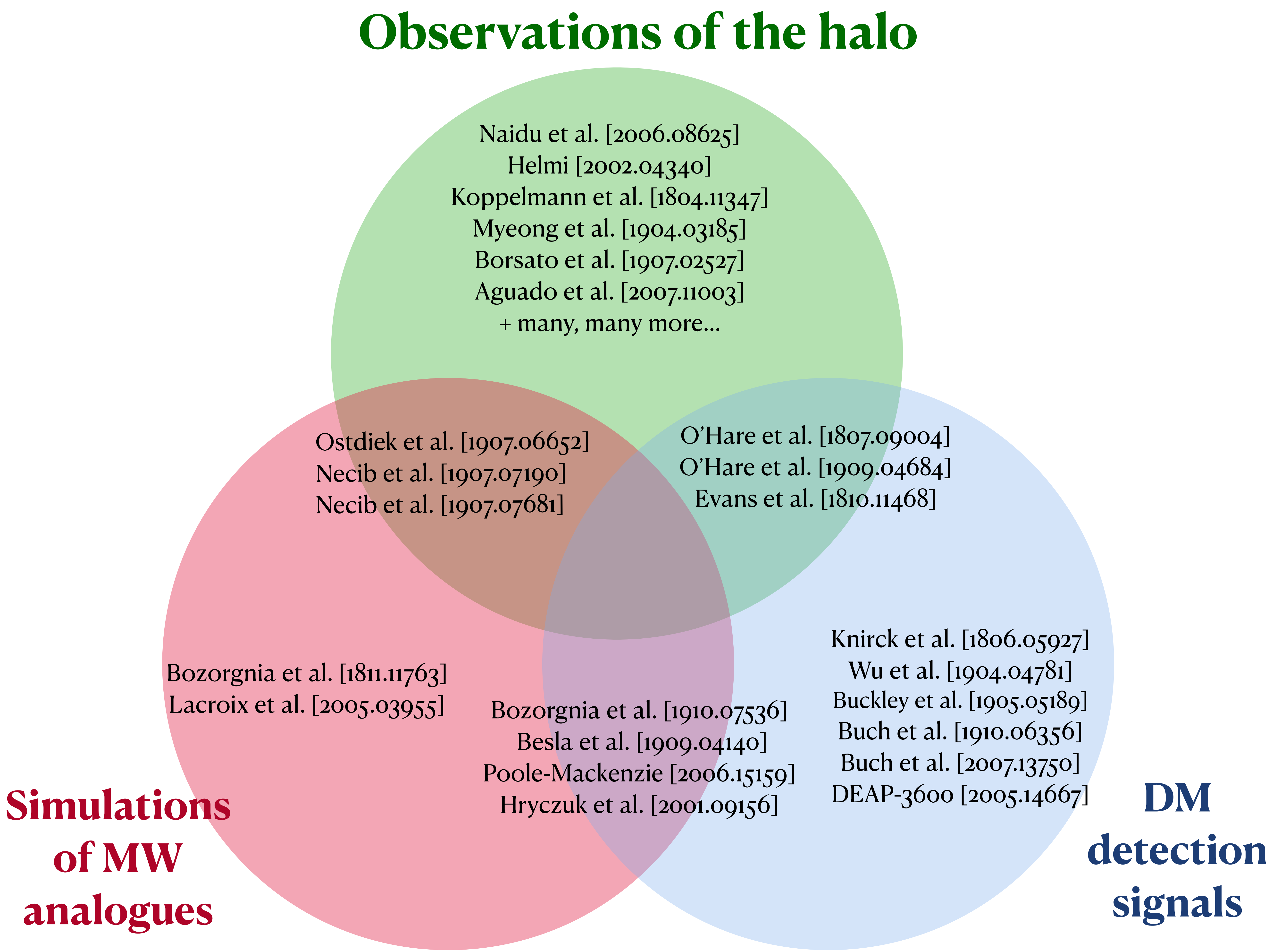
- Structure of the stellar halo in space, velocity and chemistry
- Presence of substructure?
- Evidence for recent mergers?

Simulate MW analogues

- Relationship between stars and DM
- Impact of baryonic physics

Compute DM detection signals

- Effects of $f(v)$ on particle inference/exclusion limits
- Can DM experiments tell the difference between halo models?


Observations of the halo
Naidu et al. [2006.08625]
Helmi [2002.04340]
Koppelmann et al. [1804.11347]
Myeong et al. [1904.03185]
Borsato et al. [1907.02527]
Aguado et al. [2007.11003]
+ many, many more...
Ostdiek et al. [1907.06652]
Necib et al. [1907.07190]
Necib et al. [1907.07681]
O'Hare et al. [1807.09004]
O'Hare et al. [1909.04684]
Evans et al. [1810.11468]
Bozorgnia et al. [1811.11763]
Lacroix et al. [2005.03955]
Bozorgnia et al. [1910.07536]
Besla et al. [1909.04140]
Poole-Mackenzie [2006.15159]
Hryczuk et al. [2001.09156]
Knirck et al. [1806.05927]
Wu et al. [1904.04781]
Buckley et al. [1905.05189]
Buch et al. [1910.06356]
Buch et al. [2007.13750]
DEAP-3600 [2005.14667]
Simulations of MW analogues
DM detection signals

Post-*Gaia* DM direct detection papers relating to $f(v)$

Standard WIMP/Nuclear recoils

Evans et al. [1810.11468]
O'Hare et al. [1807.09004]
Wu et al. [1904.04781]
Buckley et al. [1905.05189]
O'Hare et al. [1909.04684]
Bozorgnia et al. [1910.07536]

Extended models/EFT

DEAP-3600 [2005.14667]
Buch et al. [1910.06356]

Light DM/Electron recoils

Hryczuk et al. [2001.09156]
Buch et al. [2007.13750]

Axion experiments

O'Hare et al. [1807.09004]
Knirck et al. [1806.05927]

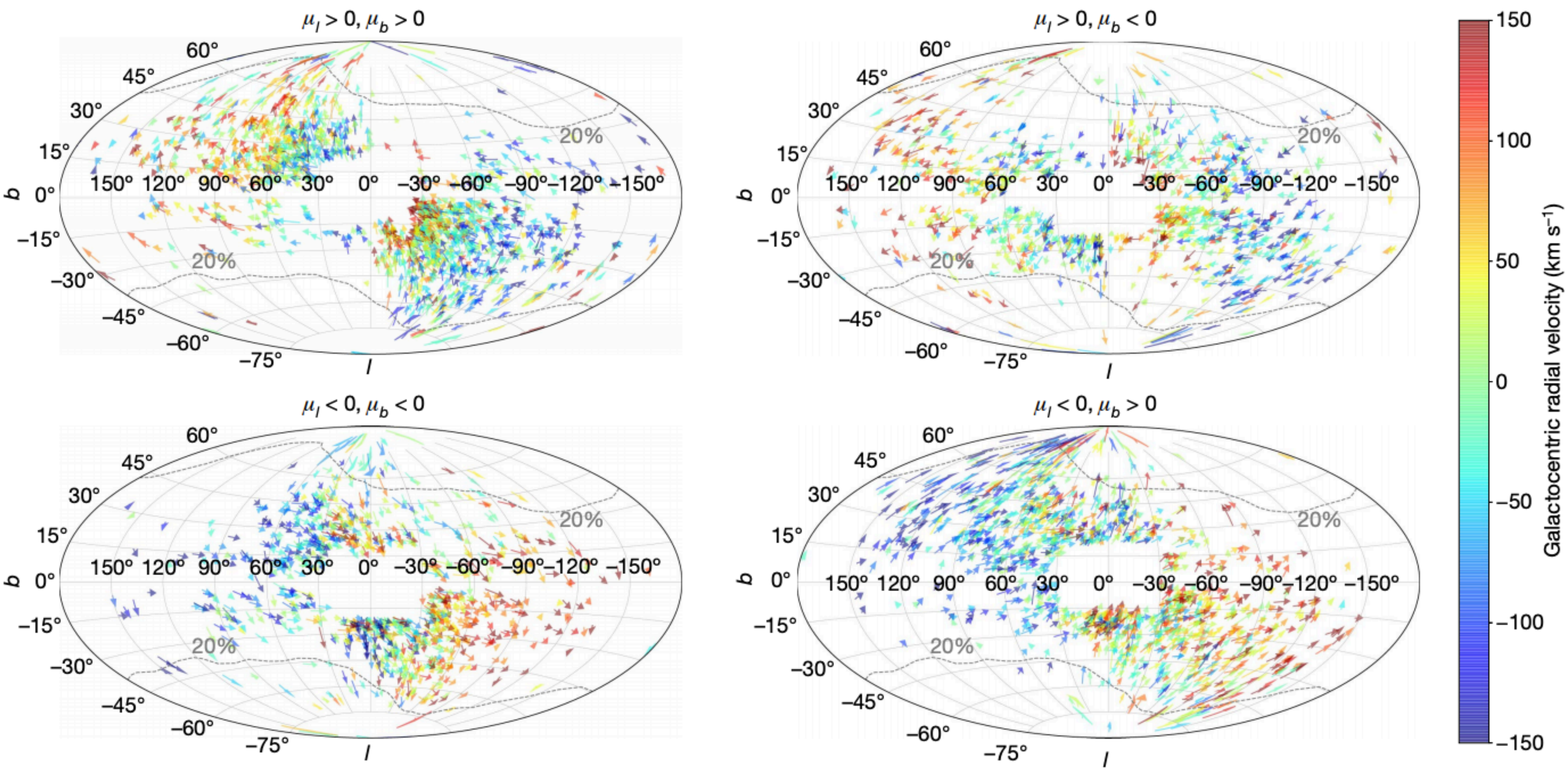
Gaia Enceladus/Sausage

1806.06038

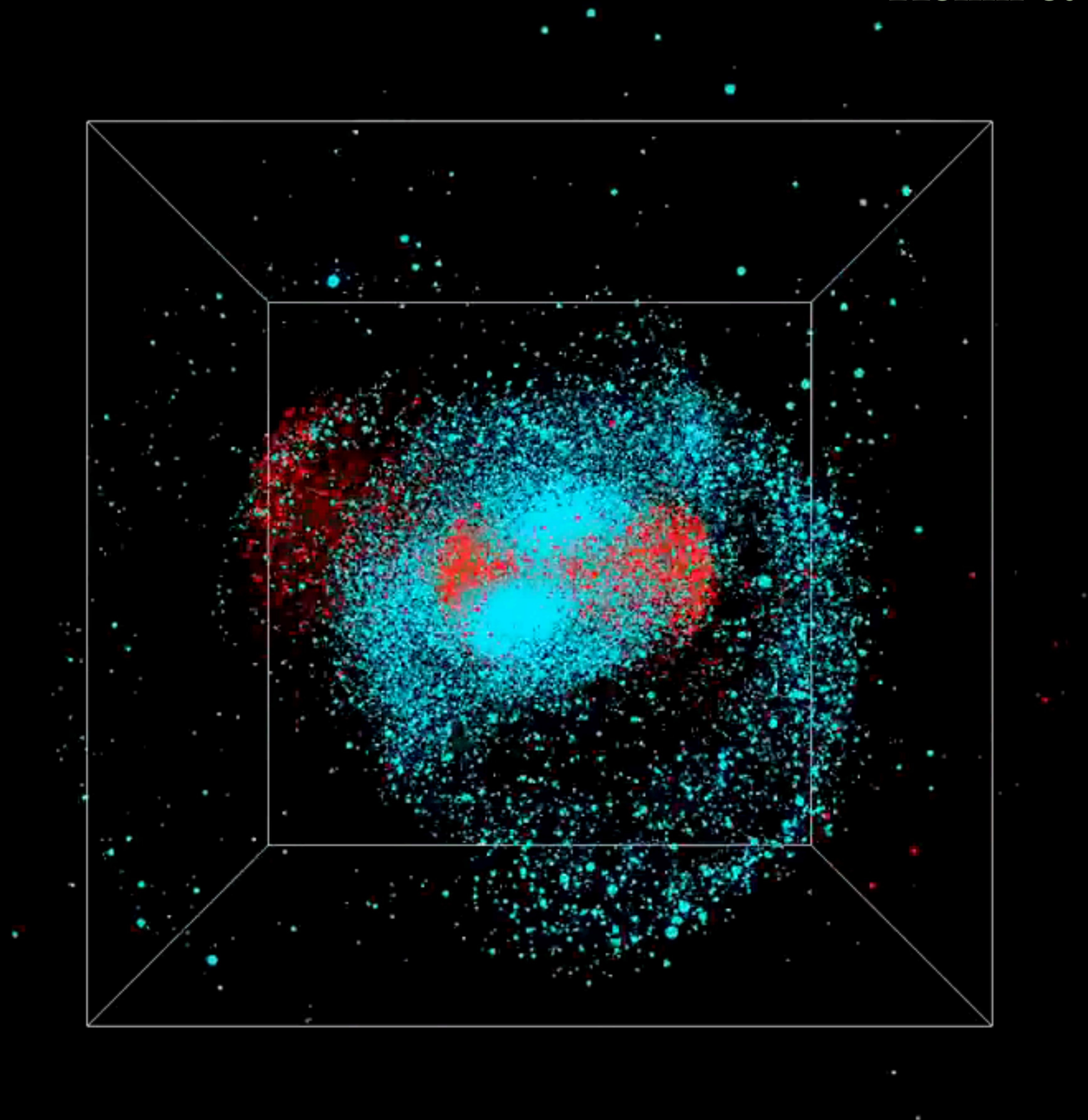
The merger that led to the formation of the Milky Way's inner stellar halo and thick disk

Amina Helmi[1]*, Carine Babusiaux[2,3], Helmer H. Koppelman[1], Davide Massari[1], Jovan Veljanoski[1] & Anthony G. A. Brown[4]

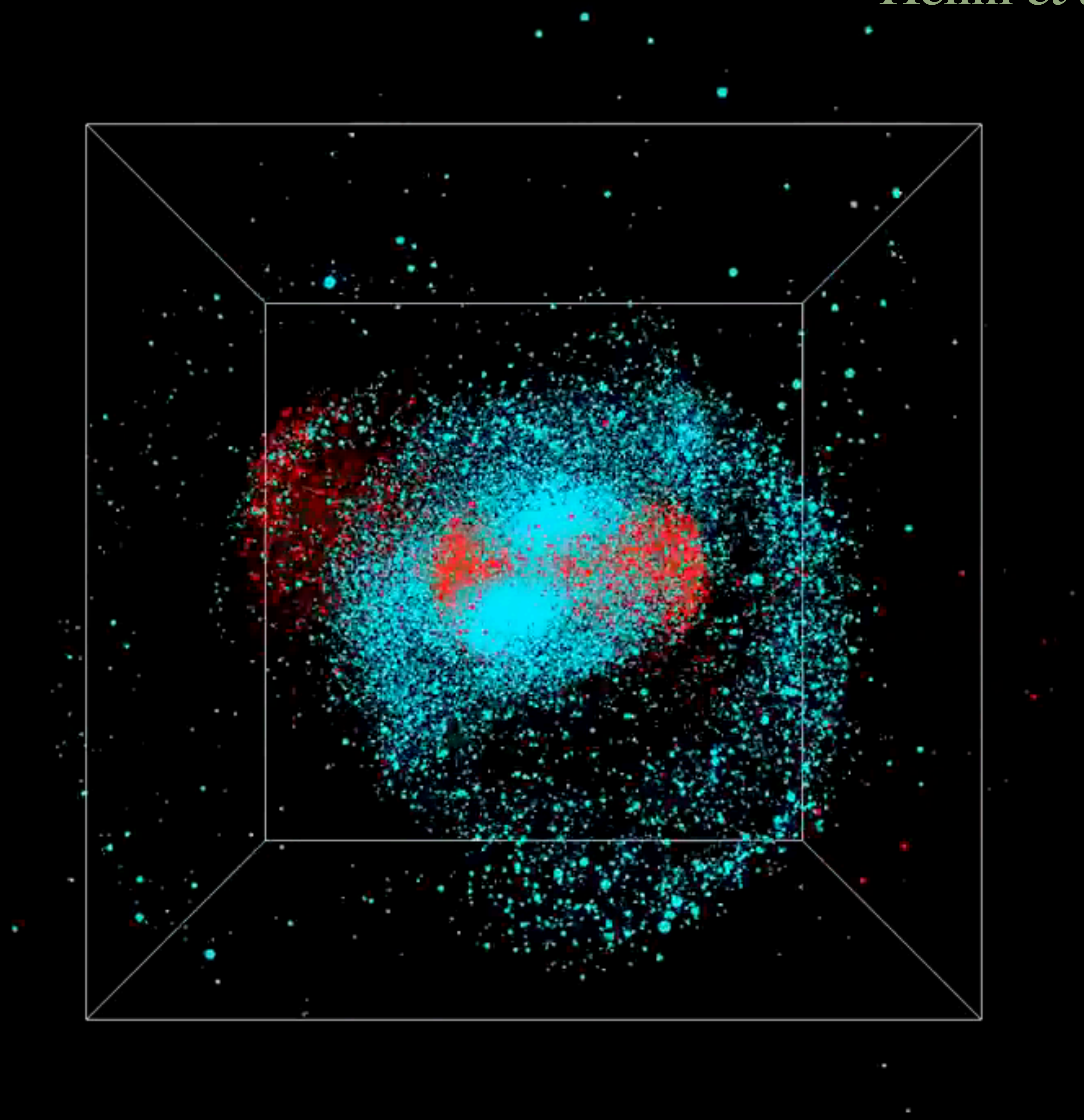
"Gaia Enceladus"



Helmi et al. 1806.06038



Helmi et al. 1806.06038



Co-formation of the disc and the stellar halo*

1802.03414

V. Belokurov,[1,2]† D. Erkal,[1,3] N. W. Evans,[1] S. E. Koposov[1,4] and A. J. Deason[5]

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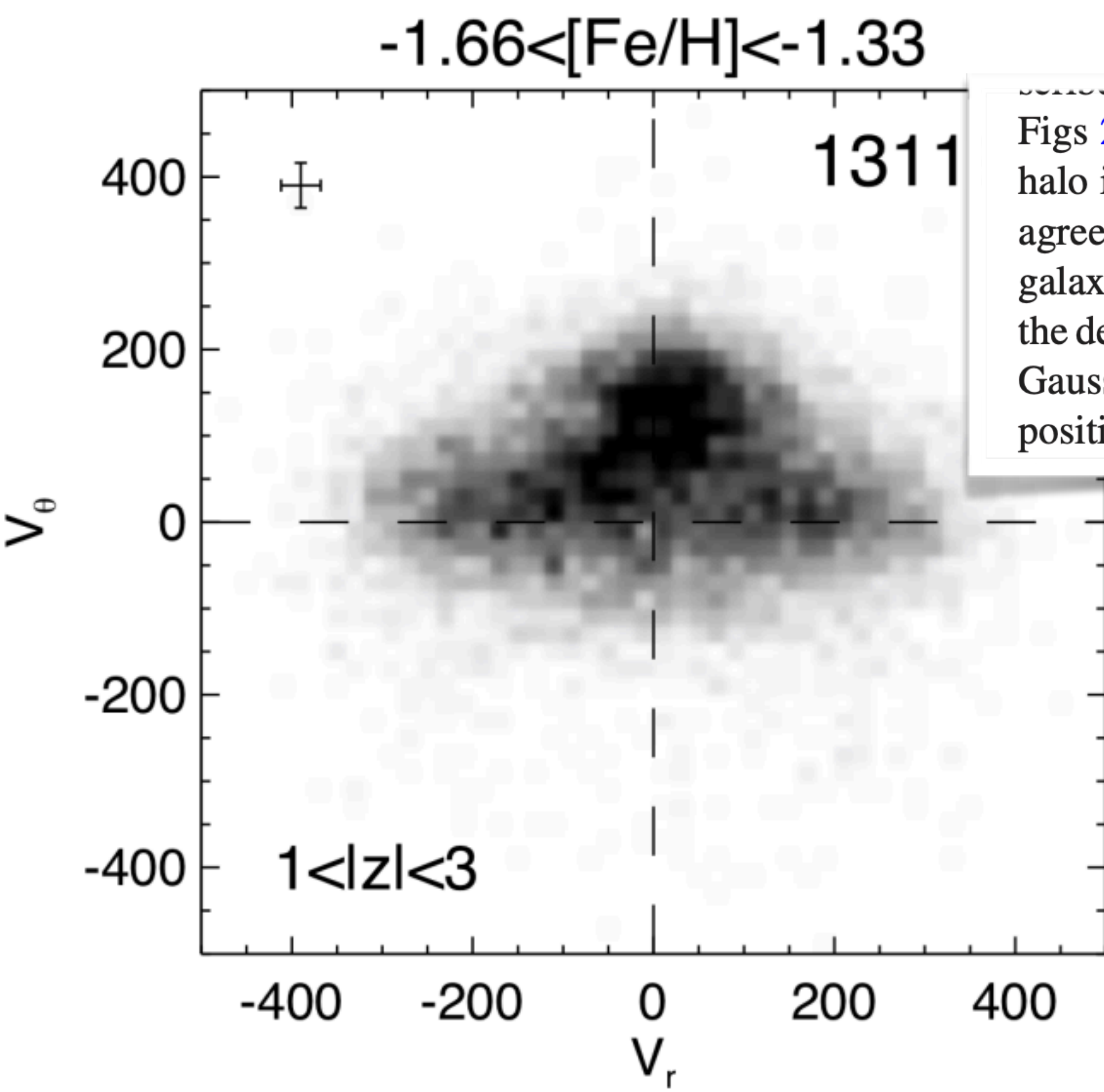
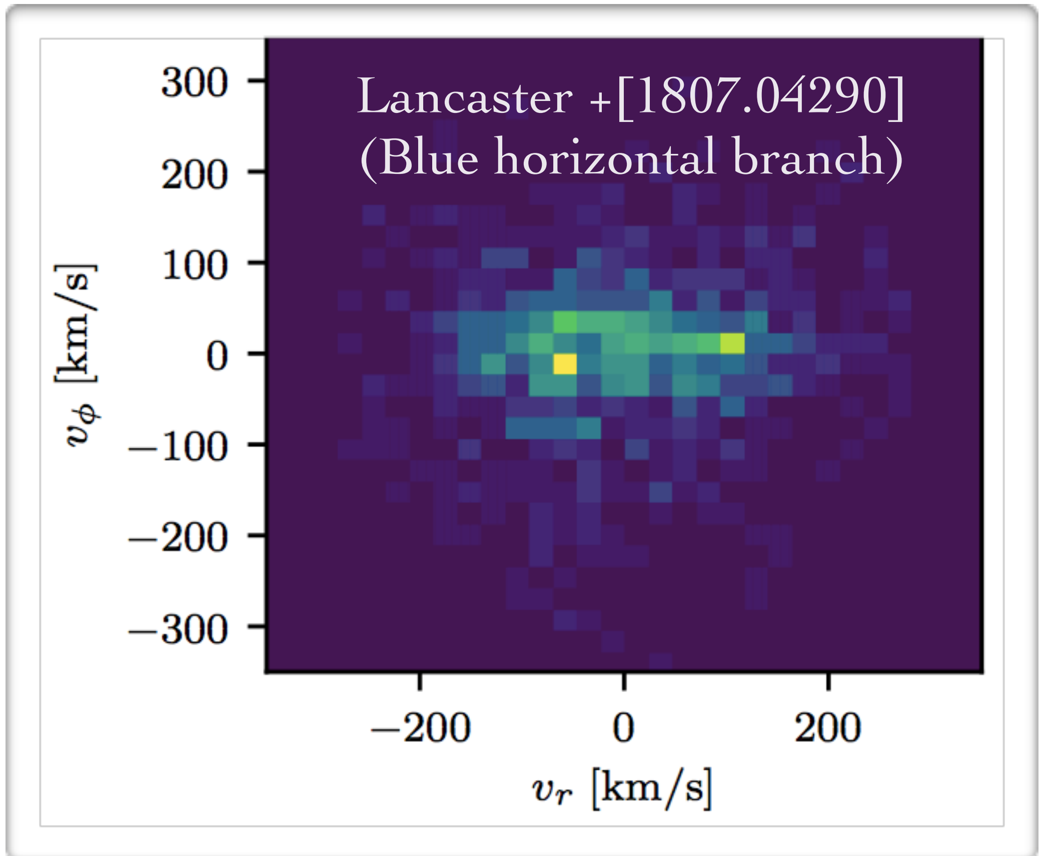
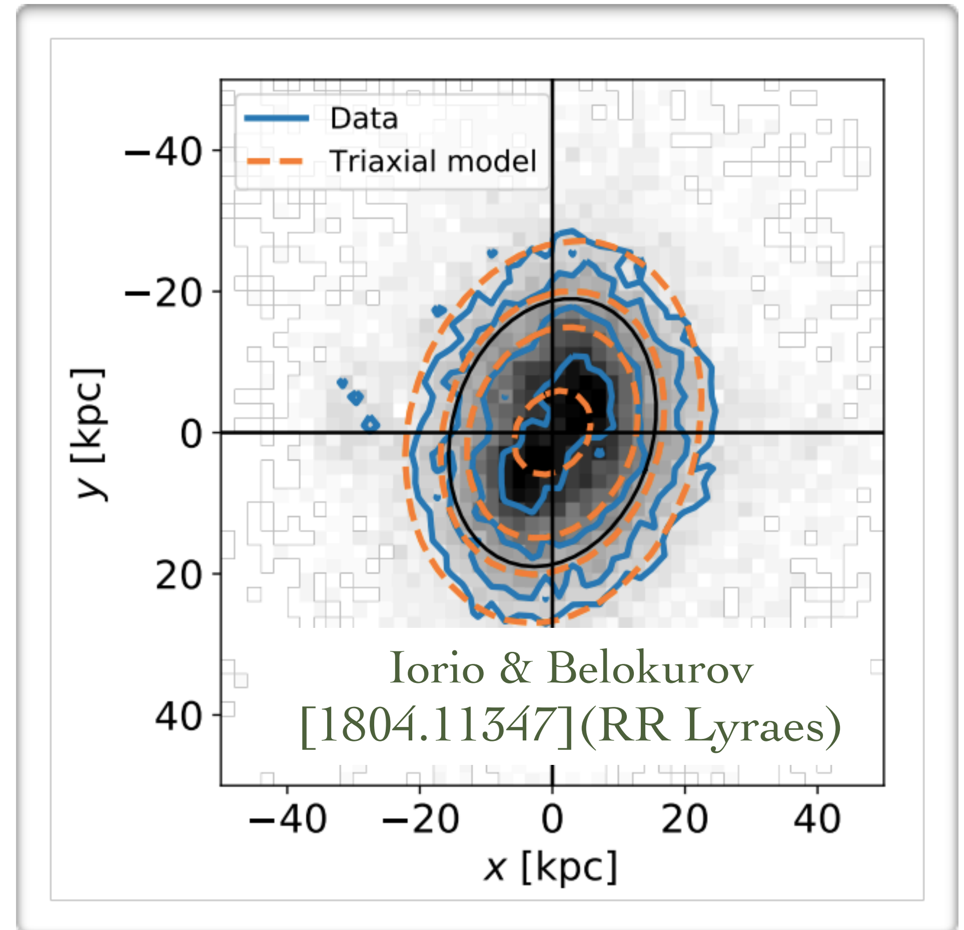
[2] *Center for Computational Astrophysics, Flatiron Institute, 162 5th Avenue, New York, NY 10010, USA*
[3] *Department of Physics, University of Surrey, Guildford GU2 7XH*
[4] *Department of Physics, McWilliams Center for Cosmology, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213, USA*
[5] *Institute for Computational Cosmology, Department of Physics, University of Durham, South Road, Durham DH1 3LE, UK*

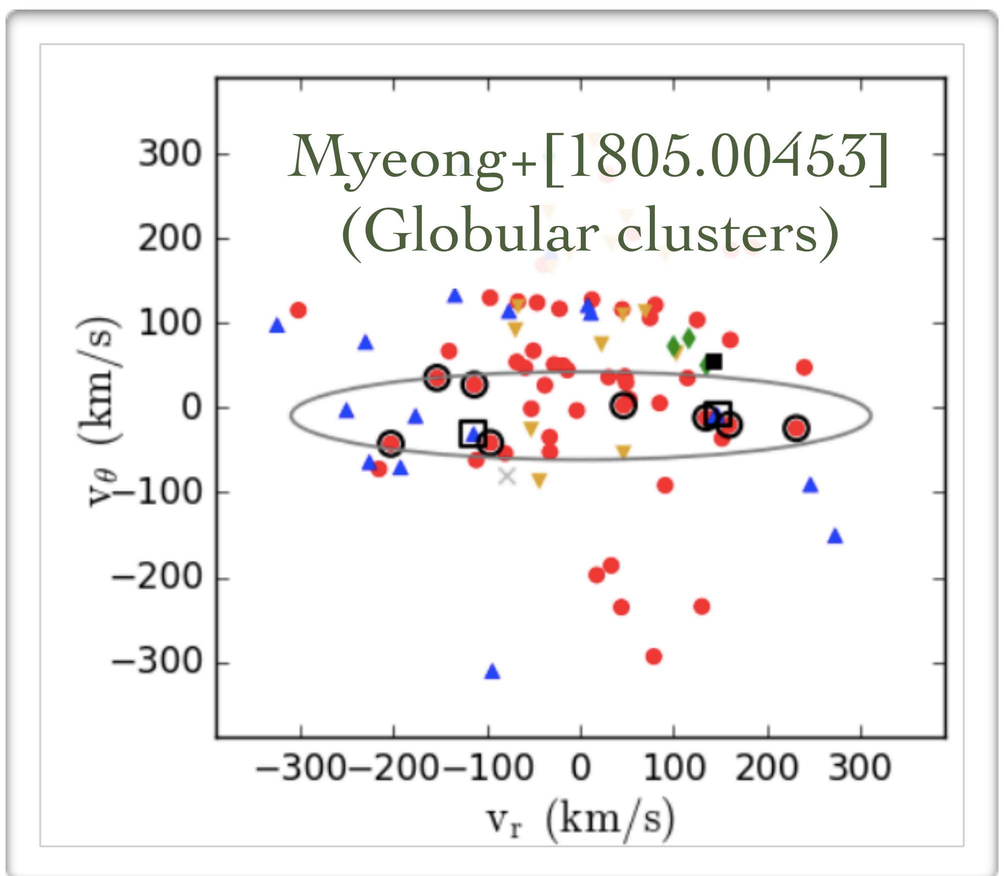


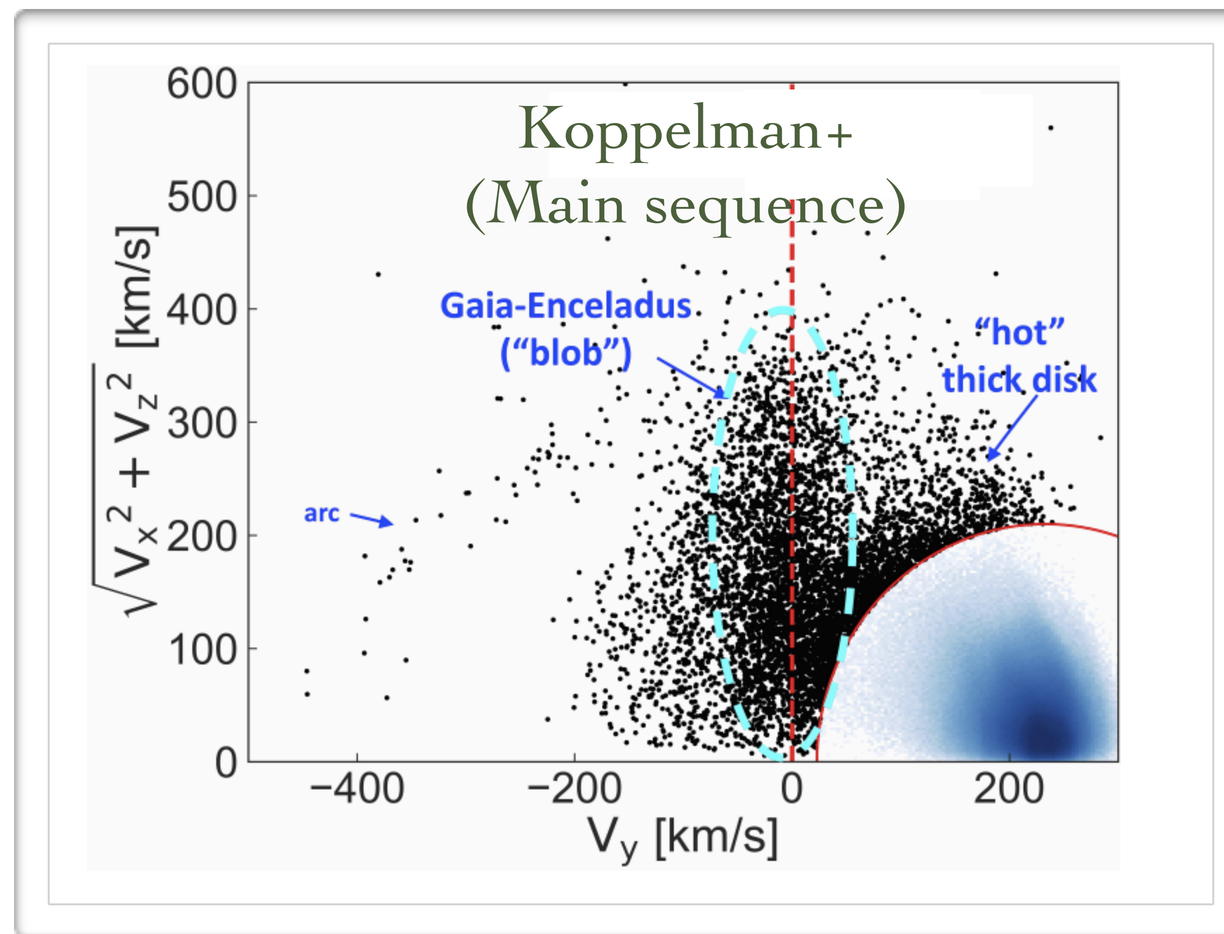
Figs 2 and 3. The radically radial component of the nearby stellar halo is also the one that contains the most metal-rich halo stars, in agreement with the mass–metallicity relationship observed in dwarf galaxies (Kirby et al. 2013). Note, however, that in the (v_r, v_θ) plane the density distribution of this sausage-like population is not exactly Gaussian, as manifested by a pronounced excess of stars with high positive/negative radial velocity (see Fig. 3). We believe, though,

The *Gaia* sausage









From Amina Helmi's review of substructure in the MW [2002.04340]

Gaia-Enceladus/Gaia-Sausage

The prominence of Gaia-Enceladus had in fact been noticed by Belokurov et al. (2018) using an unpublished catalogue of proper motions obtained by combining SDSS and *Gaia* DR1 astrometric positions (also used in Deason et al. 2017). Although the separation between the thick disk and the halo is less sharp because of the lower astrometric precision (as can be seen from **Figure 6**), the authors found (after performing a Gaussian mixture model), that a high fraction of the halo stars had very large radial motions. Through comparison to zoom-in cosmological simulations, this significant radial anisotropy was interpreted as implying that the halo stars originated in a significant merger the Galaxy experienced between redshift 1 and 3. In the spirit of what was known before *Gaia* DR2, this however was not the only possible interpretation, particularly because the lower quality of the proper motions did not reveal a retrograde mean signal (and hence somewhat "abnormal") in the multi-Gaussian component decomposition, and chemical abundance information (in particular the sequence of $[\alpha/\mathrm{Fe}]$) was not used in the study. As the authors themselves acknowledge in their paper, perhaps this blob or "sausage" structure as it was called (see Myeong et al. 2018b, and the available versions on the ArXiv), was the result of a monolithic-like collapse of the kind proposed by Eggen et al. (1962), in the traditional model of formation of an in-situ halo. The result of such a collapse would likely put the stars formed on radially biased orbits. Now with the knowledge provided by *Gaia* DR2 data in combination with that of the APOGEE survey, revealing respectively the retrograde mean motion of the halo and the distinct chemical sequence defined by the majority of its stars, there is absolutely no question that Belokurov et al. (2018) had seen Gaia-Enceladus' mark in the kinematics of halo stars, and interpreted with remarkable insight correctly its accreted origin.

Sausage & Mash: The dual origin of the Galactic thick disc and halo from the gas-rich Gaia-Enceladus-Sausage merger

Robert J. J. Grand,[1★] Daisuke Kawata[2], Vasily Belokurov[3], Alis J. Deason[4], Azadeh Fattahi[4], Francesca Fragkoudi[1], Facundo A. Gómez[5,6], Federico Marinacci[7], Rüdiger Pakmor[1]

[1]*Max-Planck-Institut für Astrophysik, Karl-Schwarzschild-Str. 1, 85748 Garching, Germany*

The Fall of a Giant. Chemical evolution of Enceladus, alias the Gaia Sausage

Fiorenzo Vincenzo[1★], Emanuele Spitoni[2], Francesco Calura[3], Francesca Matteucci[4,5,6], Victor Silva Aguirre[2], Andrea Miglio[1], Gabriele Cescutti[5]

[1]*School of Physics and Astronomy, University of Birmingham, Edgbaston, B15 2TT, UK*
[2]*Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark*

Astrophysics > Astrophysics of Galaxies

Cosmological insights into the assembly of the radial and compact stellar halo of the Milky Way

Lydia M. Elias, Laura V. Sales, Amina Helmi, Lars Hernquist

(Submitted on 6 Mar 2020)

Recent studies using Gaia DR2 have identified a massive merger in the history of the Milky Way (MW) whose debris is markedly radial and counterrotating. This event, known as the Gaia-Enceladus/Gaia-Sausage (GE/GS), is also hypothesized to have built the majority of the inner stellar halo. We use the cosmological hydrodynamic simulation

1810.12301

UNDER THE FIRELIGHT: STELLAR TRACERS OF THE LOCAL DARK MATTER VELOCITY DISTRIBUTION IN THE MILKY WAY

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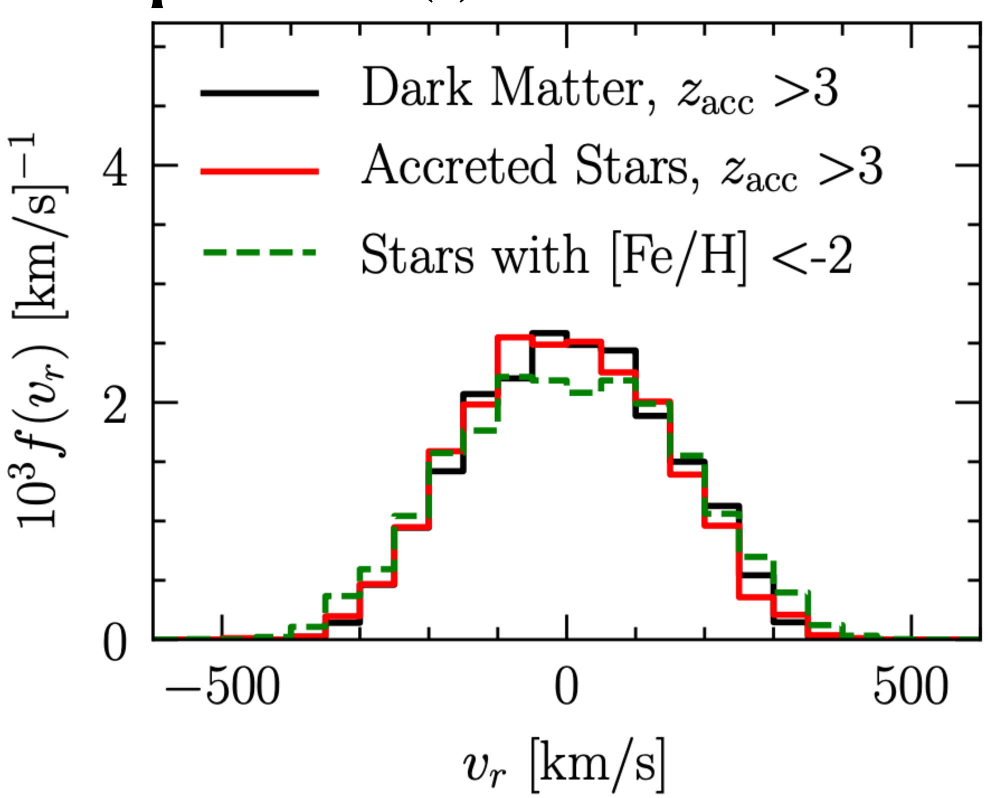
Mariangela Lisanti

Department of Physics, Princeton University, Princeton, NJ 08544, USA

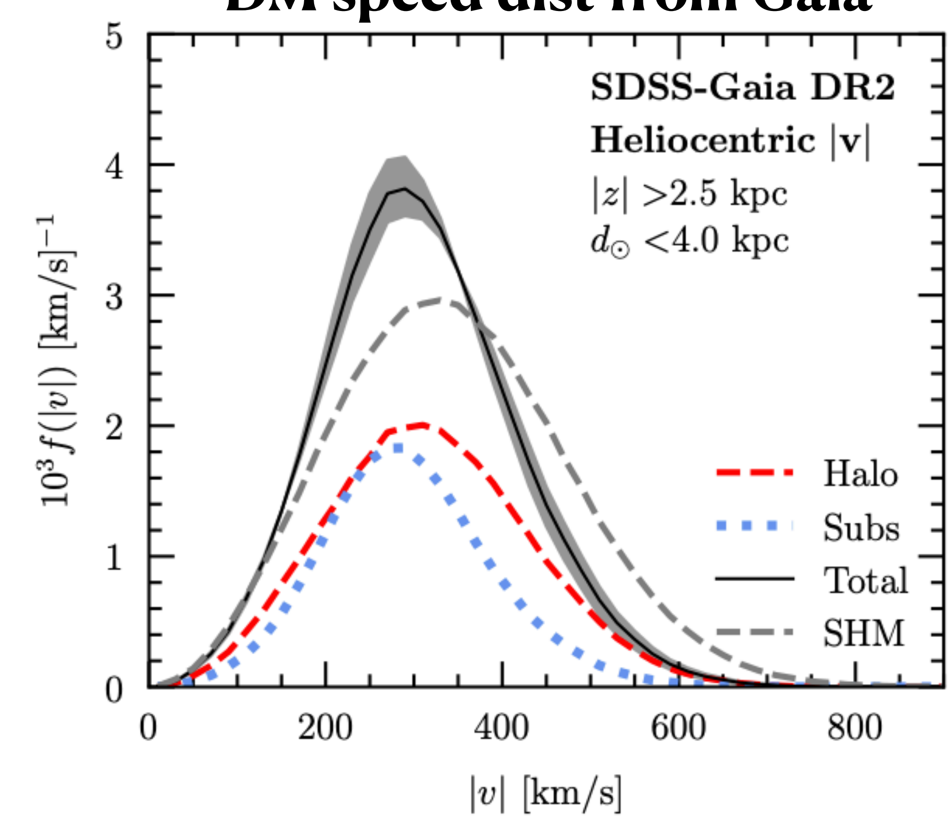
Shea Garrison-Kimmel

TAPIR, California Institute of Technology, Pasadena, CA 91125, USA

Speed dist. (r) in FIRE simulation



DM speed dist from Gaia



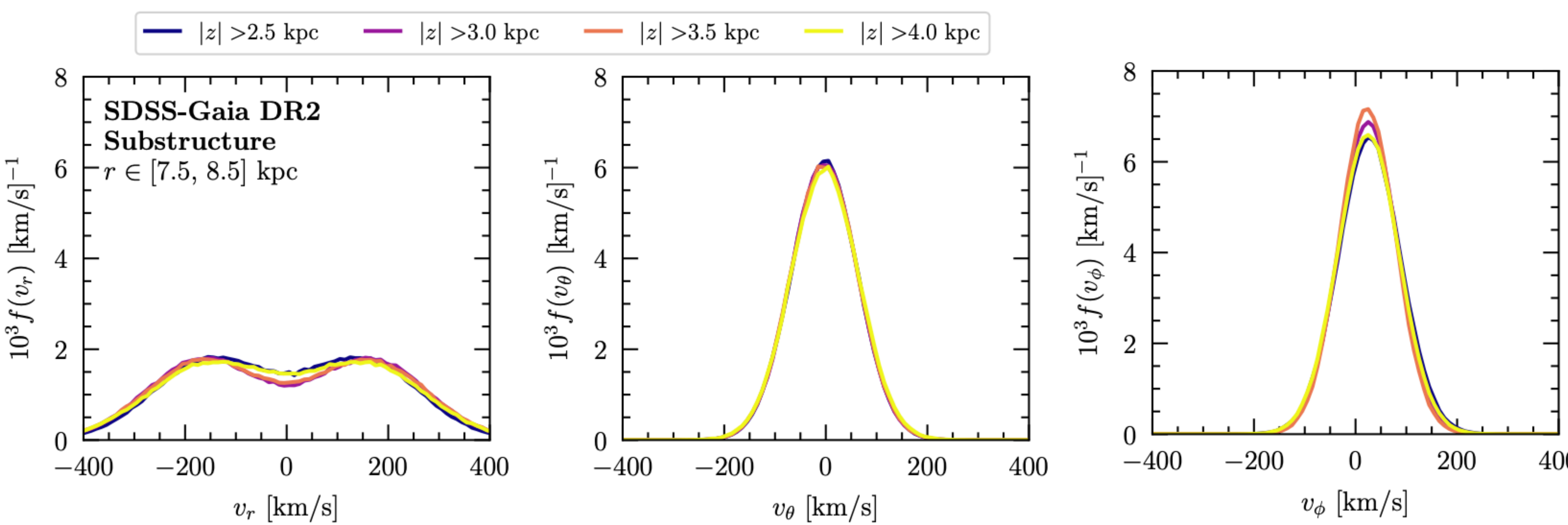
Look at metal poor stars → infer kinematics of accreted DM → apply to *Gaia* to get local DM *f(v)*

INFERRED EVIDENCE FOR DARK MATTER KINEMATIC SUBSTRUCTURE WITH SDSS-*GAIA*

Lina Necib
Walter Burke Institute for Theoretical Physics, California Institute of Technology, Pasadena, CA 91125, USA

Mariangela Lisanti
Department of Physics, Princeton University, Princeton, NJ 08544, USA

Vasily Belokurov
Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA, UK
and
Center for Computational Astrophysics, Flatiron Institute, 162 5th Avenue, New York, NY 10010, USA



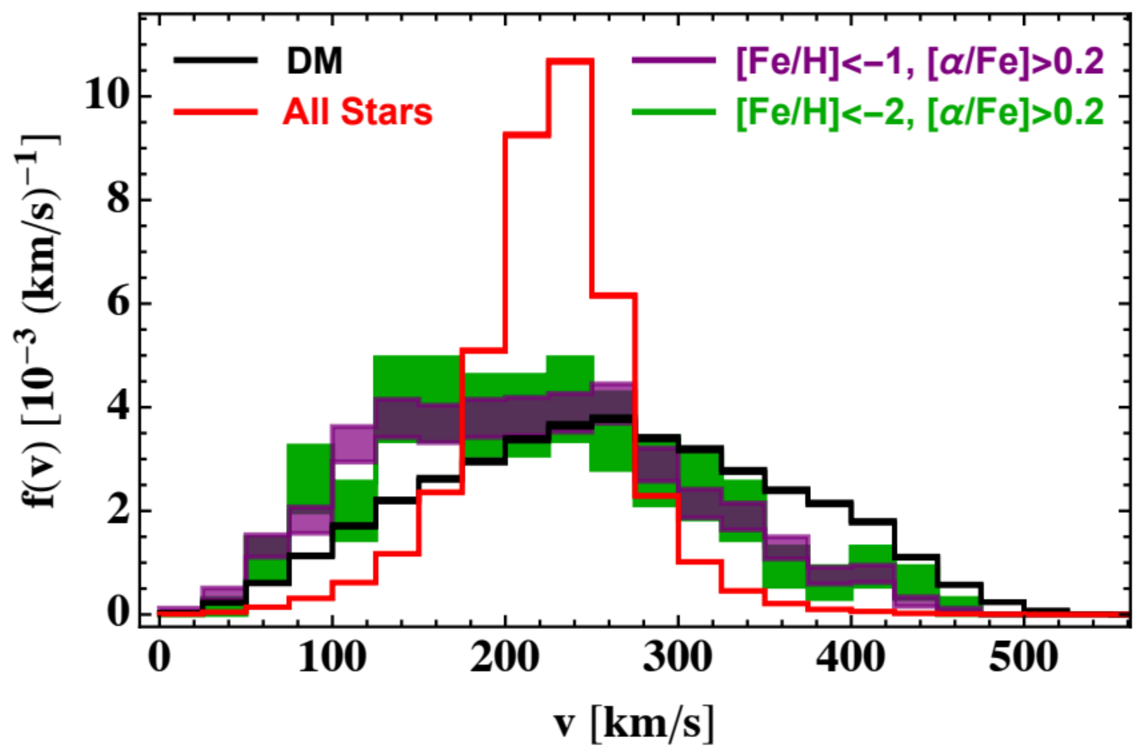
Radial component much wider → Sausage

1811.11763

On the correlation between the local dark matter and stellar velocities

Nassim Bozorgnia,[a] Azadeh Fattahi,[b] David G. Cerdeño,[a] Carlos S. Frenk,[b] Facundo A. Gómez,[c,d] Robert J. J. Grand,[e] Federico Marinacci,[f] and Rüdiger Pakmor[e]

[a]Institute for Particle Physics Phenomenology, Department
Durham University, Durham DH1 3LE, UK



their velocity distributions with that of dark matter in the same Solar neighbourhood region. Our main findings are listed below:

- The velocity distributions of old stars formed less than 1 Gyr or 3 Gyr after the Big Bang show no correlation with the dark matter velocity distribution in the Solar neighbourhood.

- The local dark matter speed distributions have peak speeds which are systematically larger than the peak speeds of the distributions of metal-poor stars.

1812.04114

COMMENT ON THE PAPER

"ON THE CORRELATION BETWEEN THE LOCAL DARK MATTER AND STELLAR VELOCITIES"

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LINA NECIB
Walter Burke Institute for Theoretical Physics, California Institute of Technology, Pasadena, CA 91125, USA

1. The most metal-poor stars ([Fe/H] $\lesssim -2$) trace the dark matter accreted from the oldest mergers ($z \gtrsim 3$). This dark matter population appears to be fully relaxed, or virialized.

2. More intermediate metallicity stars ($-2 \lesssim$ [Fe/H] $\lesssim -1$) trace the dark matter accreted from younger mergers ($z \lesssim 3$). This correspondence holds for dark matter that is in debris flow, but is less robust for streams.

3. Dark matter originating from non-luminous satellites or smooth accretion is not necessarily traced by stars.

Again, neither Herzog-Arbeitman et al. (2017) nor Necib et al. (2018) claimed that metal-poor stars should trace the *total* local dark matter distribution, as suggested by Bozorgnia et al. (2018).

Properties of Gaia Sausage/Enceladus we want to know

1. Anisotropy parameter, β (0 is isotropic, 1 = maximally anisotropic)
2. Fraction of local DM made up of radially anisotropic feature

↓

1. β for the Sausage stars/clusters ~ 0.9—0.95

1805.00453, 1807.04290, 1804.11347…

2. DM fraction harder to estimate…

Evidence from the H3 Survey that the Stellar Halo is Entirely Comprised of Substructure

Rohan P. Naidu,[1] Charlie Conroy,[1] Ana Bonaca,[1] Benjamin D. Johnson,[1] Yuan-Sen Ting (丁源森),[2,3,4,5,*] Nelson Caldwell,[1] Dennis Zaritsky,[6] and Phillip A. Cargile[1]

[1] *Center for Astrophysics | Harvard & Smithsonian, 60 Garden Street, Cambridge, MA 02138, USA*
[2] *Institute for Advanced Study, Princeton, NJ 08540, USA*

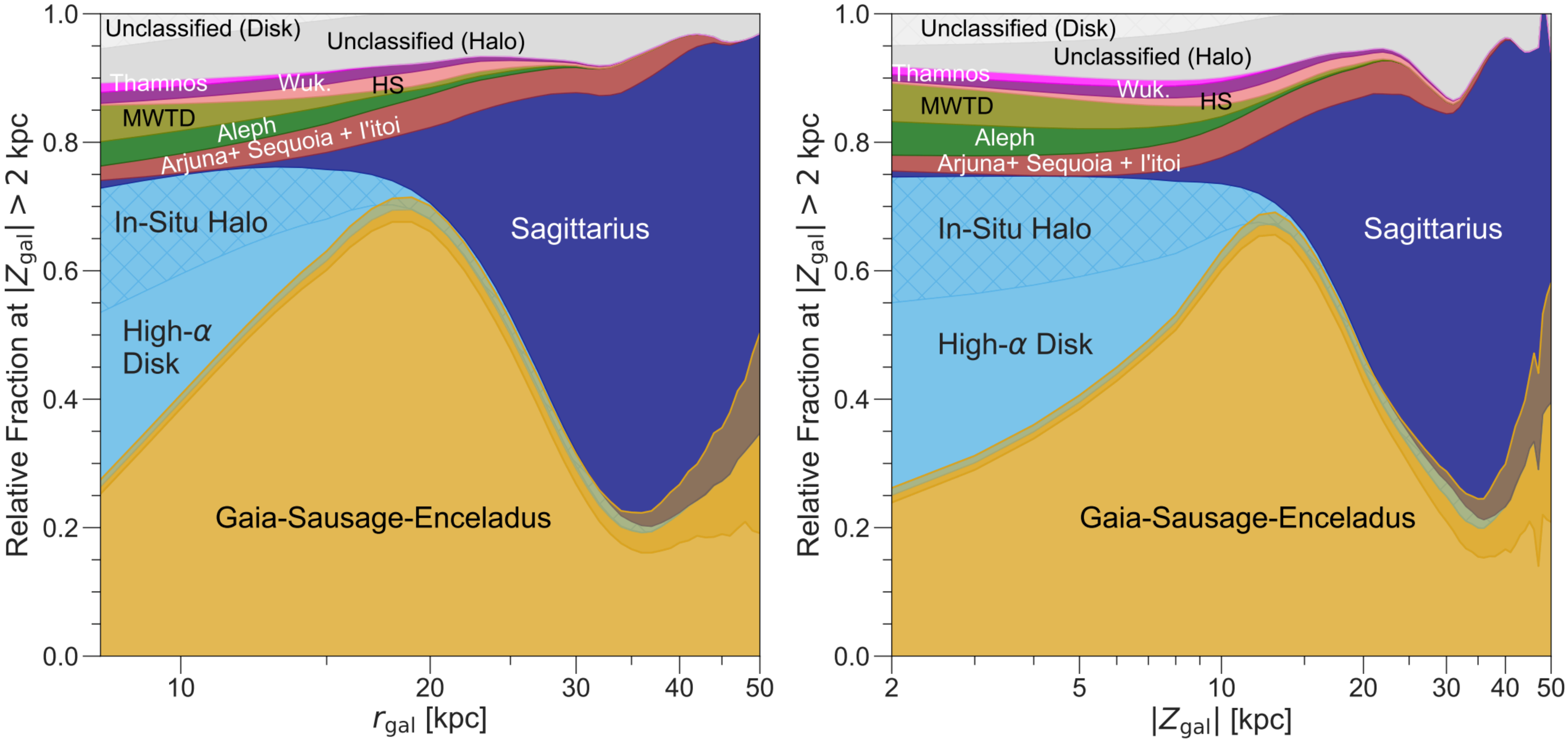

Figure 19. Relative fractions of structures as a function of total Galactocentric distance, $r_{\rm gal}$ (**left**) and distance from the plane, $|Z_{\rm gal}|$ (**right**). Fractions have been corrected for the H3 Survey selection function. The high-α disk is defined to lie at

The dark matter component of the Gaia radially anisotropic substructure

1910.07536

Nassim Bozorgnia,[a,b] **Azadeh Fattahi,**[c] **Carlos S. Frenk,**[c] **Andrew Cheek,**[b,d] **David G. Cerdeño,**[b] **Facundo A. Gómez,**[e,f] **Robert J. J. Grand,**[g] **and Federico Marinacci**[h]

[a]York University, Department of Physics and Astronomy, 4700 Keele Street, Toronto, Ontario M3J 1P3, Canada

[b]Institute for Particle Physics Phenomenology, Department of Physics, Durham University, Durham DH1 3LE, UK

10 Auriga halos, 4 with a radially anisotropic feature (GRASP)

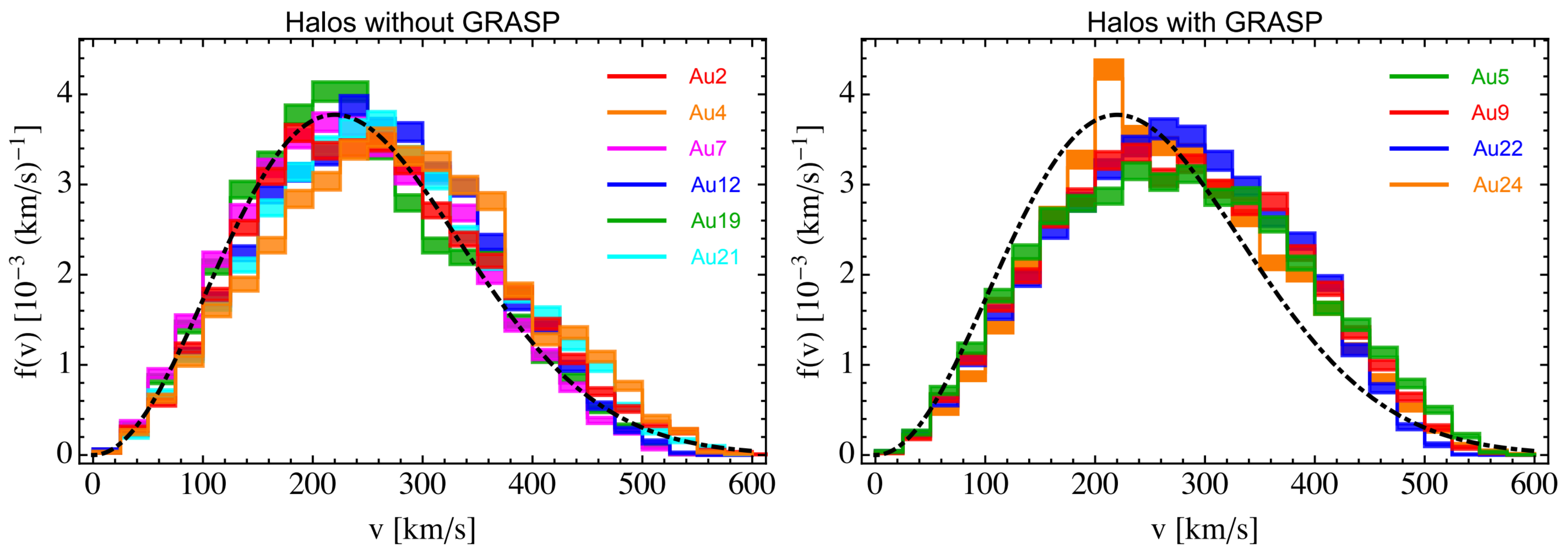

Figure 8. A comparison of the local DM speed distributions in the Galactic rest frame for the Auriga MW-like halos without (left panel) and with (right panel) the GRASP (shaded colour bands), and the SHM Maxwellian speed distribution with a peak speed of 220 km s^{-1} (black dot-dashed curve).

The dark matter component of the Gaia radially anisotropic substructure

1910.07536

Nassim Bozorgnia,[a,b] **Azadeh Fattahi,**[c] **Carlos S. Frenk,**[c] **Andrew Cheek,**[b,d] **David G. Cerdeño,**[b] **Facundo A. Gómez,**[e,f] **Robert J. J. Grand,**[g] **and Federico Marinacci**[h]

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Durham University, Durham DH1 3LE, UK

altered for halos with and without the GRASP. We summarize our findings below.

- The fraction of the DM particles belonging to the GRASP in a torus around the Solar circle is between 0.6% and 17% for the Auriga MW-like halos with the GRASP. The anisotropy parameter of these DM particles is in the range of $\beta = [0.48 - 0.82]$. There exists an anti-correlation between the fraction and anisotropy of the DM particles belonging to the GRASP in the torus.

How much of local DM is in Gaia Enceladus/Sausage

Bozorgnia et al. 1810.11468

0.4-17% of local DM. Inferred from four Auriga halos that contain a radially anistropic feature

Naidu et al. 2006.08625

Fraction of ***stellar*** halo around 20% locally, inferred from H3 survey

Necib et al. 1810.12301

Sausage fraction ~ 23% inferred from FIRE simulation

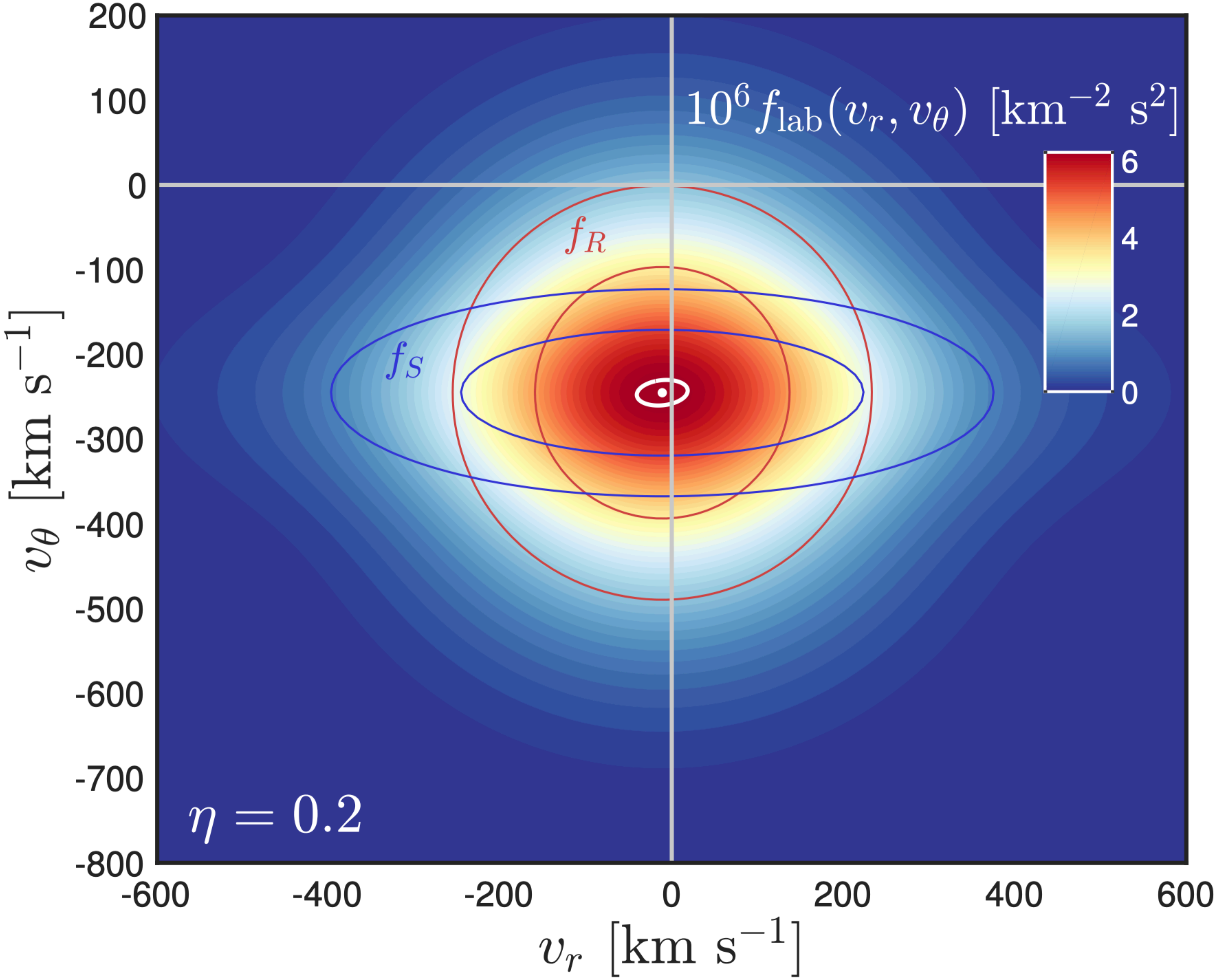
Evans et al. 1810.11468

Sausage fraction ~ 20% from sphericity of MW potential

1810.11468

SHM^{++}: A Refinement of the Standard Halo Model for Dark Matter Searches

N. Wyn Evans,[1,*] Ciaran A. J. O'Hare,[2,†] and Christopher McCabe[3,‡]
[1] *Institute of Astronomy, Madingley Rd, Cambridge, CB3 0HA, United Kingdom*



Simple model for the DM halo velocity distribution composed of a round part (fR), and the radially anisotropic sausage (fS)

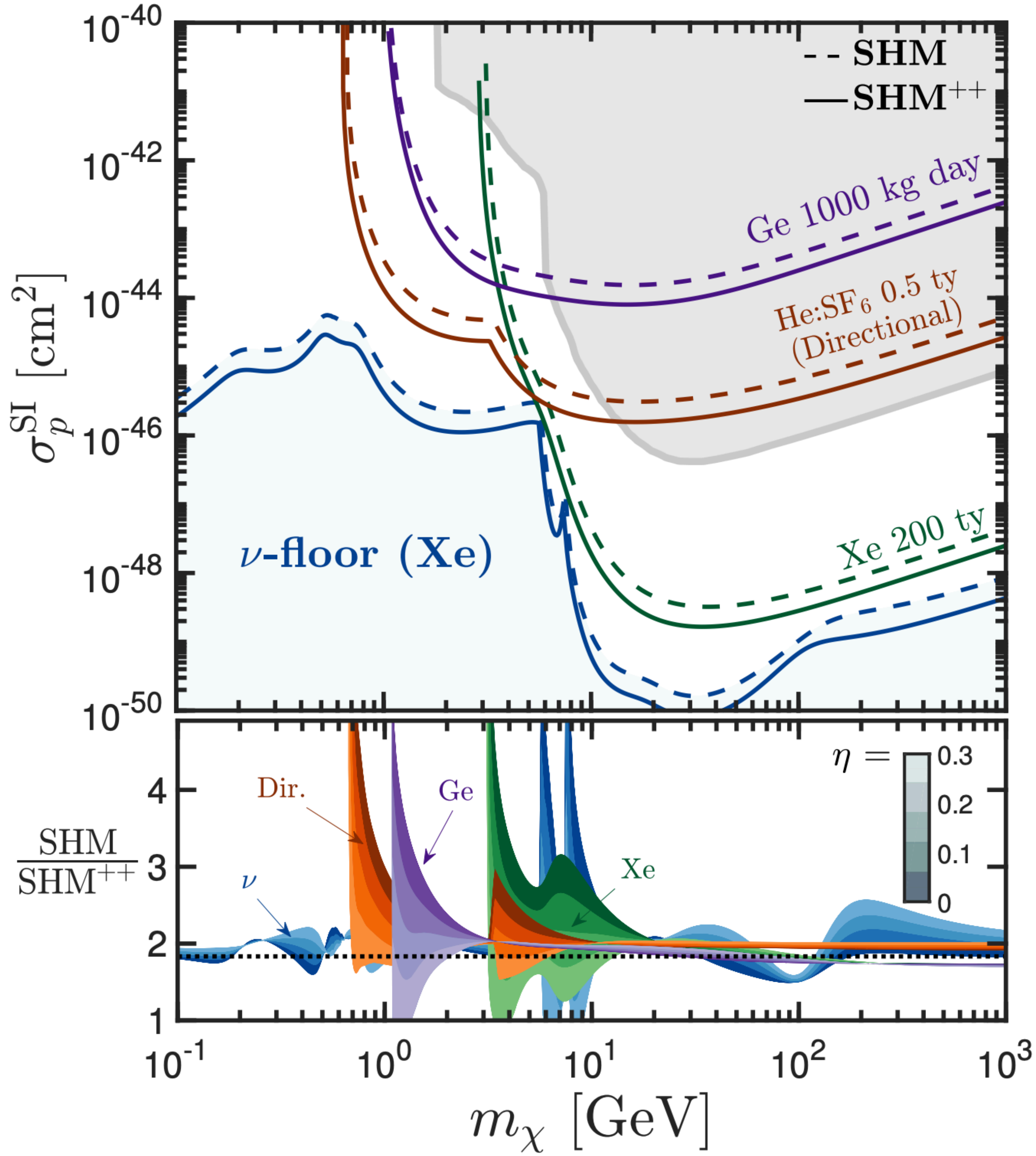
With Sausage fraction ~ 0.2

1810.11468

SHM^{++}: A Refinement of the Standard Halo Model for Dark Matter Searches

N. Wyn Evans,[1,*] Ciaran A. J. O'Hare,[2,†] and Christopher McCabe[3,‡]

[1] Institute of Astronomy, Madingley Rd, Cambridge, CB3 0HA, United Kingdom



SHM	Local DM density	ρ_0	$0.3\,\mathrm{GeV\,cm^{-3}}$
	Circular rotation speed	v_0	$220\ \mathrm{km\ s^{-1}}$
	Escape speed	$v_{\rm esc}$	$544\ \mathrm{km\ s^{-1}}$
	Velocity distribution	$f_{\rm R}(\mathbf{v})$	Eq. (1)
SHM^{++}	Local DM density	ρ_0	$0.55 \pm 0.17\ \mathrm{GeV\ cm^{-3}}$
	Circular rotation speed	v_0	$233 \pm 3\ \mathrm{km\ s^{-1}}$
	Escape speed	$v_{\rm esc}$	$528^{+24}_{-25}\ \mathrm{km\ s^{-1}}$
	Sausage anisotropy	β	0.9 ± 0.05
	Sausage fraction	η	0.2 ± 0.1
	Velocity distribution	$f(\mathbf{v})$	Eq. (3)

Implications of the *Gaia* Sausage for Dark Matter Nuclear Interactions

Jatan Buch,[1,*] JiJi Fan,[1,†] and John Shing Chau Leung[1,‡]
[1] *Department of Physics, Brown University, Providence, RI, 02912, USA*

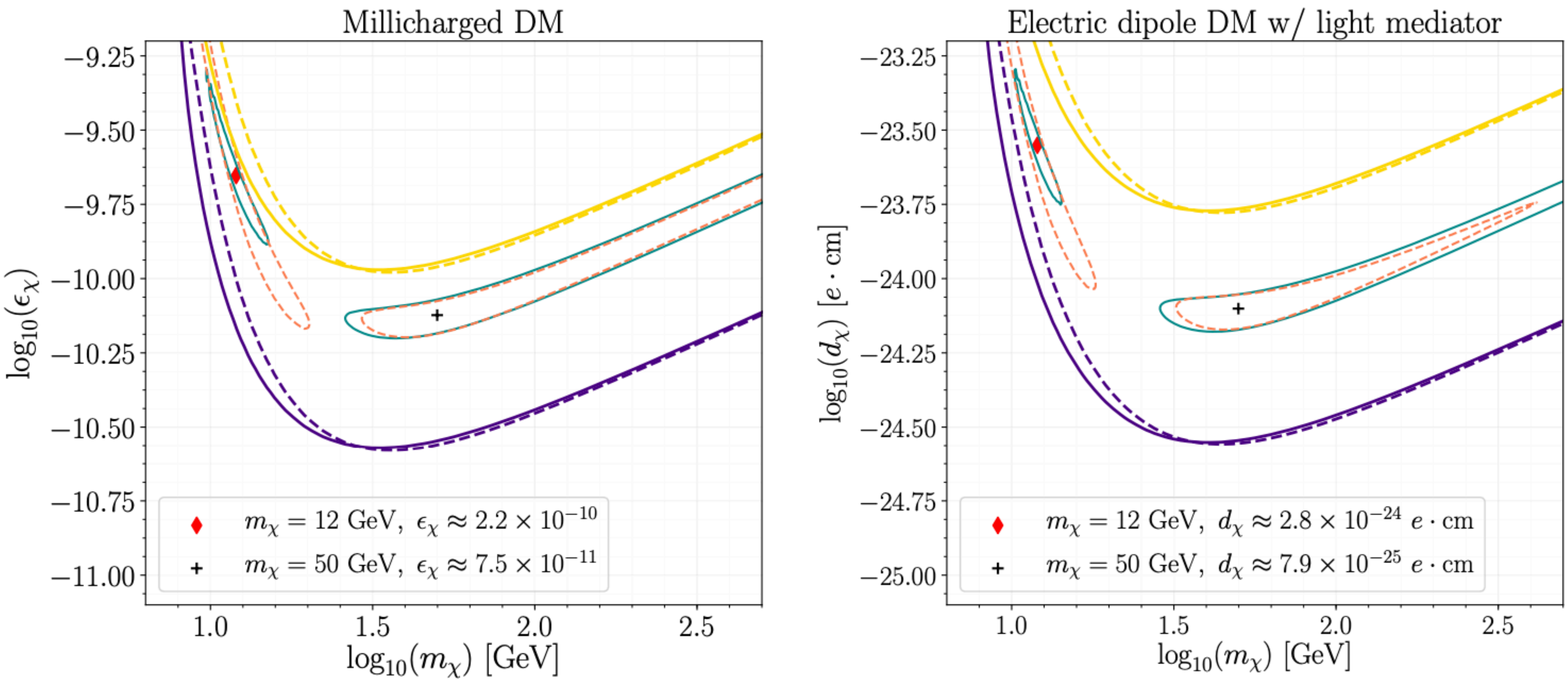
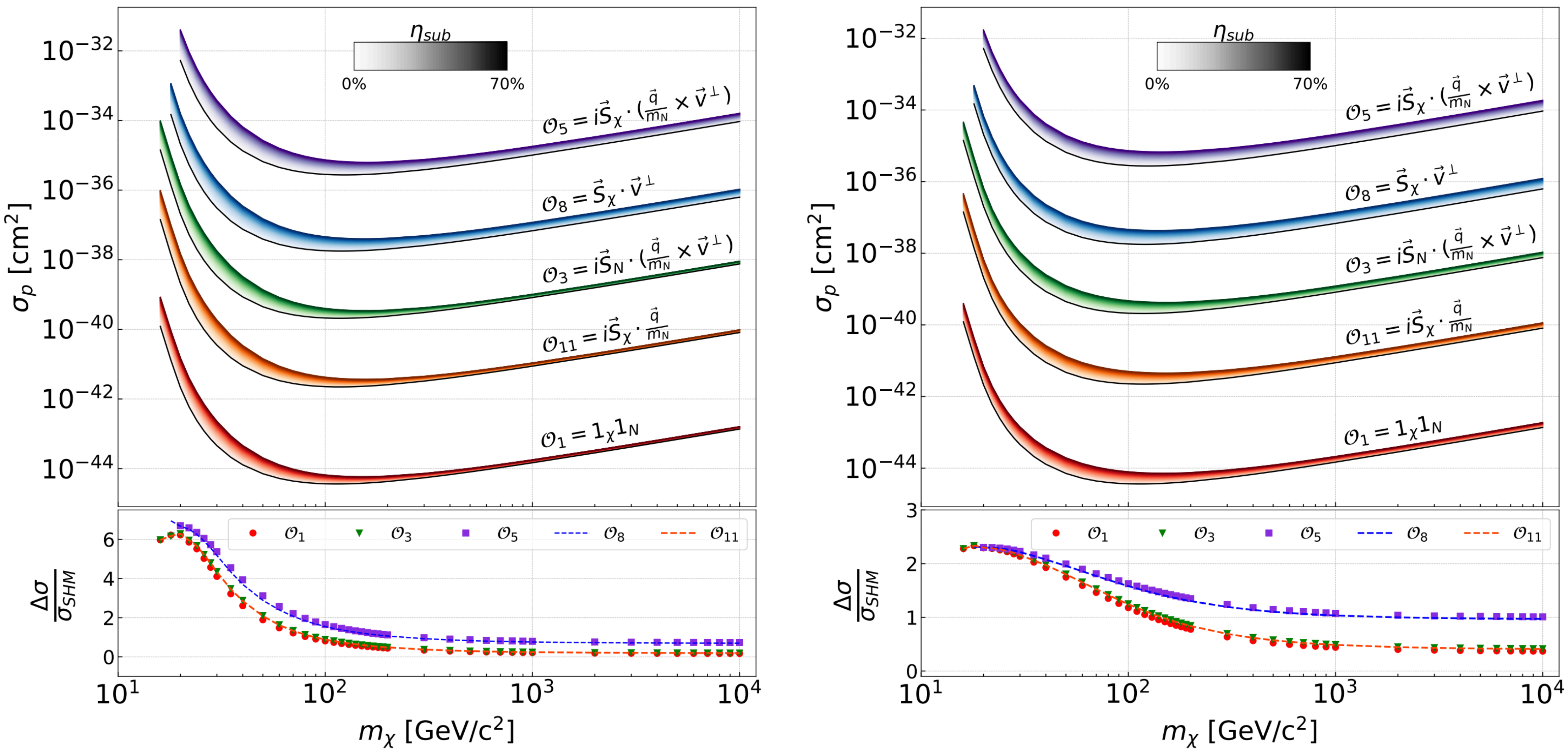


FIG. 7: Constraints and forecasts in the DM coupling-mass plane for all the benchmark models in Table II with varying q^2 and v^2 dependence. The 68% CL forecast contours for SHM (cyan, solid) and *Gaia* (orange, dashed) velocity distributions are shown for both light (red diamond, $m_\chi = 12$ GeV) and heavy (black cross, $m_\chi = 50$ GeV) DM. Also indicated for reference are 90% CL upper limits following the latest XENON-1T results (yellow) and projected upper limits for a DARWIN-like experiment (indigo) assuming SHM (solid) and *Gaia* (dashed) velocity distributions. The constraints for MD with heavy mediator are quoted in units of electron Bohr magneton, $\mu_e = \frac{e}{2m_e}$.

2005.14667

Constraints on dark matter-nucleon effective couplings in the presence of kinematically distinct halo substructures using the DEAP-3600 detector

P. Adhikari,[5] R. Ajaj,[5,24] C. E. Bina,[1,24] W. Bonivento,[14] M. G. Boulay,[5] M. Cadeddu,[7,14] B. Cai,[5,24] M. Cárdenas-Montes,[4] S. Cavuoti,[6,13] Y. Chen,[1] B. T. Cleveland,[20,9] J. M. Corning,[17] S. Daugherty,[9] P. DelGobbo,[5,24] P. Di Stefano,[17] L. Doria,[15] M. Dunford,[5] A. Erlandson,[5,3] S. S. Farahani,[1]



(a) *Gaia* Sausage (Necib *et al.*) [61]

(b) *Gaia* Sausage (O'Hare *et al.*) [17]

FIG. 9. Upper limits (90 % C. L.) on DM-nucleon scattering cross sections for the $\mathcal{O}_1$, $\mathcal{O}_{11}$, $\mathcal{O}_3$, $\mathcal{O}_8$, and $\mathcal{O}_5$ effective operators, in the presence of VDFs corresponding to both *Gaia* Sausage models, G1 streams, and G2 streams, with $\eta_{\rm sub}$ of the DM contained in the specified substructure. Beneath each set of exclusion curves is the relative deviation of each operator with the given substructure at its maximum value compared to the SHM and where $\Delta\sigma = \sigma_{\rm sub} - \sigma_{\rm SHM}$.

2005.14667

Constraints on dark matter-nucleon effective couplings in the presence of kinematically distinct halo substructures using the DEAP-3600 detector

P. Adhikari,[5] R. Ajaj,[5,24] C. E. Bina,[1,24] W. Bonivento,[14] M. G. Boulay,[5] M. Cadeddu,[7,14] B. Cai,[5,24] M. Cárdenas-Montes,[4] S. Cavuoti,[6,13] Y. Chen,[1] B. T. Cleveland,[20,9] J. M. Corning,[17] S. Daugherty,[9] P. DelGobbo,[5,24] P. Di Stefano,[17] L. Doria,[15] M. Dunford,[5] A. Erlandson,[5,3] S. S. Farahani,[1]

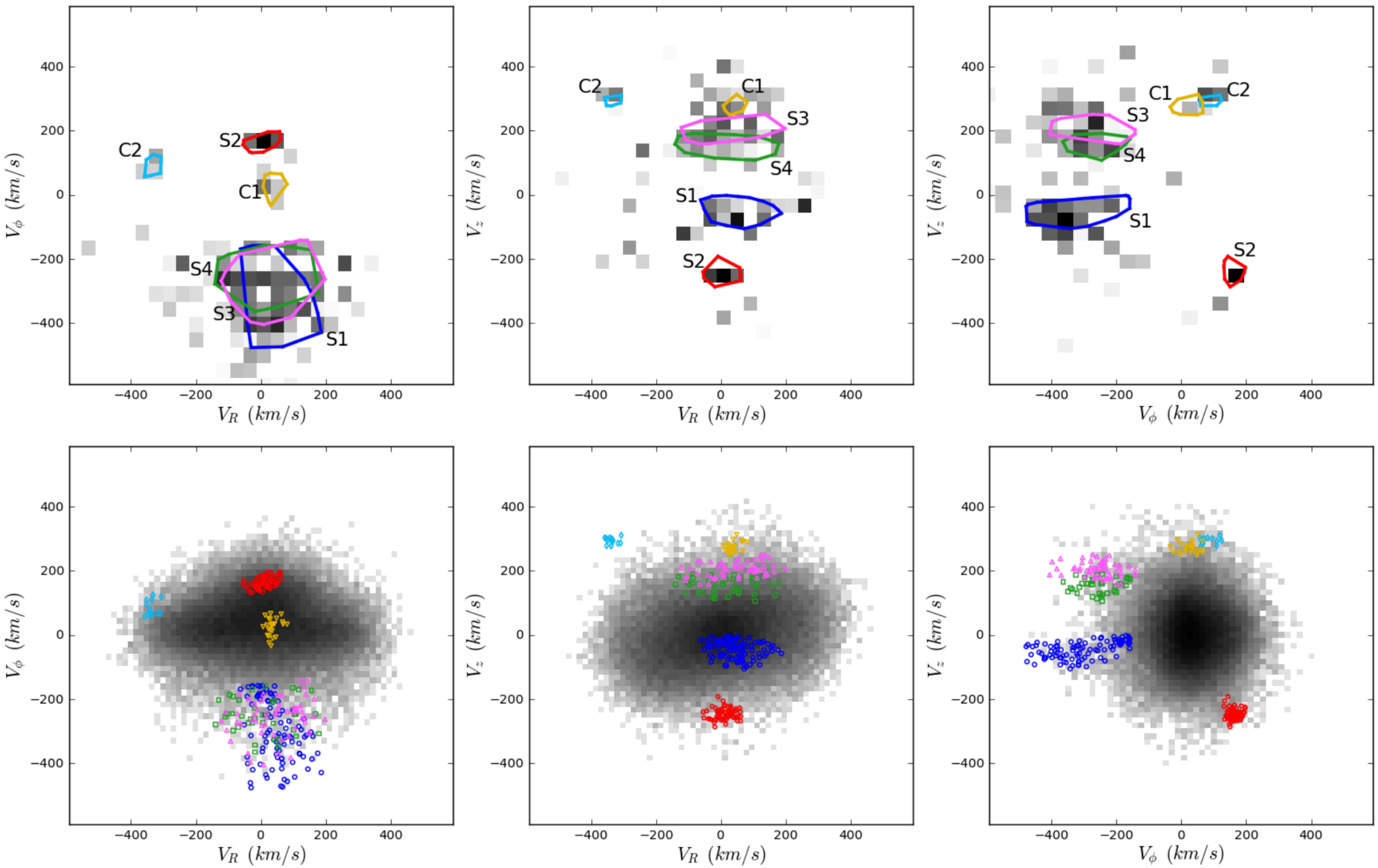
Both realizations of the *Gaia* Sausage considered here show qualitatively similar effects on upper limits; however, the model described in [61] by Necib *et al.*, has stronger effects at lower masses, while the model in [17] by O'Hare *et al.*, is more significant at higher masses. Upper limits set with these models may disagree with each other by around 30 %.

Streams and substructure

Halo Substructure in the SDSS-Gaia Catalogue: Streams and Clumps

1712.04071

G. C. Myeong[1★], N. W. Evans[1], V. Belokurov[1], N.C. Amorisco[2,3] & S.E. Koposov[1,4]
[1]Institute of Astronomy, University of Cambridge, Madingley Road, Cambridge CB3 0HA



A Dark Matter Hurricane: Measuring the S1 Stream with Dark Matter Detectors

Ciaran A. J. O'Hare,[1,*] Christopher McCabe,[2,†] N. Wyn Evans,[3,‡] GyuChul Myeong,[3] and Vasily Belokurov[3]

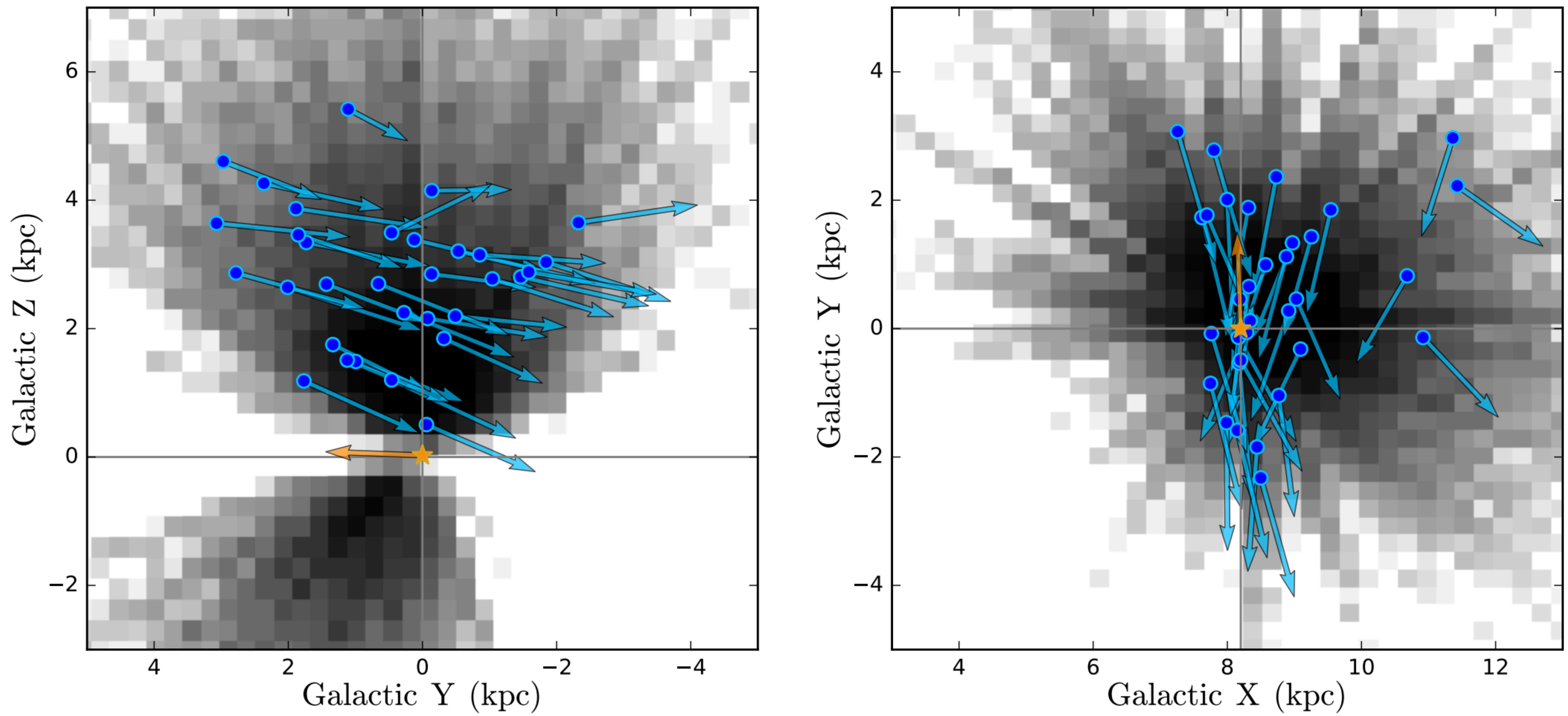


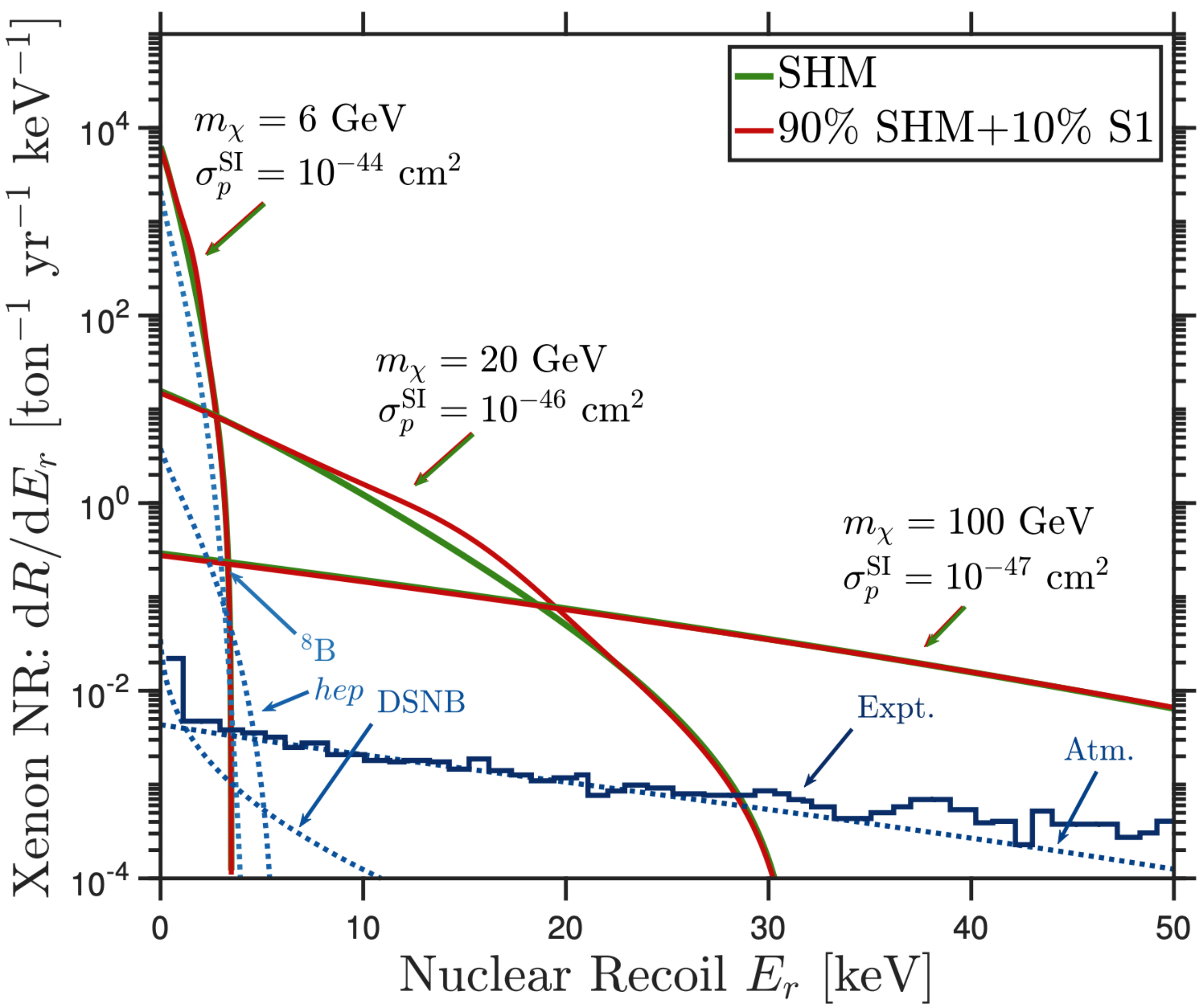
FIG. 2. The S1 stars projected into the (Y, Z) and (X, Y) planes. The stream is seen sideways-on (left) and face-on (right) in the two projections. The Sun's velocity is marked as a yellow arrow, whilst the position of the Sun is indicated by the grey crosshair. S1 has modest inclination with respect to the Galactic plane, but it is broad ($\sim$ 2 kpc) as befits its dwarf galaxy origin. The 34 S1 stars plotted here were found in searches through the comparatively local SDSS-*Gaia* dataset [23] shown as a grey distribution, but the full extent and morphology of the stream awaits searches through the more extensive *Gaia* Data Release 2.

1807.09004

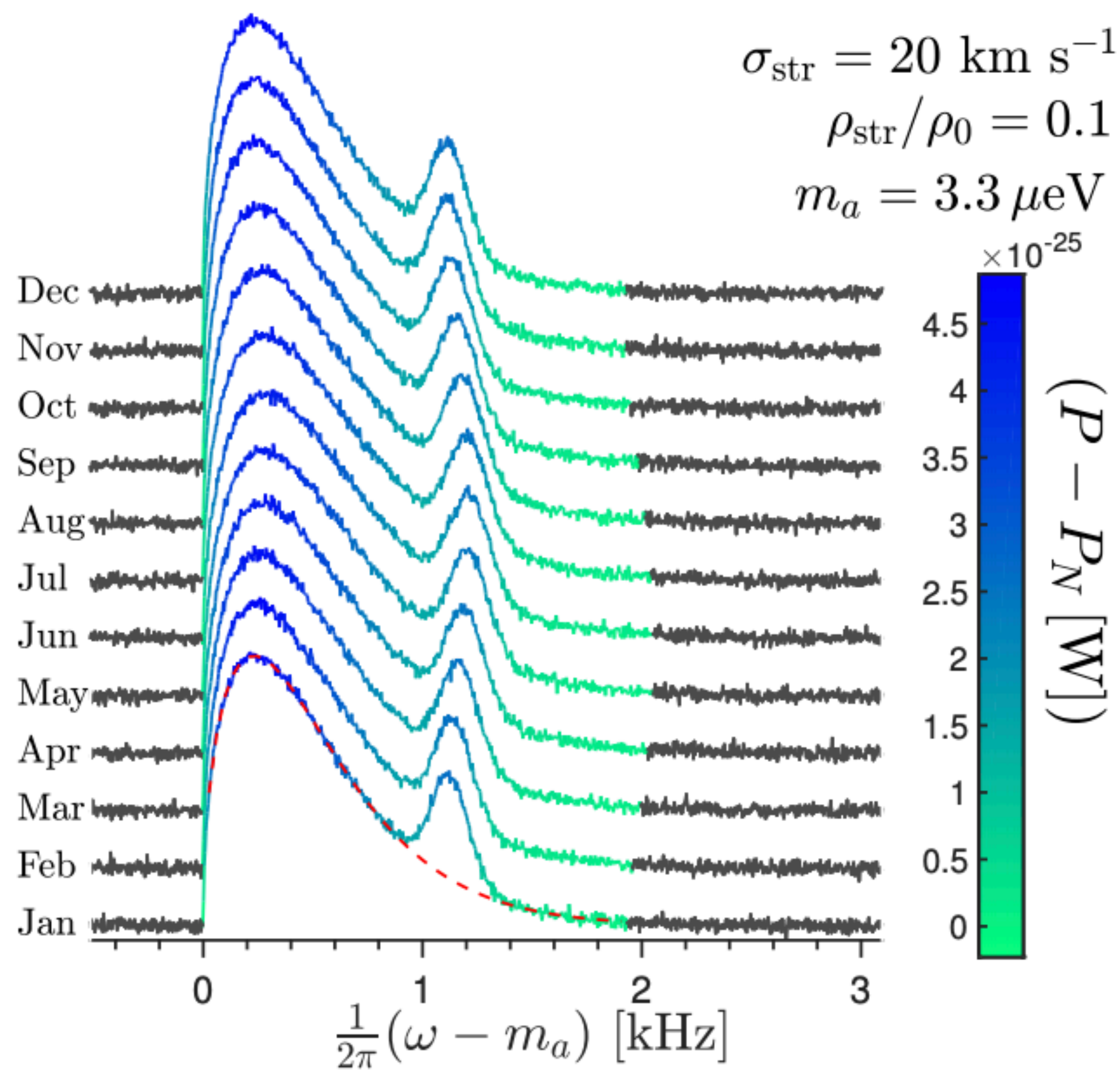
A Dark Matter Hurricane: Measuring the S1 Stream with Dark Matter Detectors

Ciaran A. J. O'Hare,[1,*] Christopher McCabe,[2,†] N. Wyn Evans,[3,‡] GyuChul Myeong,[3] and Vasily Belokurov[3]

Xenon experiments



Axion haloscopes



1905.05189

Direct Detection Anomalies in light of *Gaia* Data

Matthew R. Buckley,[1] Gopolang Mohlabeng,[2] and Christopher W. Murphy[2,3]

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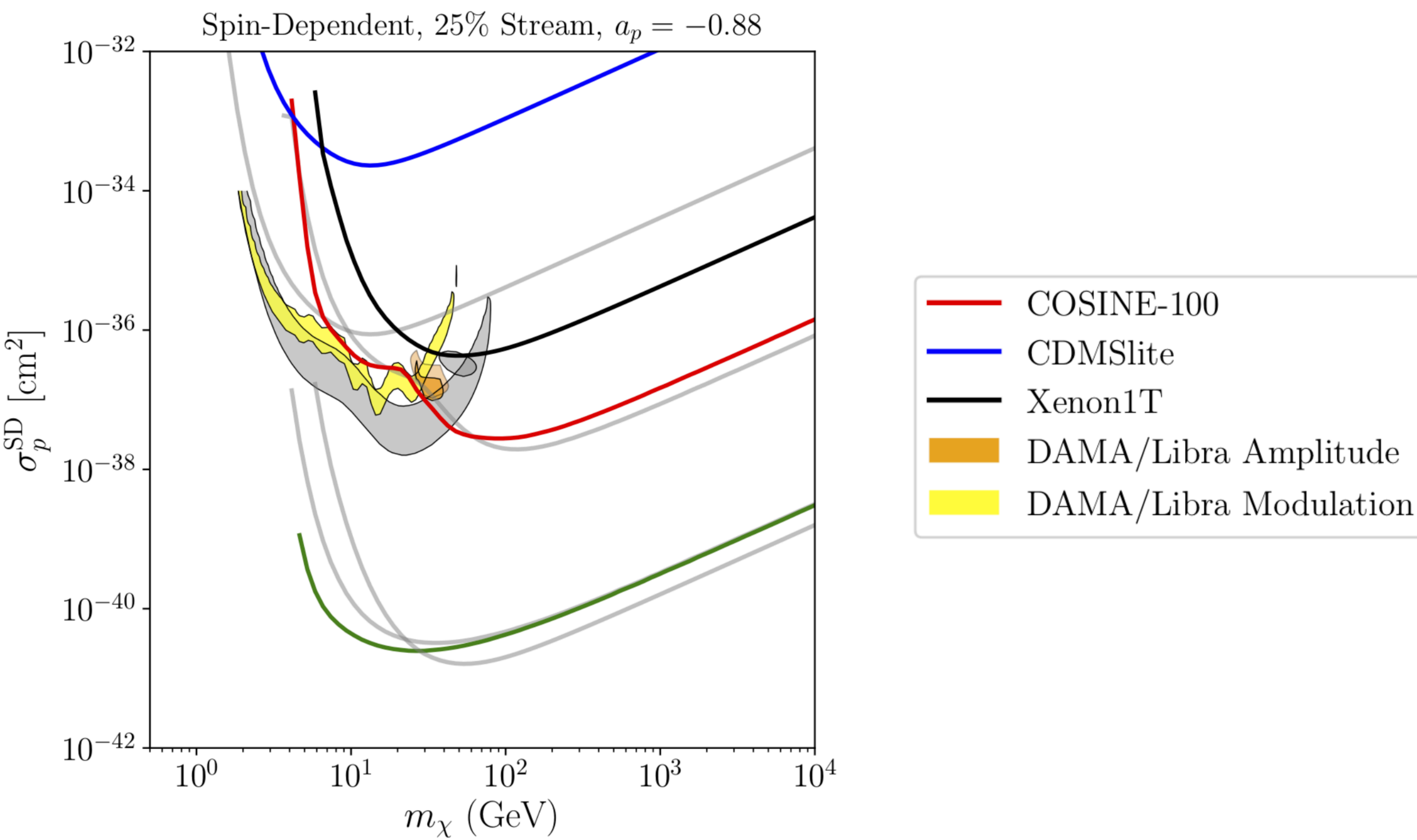
[2] *Physics Department, Brookhaven National Laboratory, Upton, New York 11973, USA*
[3] *Insight Data Science, San Francisco, California 94107, USA*



1909.04684

Dark Shards: velocity substructure from *Gaia* and direct searches for dark matter

Ciaran A. J. O'Hare,[1,*] N. Wyn Evans,[2,†] Christopher McCabe,[3,‡] GyuChul Myeong,[2,§] and Vasily Belokurov[2]

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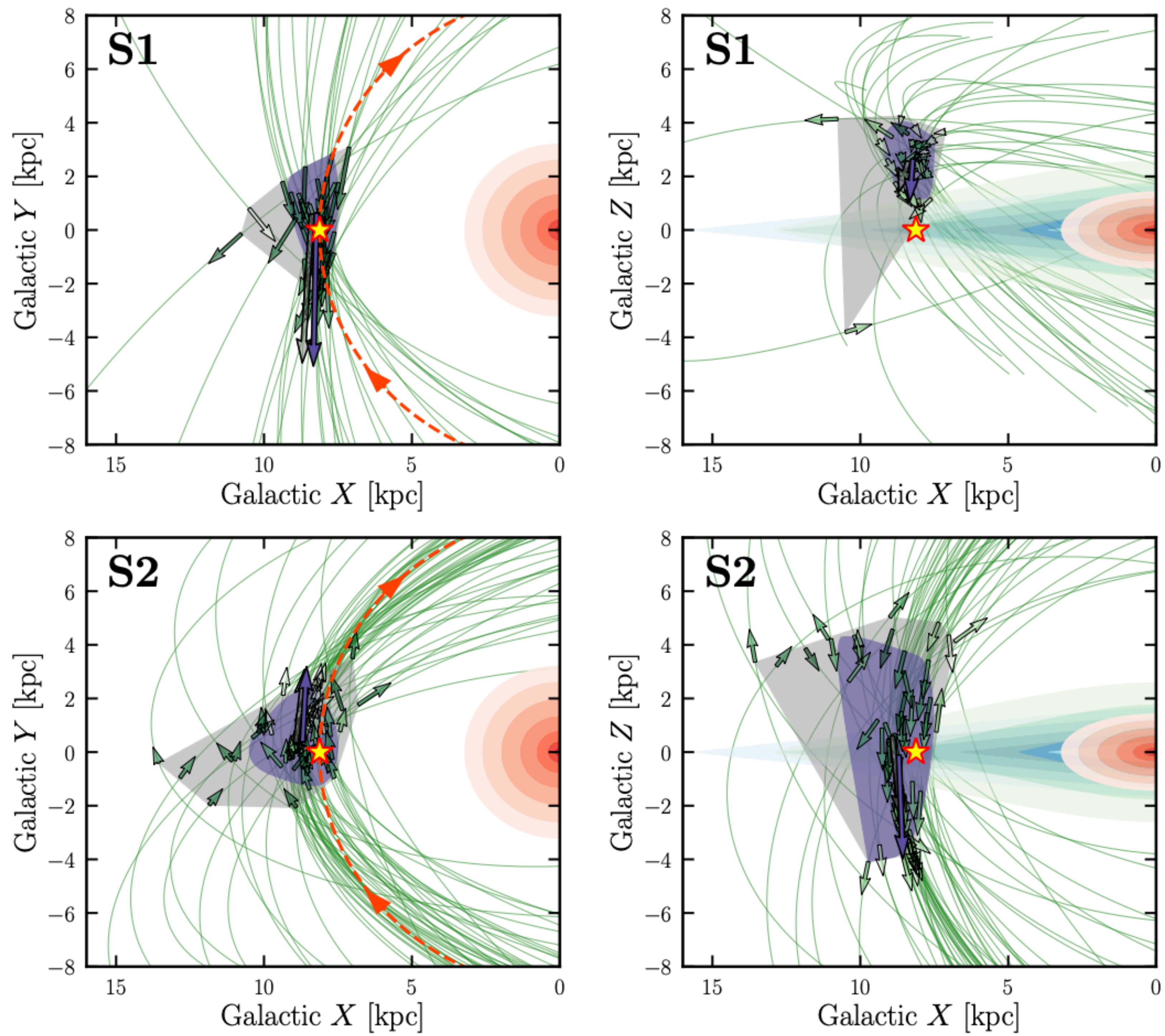
(Dated: January 15, 2020)



1812.00846

Characterization and history of the Helmi streams with *Gaia* DR2

Helmer H. Koppelman[1], Amina Helmi[1], Davide Massari[1], Sebastian Roelenga[1], and Ulrich Bastian[2]

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e-mail: koppelman@kapteyn.astro.rug.nl
[2] Zentrum für Astronomie, Heidelberg University, Astronomisches Rechen-Institut, Mönchhofstrasse 12-14, 69120 Heidelberg, Germany

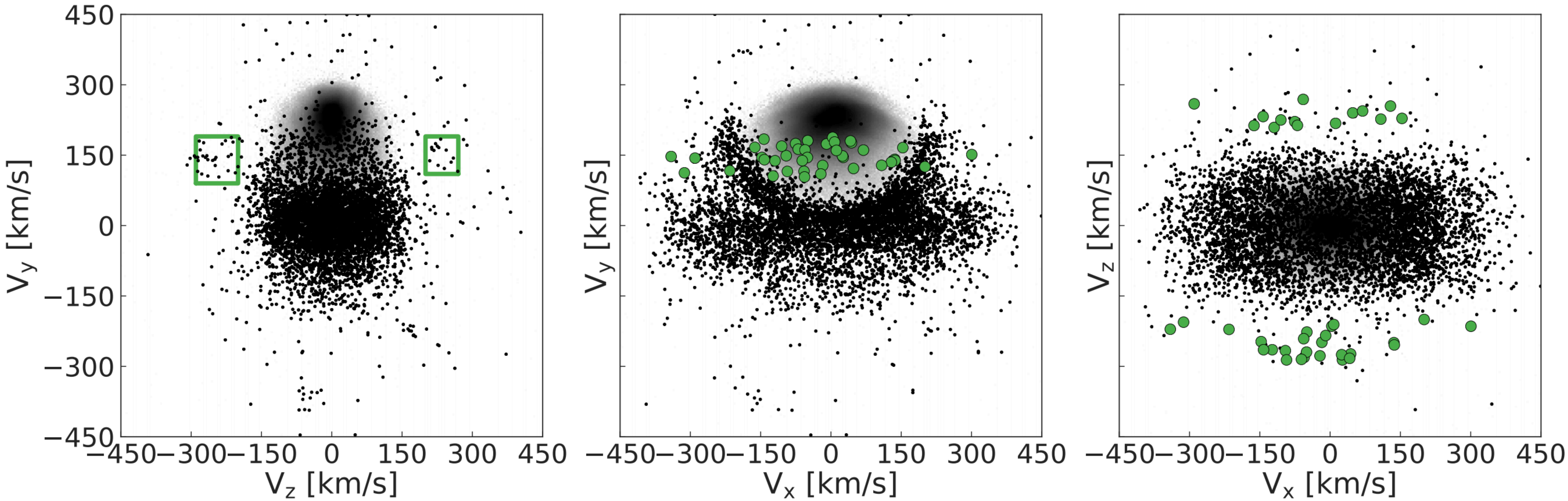

Fig. 1. Velocity distribution of kinematically selected halo stars (black dots) within 1 kpc from the Sun from the *Gaia*-only 6D sample. The grey density in the background shows the location and extent of the disk in this diagram. The velocities have been corrected for the motion of the Sun and LSR. The green boxes in the left panel indicate the location of the Helmi streams, and are drawn based on the velocities of the original stream members. The stars inside these boxes are highlighted with green symbols in the other two panels.

1909.04684

Dark Shards: velocity substructure from *Gaia* and direct searches for dark matter

Ciaran A. J. O'Hare,[1,*] N. Wyn Evans,[2,†] Christopher McCabe,[3,‡] GyuChul Myeong,[2,§] and Vasily Belokurov[2]

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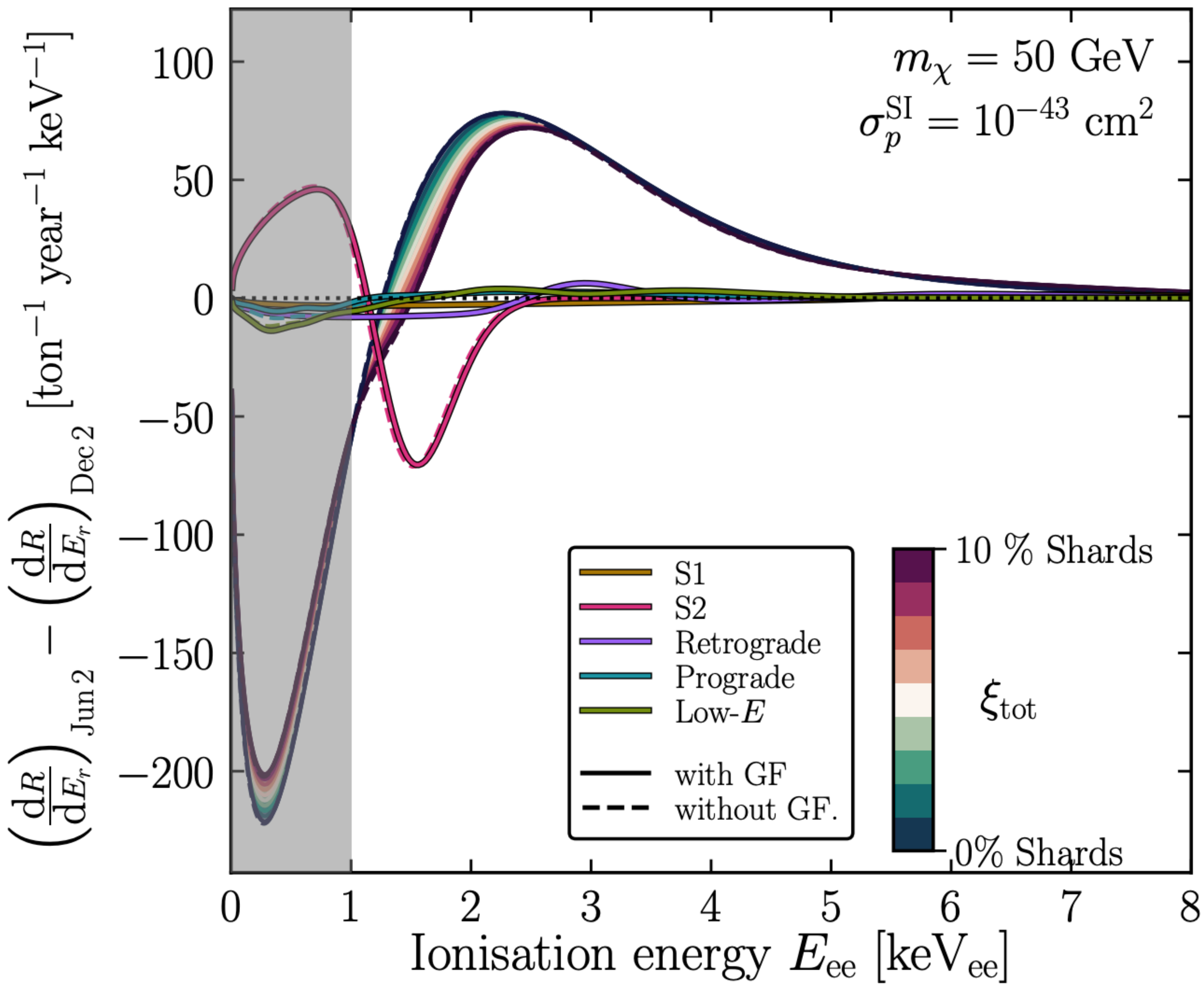

NaI annual modulation signal

1907.06652

Cataloging Accreted Stars within Gaia DR2 using Deep Learning

B. Ostdiek ⋆[1], L. Necib[2], T. Cohen[1], M. Freytsis[34], M. Lisanti[5], S. Garrison-Kimmmel[6], A. Wetzel[7], R. E. Sanderson[89], and P. F. Hopkins[6]

[1] Institute of Theoretical Science, Department of Physics, University of Oregon, Eugene, OR 97403, USA

ABSTRACT

Aims. The goal of this study is to present the development of a machine learning based approach that utilizes phase space alone to separate the *Gaia* DR2 stars into two categories: those accreted onto the Milky Way from those that are in situ. Traditional selection methods that have been used to identify accreted stars typically rely on full 3D velocity, metallicity information, or both, which significantly reduces the number of classifiable stars. The approach advocated here is applicable to a much larger portion of *Gaia* DR2.

Methods. A method known as "transfer learning" is shown to be effective through extensive testing on a set of mock *Gaia* catalogs that are based on the Fire cosmological zoom-in hydrodynamic simulations of Milky Way-mass galaxies. The machine is first trained on simulated data using only 5D kinematics as inputs and is then further trained on a cross-matched *Gaia*/RAVE data set, which improves sensitivity to properties of the real Milky Way.

Results. The result is a catalog that identifies $\sim 767,000$ accreted stars within *Gaia* DR2. This catalog can yield empirical insights into the merger history of the Milky Way and could be used to infer properties of the dark matter distribution.

1907.07681

CHASING ACCRETED STRUCTURES WITHIN GAIA DR2 USING DEEP LEARNING

Lina Necib
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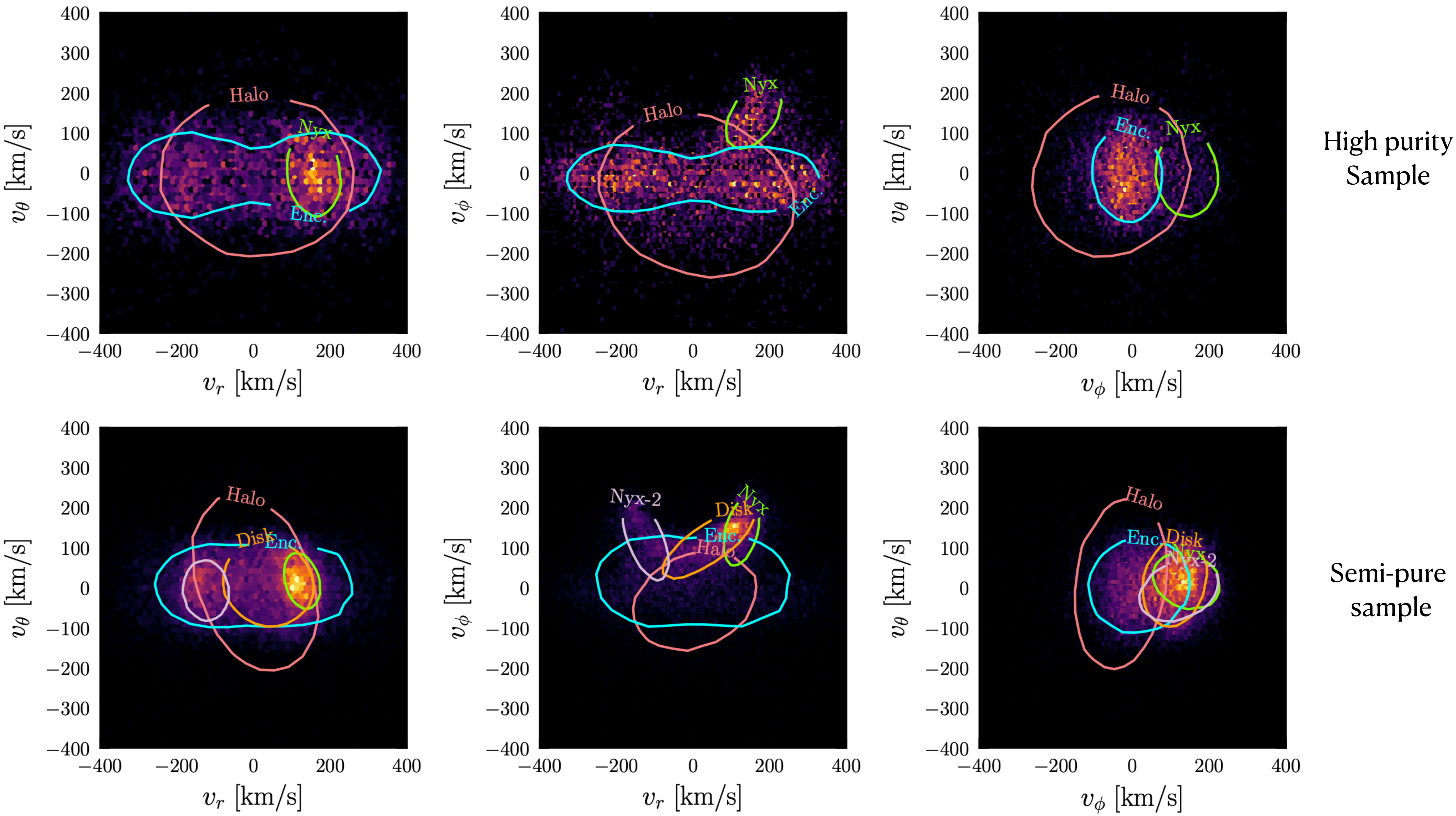
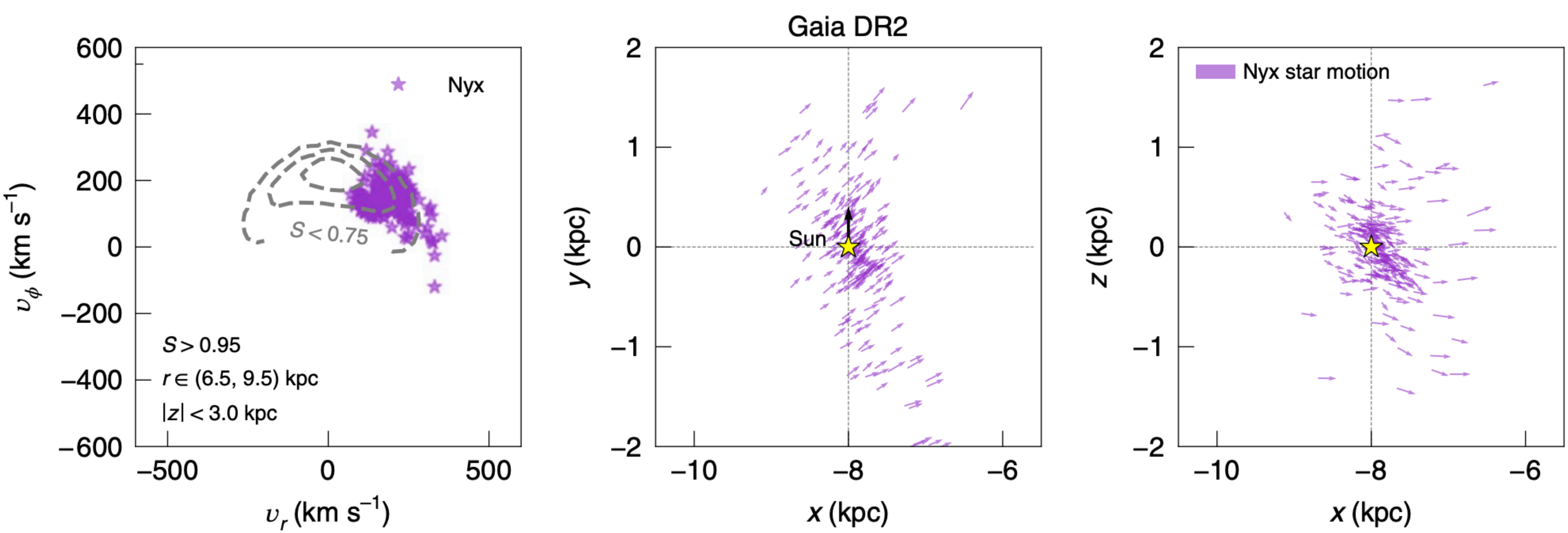


Figure 5. Kinematic distributions of stars in the *Gaia* DR2 catalog that have measured radial velocities and fall within Galactocentric radii $r \in [6.5, 9.5]$ kpc and vertical distances $|z| < 3$ kpc of the midplane. These stars have been identified as accreted by the neural network developed in Ostdiek et al. (2019); the top row shows the distributions for the high-purity

1907.07190

Evidence for a vast prograde stellar stream in the solar vicinity

Lina Necib[1]✉, Bryan Ostdiek[2], Mariangela Lisanti[3], Timothy Cohen[2], Marat Freytsis[4,5], Shea Garrison-Kimmel[6], Philip F. Hopkins[6], Andrew Wetzel[7] and Robyn Sanderson[8,9]



From Amina Helmi's review of substructure in the MW [2002.04340]

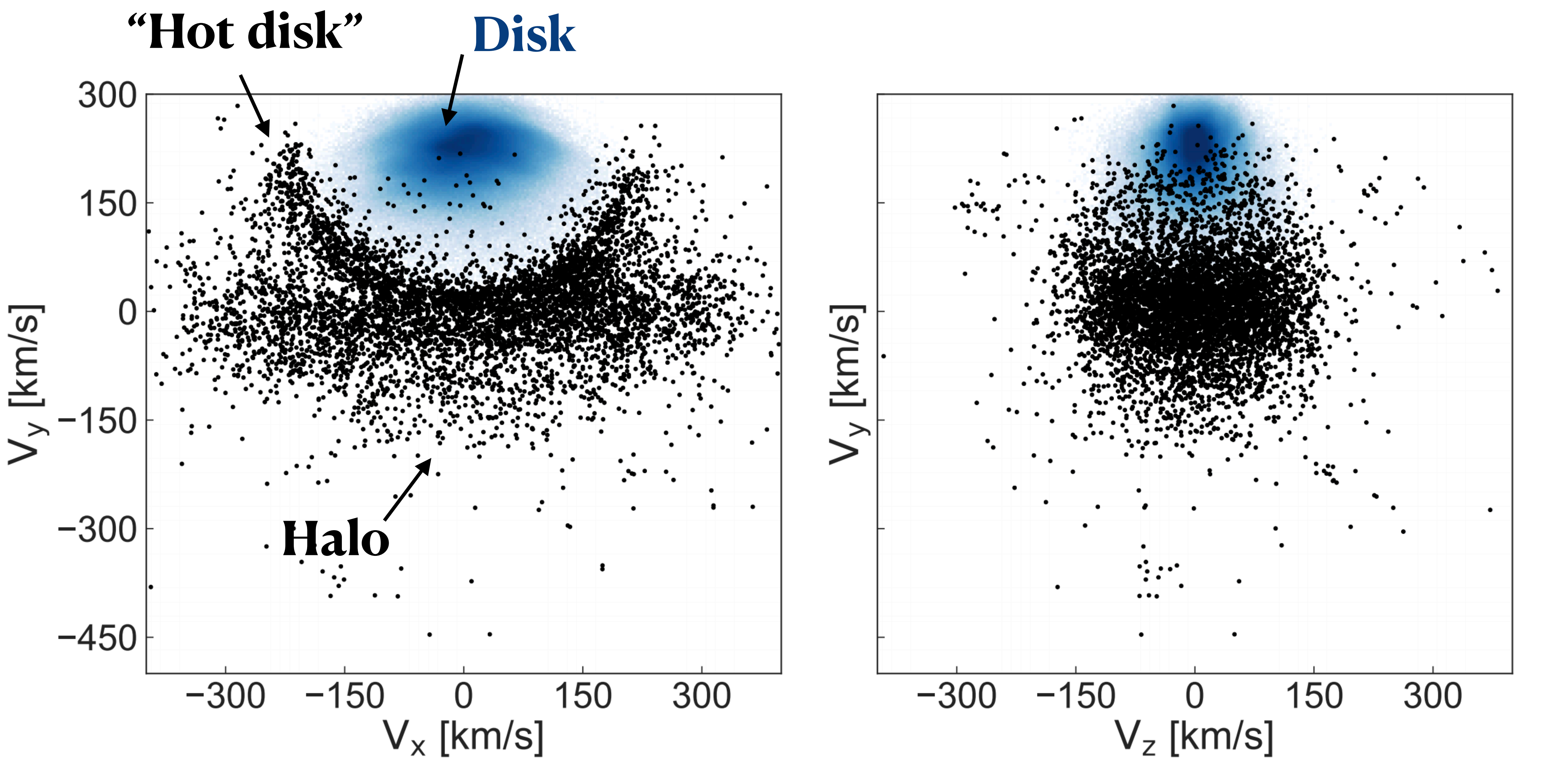


Figure 2

Velocity distribution of stars in the solar neighborhood as determined by *Gaia*. In this figure, all stars from *Gaia* DR2 with full phase-space information, located within 1 kpc from the Sun, and with relatively accurate parallaxes, i.e. with $\varpi/\sigma_{\varpi} \geq 5$ have been considered. The nearby halo stars are plotted with black dots and defined as those that satisfy $|\mathbf{V} - \mathbf{V}_{LSR}| > 210$ km/s, for $V_{LSR} = 232$ km/s. The blue density maps reveal the contribution of the thin and thick disks. The "banana"-shaped structure seen in the left panel reveals an important contribution of "hot" thick disk-like stars to the halo. *Credits: H.H. Koppelman (see also Fig. 2 in Koppelman et al. 2018).*

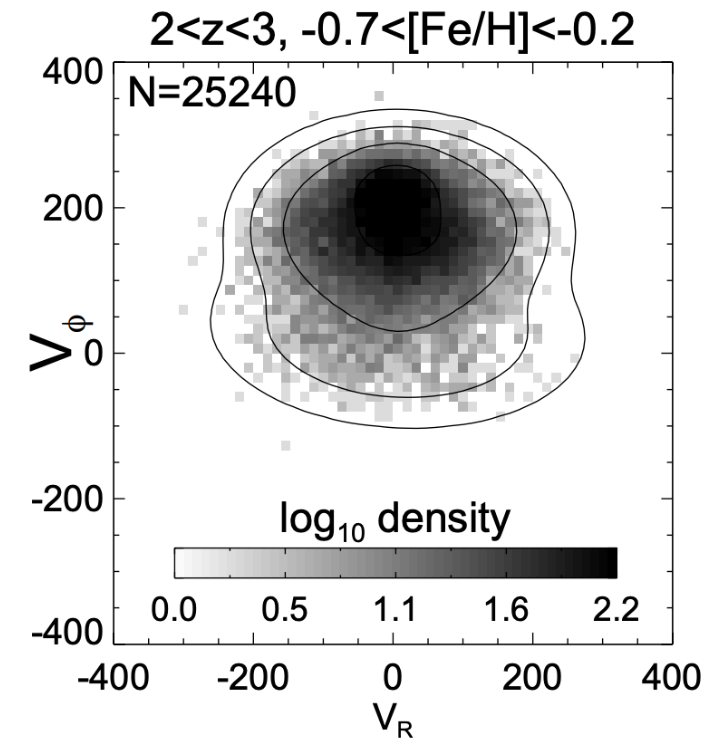
1909.04679

The biggest Splash

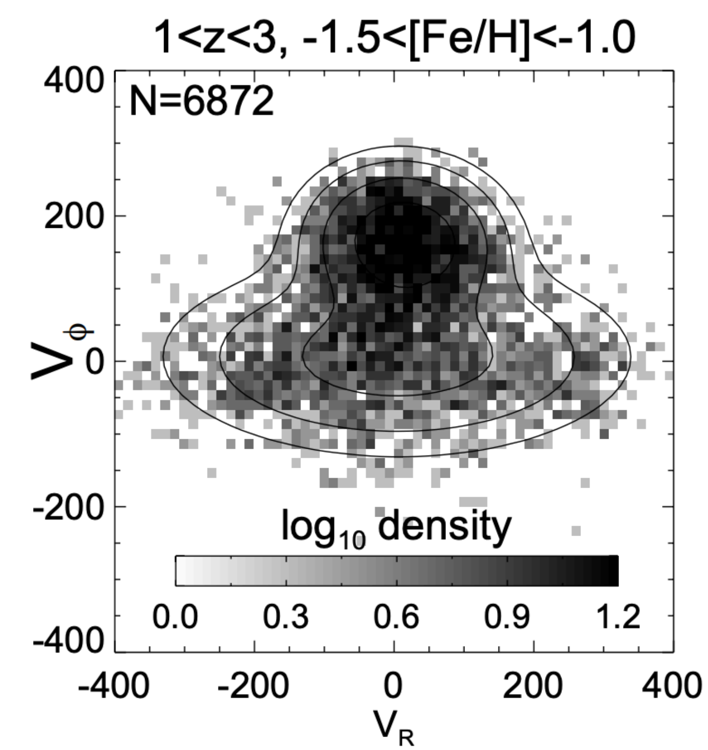
Vasily Belokurov[1⋆], Jason L. Sanders[1], Azadeh Fattahi[2], Martin C. Smith[3], Alis J. Deason[2], N. Wyn Evans[1] and Robert J. J. Grand[4,5,6]
[1] *Institute of Astronomy, Madingley Rd, Cambridge, CB3 0HA*

Note however that according to our kinematic modelling presented in Section 3, the Splash population reaches to much higher values of v_ϕ and has a clear net positive spin. Our 3-component Gaussian model is rather naive, and should not be over-interpreted. However, it does show quite clearly both the necessity for an additional kinematic component (the knee at around $v_\phi \sim 0$ km s^{-1}) and the extent of this component to v_ϕ as high as 100-200 km s^{-1}. In connection to this, the recently discovered giant, prograde and metal-rich stream Nyx (see Necib et al. 2019a) may well be nothing but a piece of the Splash. Additionally, it is interesting to point out that our high-metallicity boundary for the Splash population of < -0.2 (also see Di Matteo et al. 2018) coincides with the value of [Fe/H] where changes in the disc's chemo-dynamical properties had been noted before. For example, this is the highest metallicity

"Splash"



"Sausage"



2005.14667

Constraints on dark matter-nucleon effective couplings in the presence of kinematically distinct halo substructures using the DEAP-3600 detector

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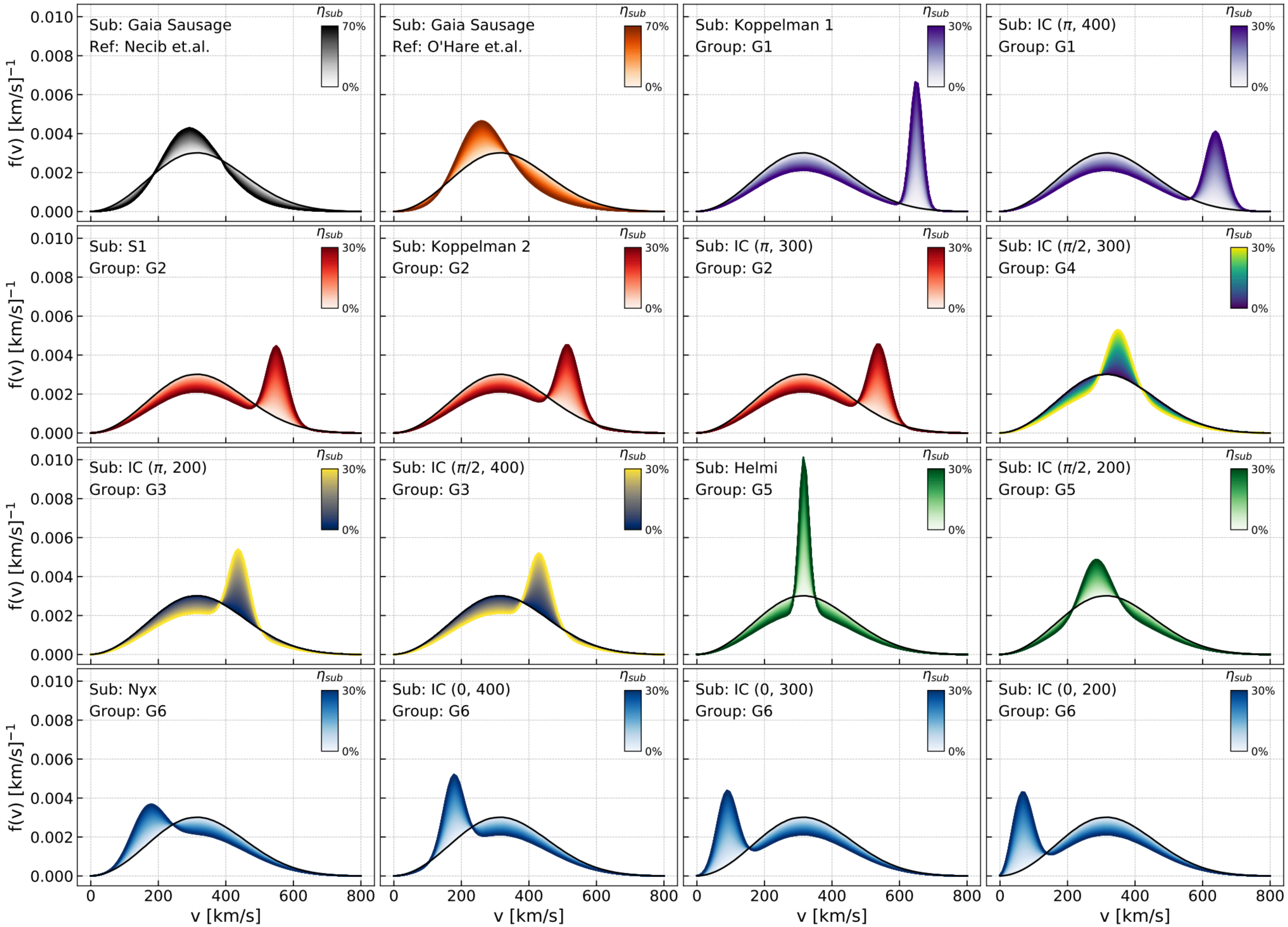


2007.13750

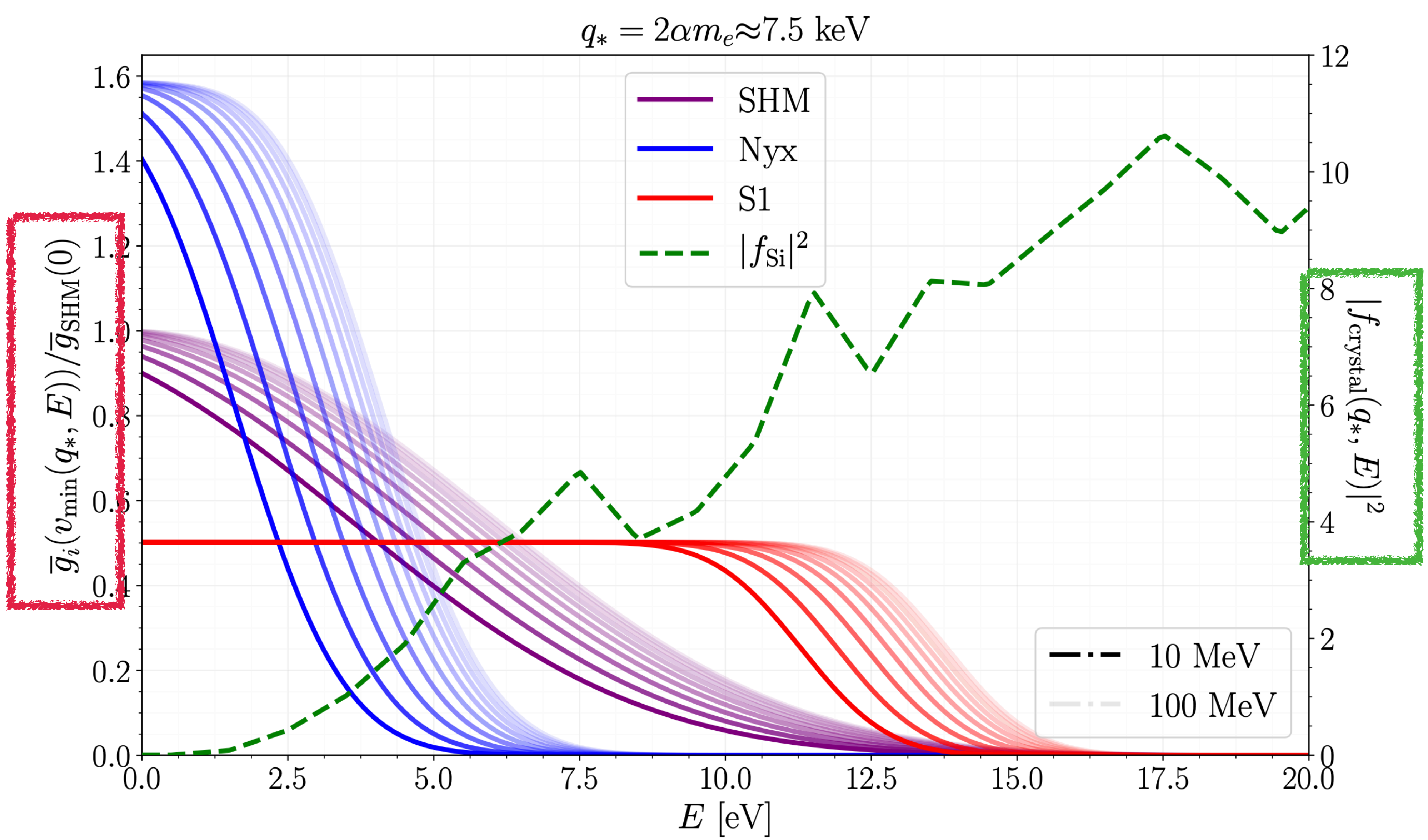
Dark Matter Substructure under the Electron Scattering Lamppost

Jatan Buch,* Manuel A. Buen-Abad,† JiJi Fan,‡ and John Shing Chau Leung§
Department of Physics, Brown University, Providence, RI, 02912, USA

(Dated: July 29, 2020)

Rate of electron recoils in semiconductor:

$$\frac{\mathrm{d}R}{\mathrm{d}\ln E} = N_{\mathrm{cell}} \frac{\rho_\chi}{m_\chi} \overline{\sigma}_e \alpha \frac{m_e^2}{\mu_{\chi e}^2} \int \mathrm{d}q \ \frac{E}{q^2} F_{\mathrm{DM}}^2(q) |f_{\mathrm{crystal}}(q,E)|^2 \ g(v_{\min}(q,E),t)$$



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(Dated: July 29, 2020)

$$Q = \left(1 + \left\lfloor \frac{E - E_{\rm gap}}{\varepsilon} \right\rfloor\right) \Theta(E - E_{\rm gap})$$

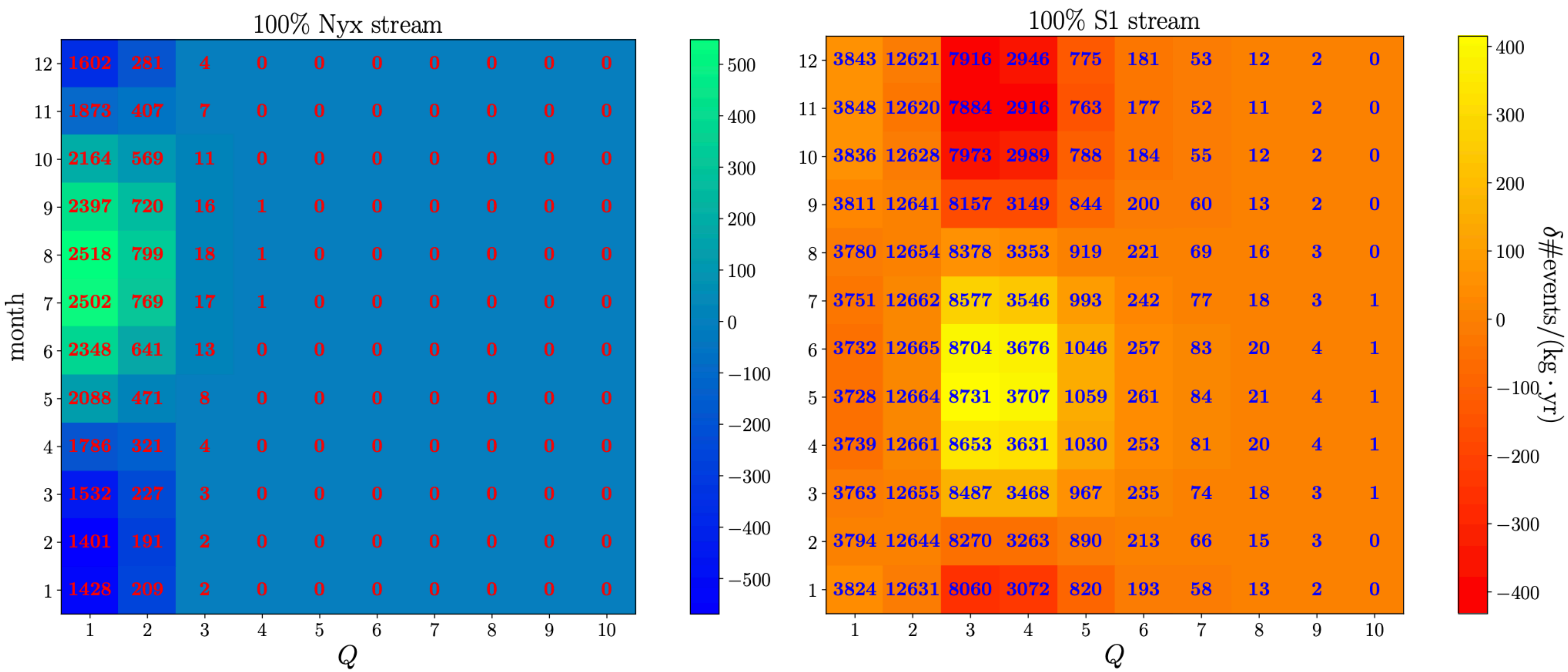
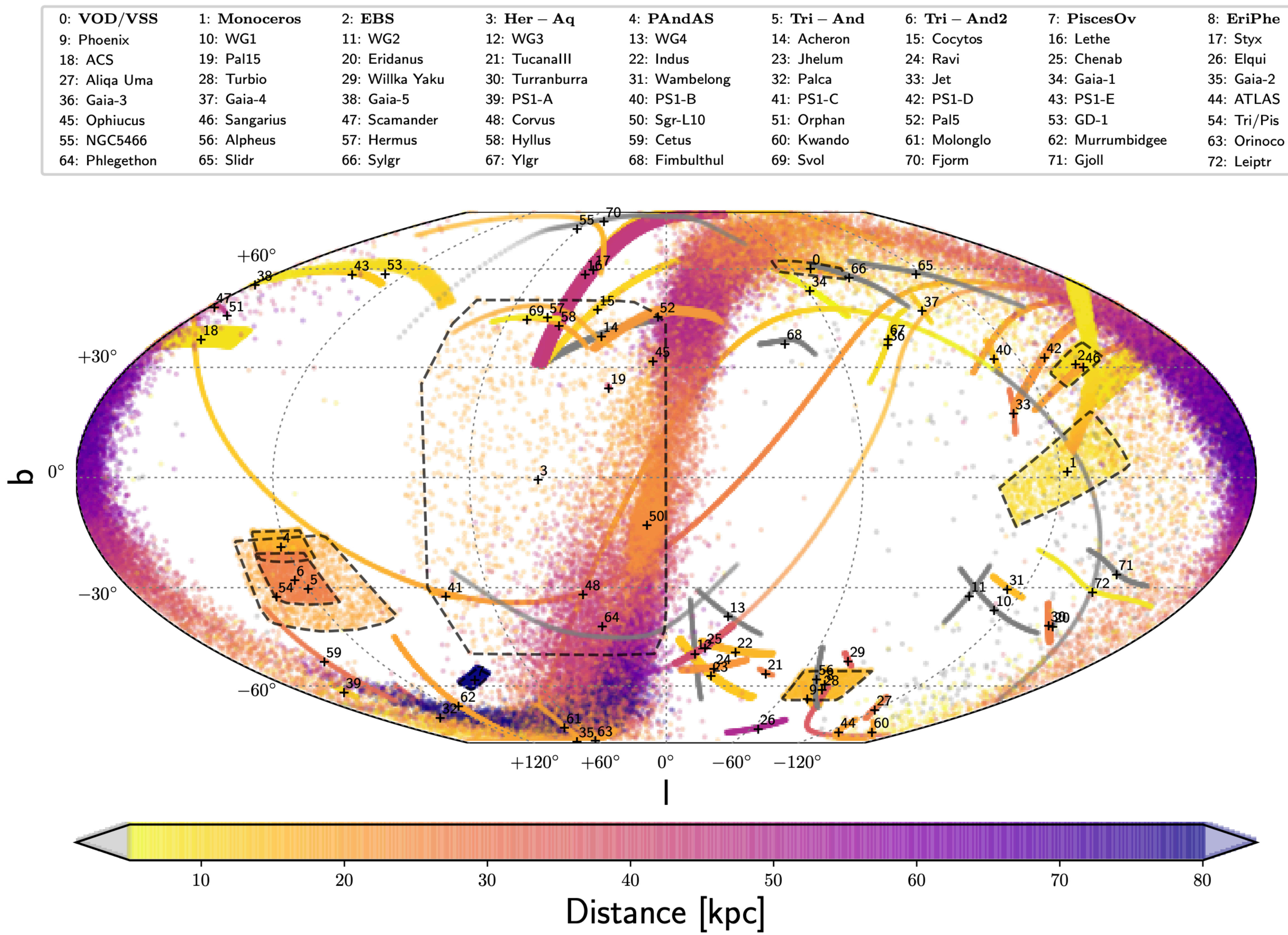


FIG. 5: Q-month binned scattering spectra off silicon for DM mass $m_\chi = 20$ MeV, $F_{\rm DM} = 1$, $\overline{\sigma}_e = 10^{-37}$ cm^2, assuming that all DM particles coming from the Nyx stream (*left*), or the S1 stream (*right*). The numbers indicate the expected number of events in that bin, while the colors correspond to the annual modulation and indicate whether the numbers are above or below the yearly average.

For another day… stellar streams encircling the Milky Way
→ important for indirect/gravitational probes of DM

- Cold/Warm/Fuzzy dark matter
- Subhalo mass function of MW
- Shape of gravitational potential
- Indirect DM signals



GalStreams, Mateu & Balbinot