Universidad Zaragoza 1542

Dark matter hurricane

Ciaran O'Hare
Universidad de Zaragoza

Topics for today

arXiv:[1807.09004]

KCL-PH-TH-2018-38

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

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(Dated: July 25, 2018)

The recently discovered S1 stream passes through the Solar neighbourhood on a low inclination, counter-rotating orbit. The progenitor of S1 is a dwarf galaxy with a total mass comparable to the present-day Fornax dwarf spheroidal, so the stream is expected to have a significant DM component. We compute the effects of the S1 stream on WIMP and axion detectors as a function of the density of its unmeasured dark component. In WIMP detectors the S1 stream supplies more high energy

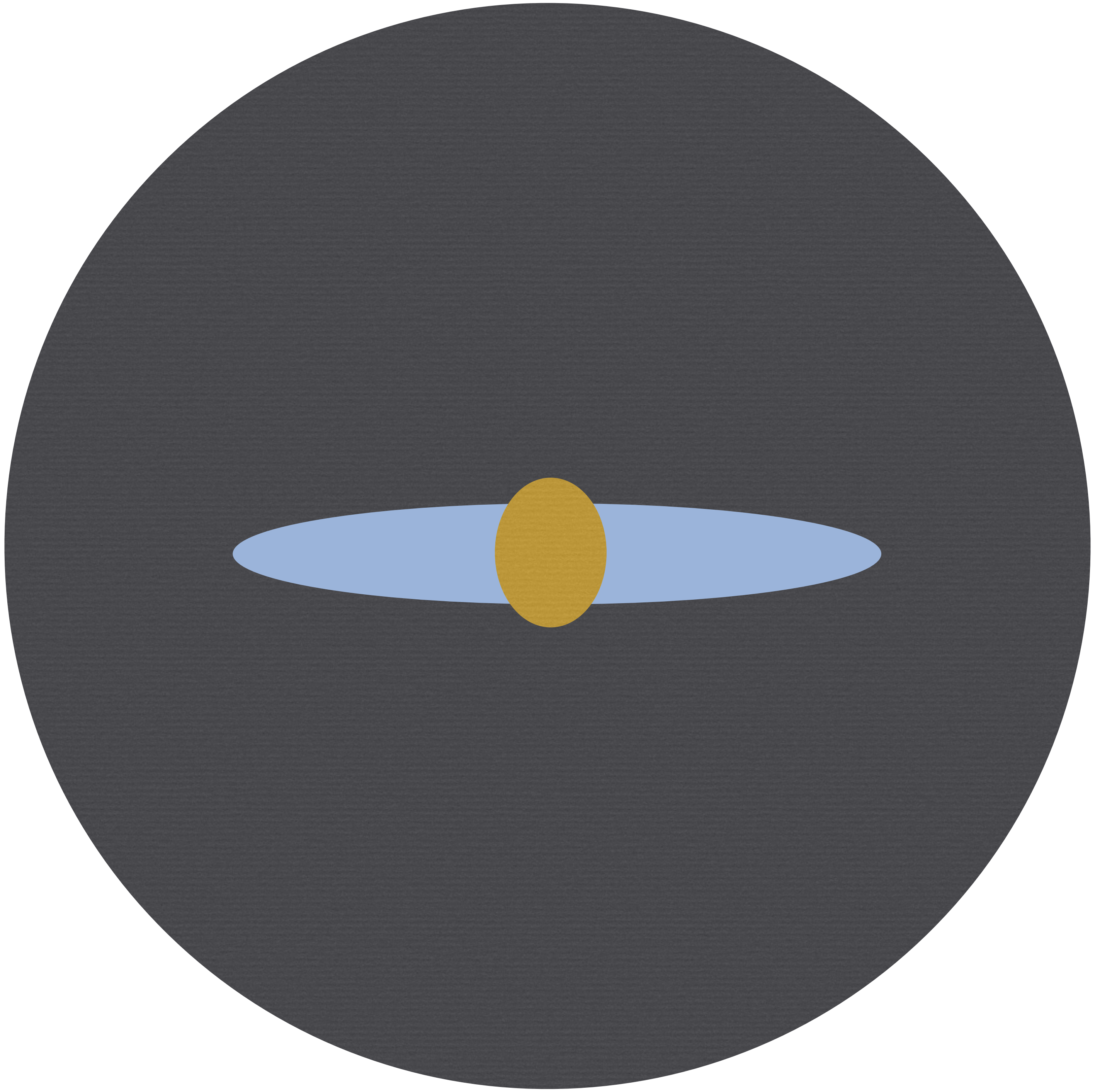
What is a stream?

What is the S1 stream?

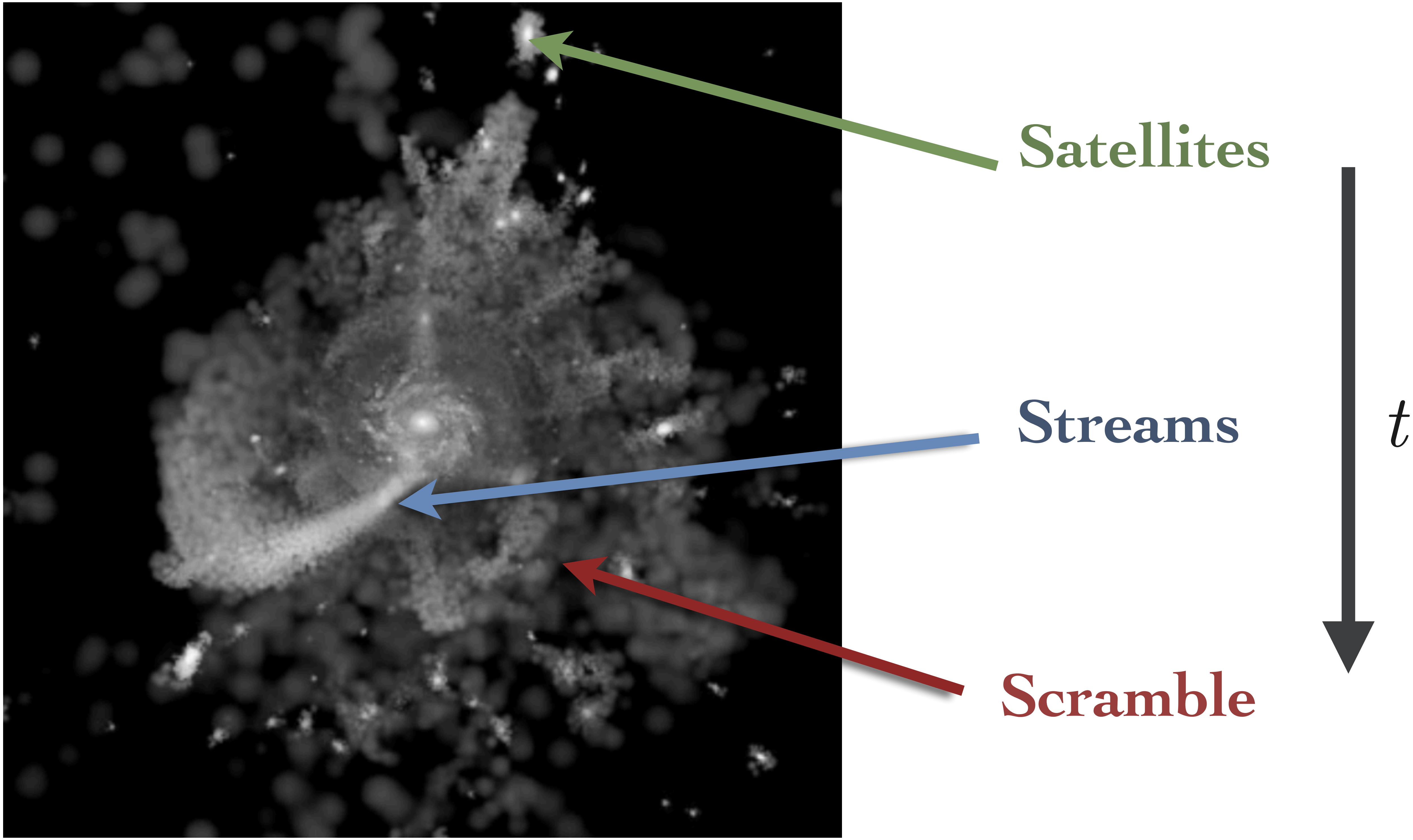
What is the impact for WIMPs?

What is the impact for axions?

A dark matter halo



A dark matter halo (really)



Importance for DM

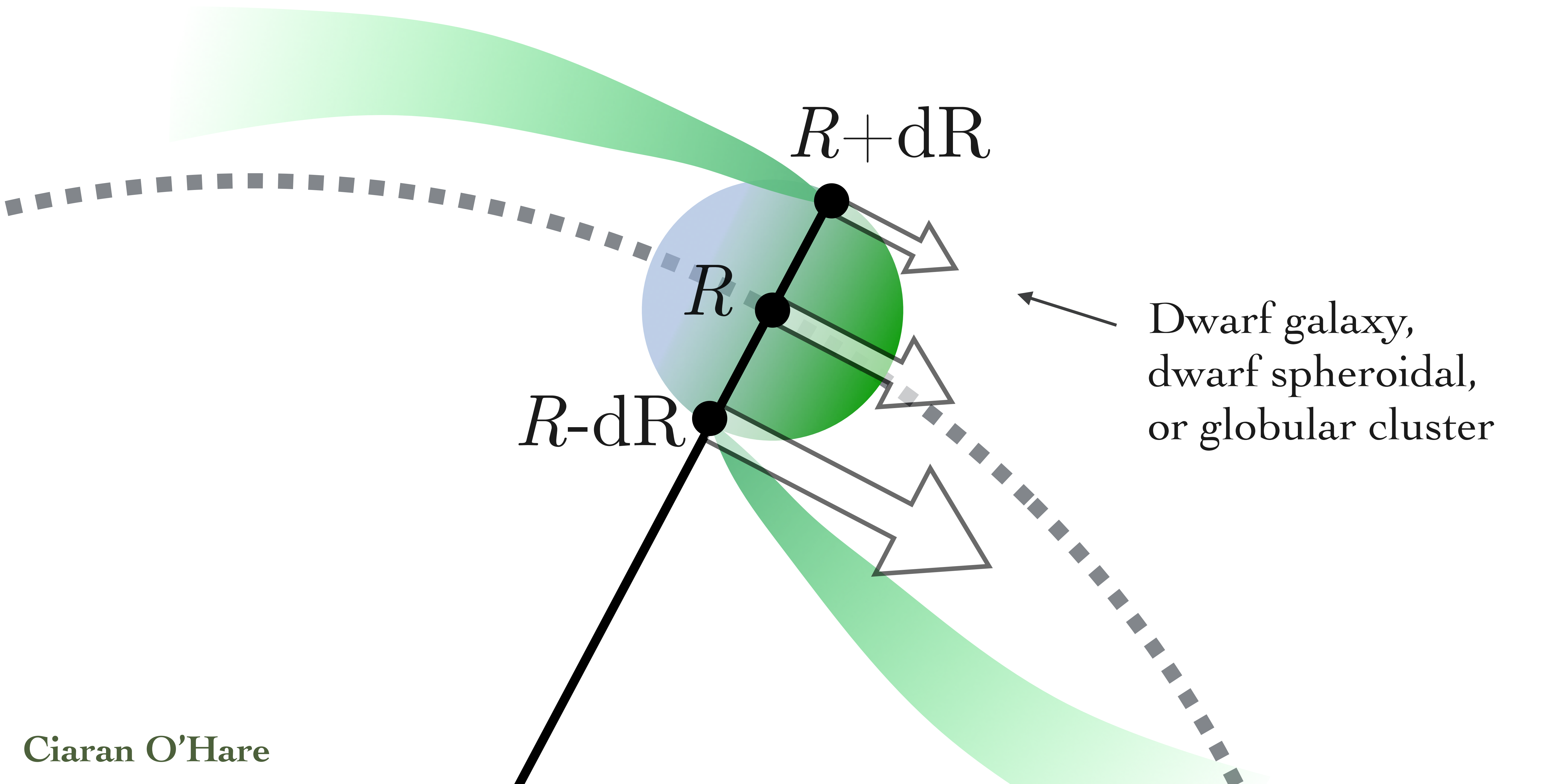
Satellites → Distinguishing warm/cold DM
→ Targets for DM annihilation or decay

Streams → Informs about the granularity of DM halo
→ Traces the shape of MW potential
→ Can be used to constrain fuzzy DM

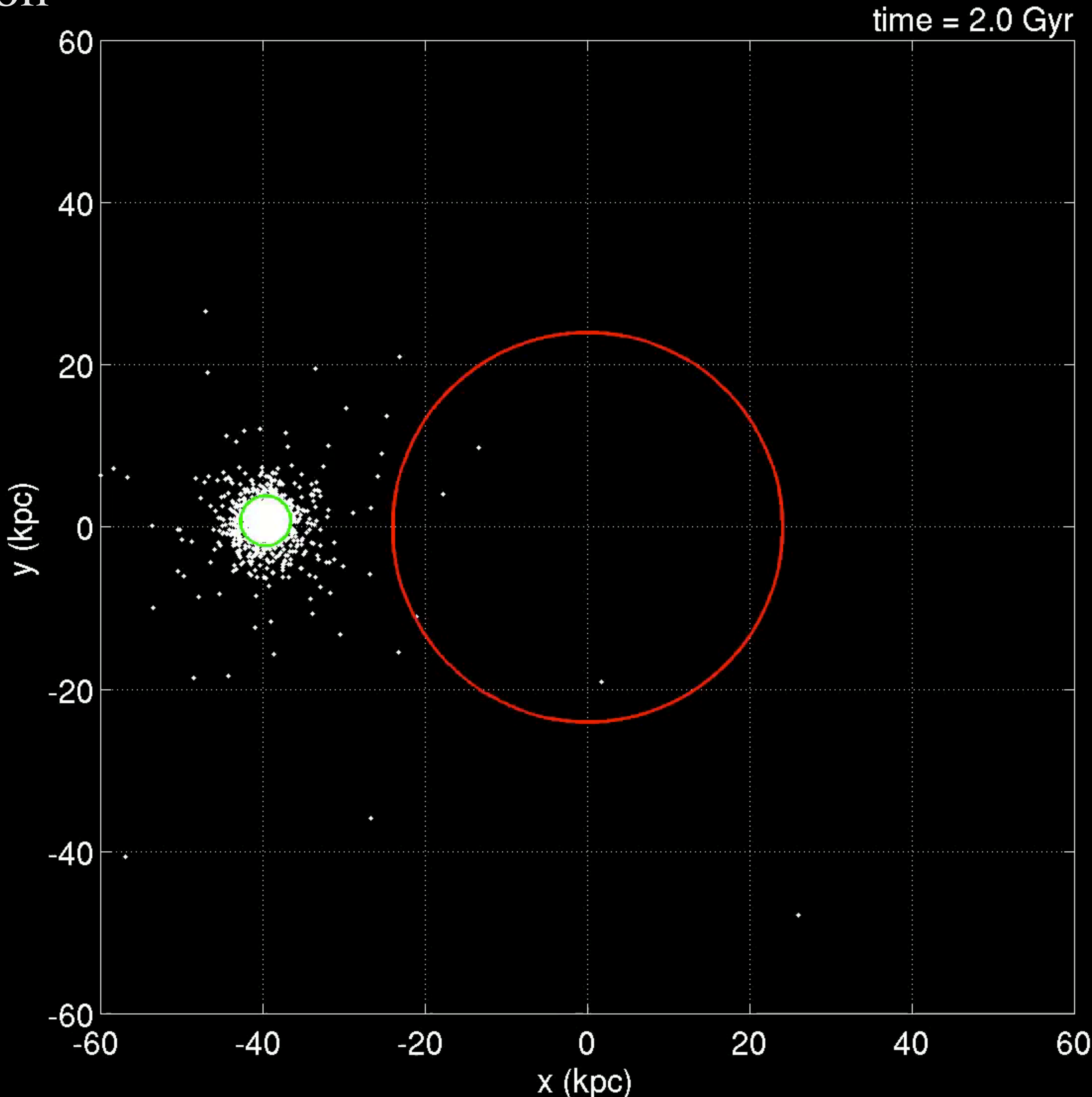
Scramble → Clumpiness of the dark matter halo
→ Crucial input for all direct DM searches

Forming tidal streams

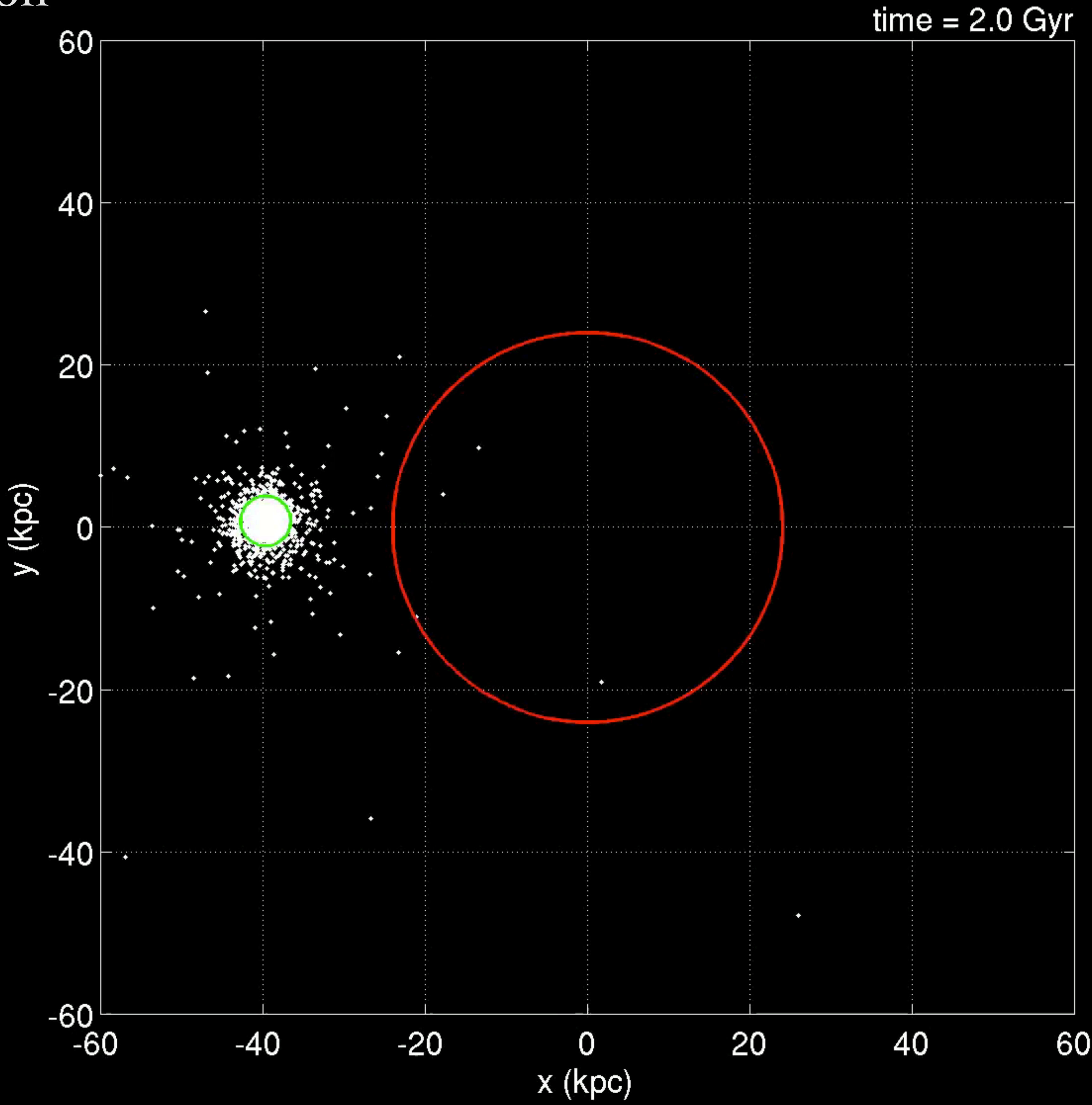
Satellite is pulled apart when the tidal force across it overcomes its own self-gravity



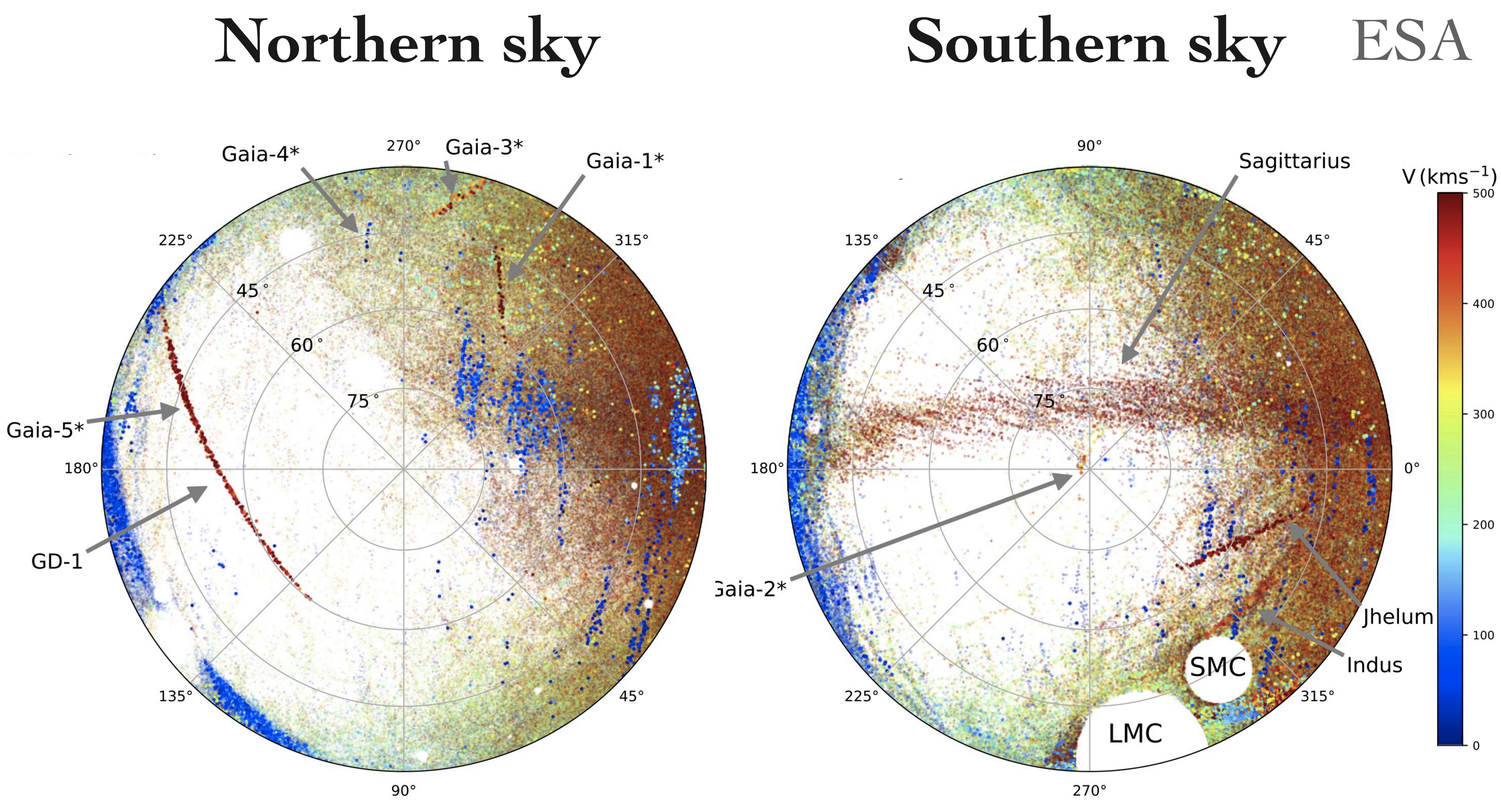
R. Sanderson



R. Sanderson



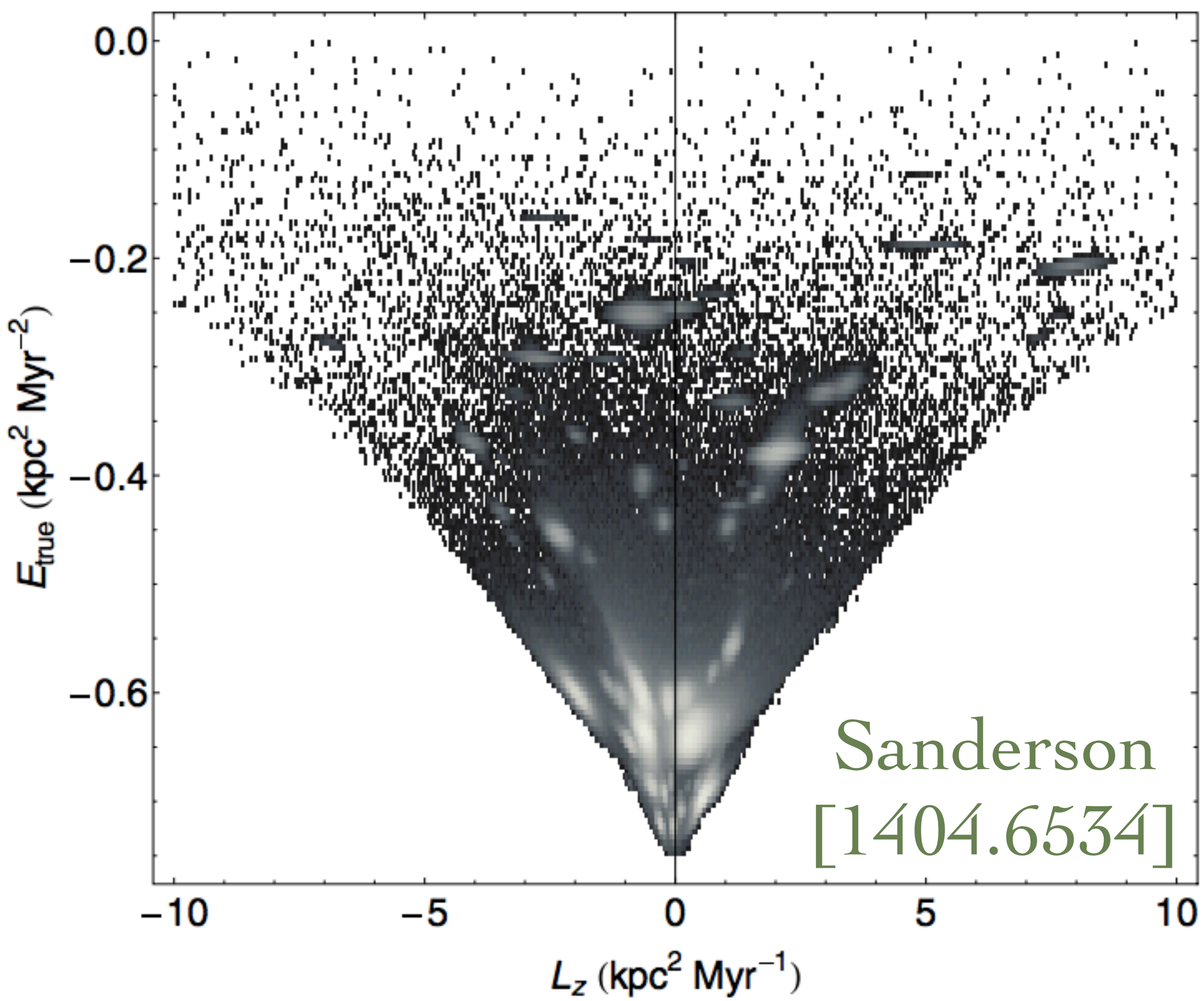
Finding streams spatially



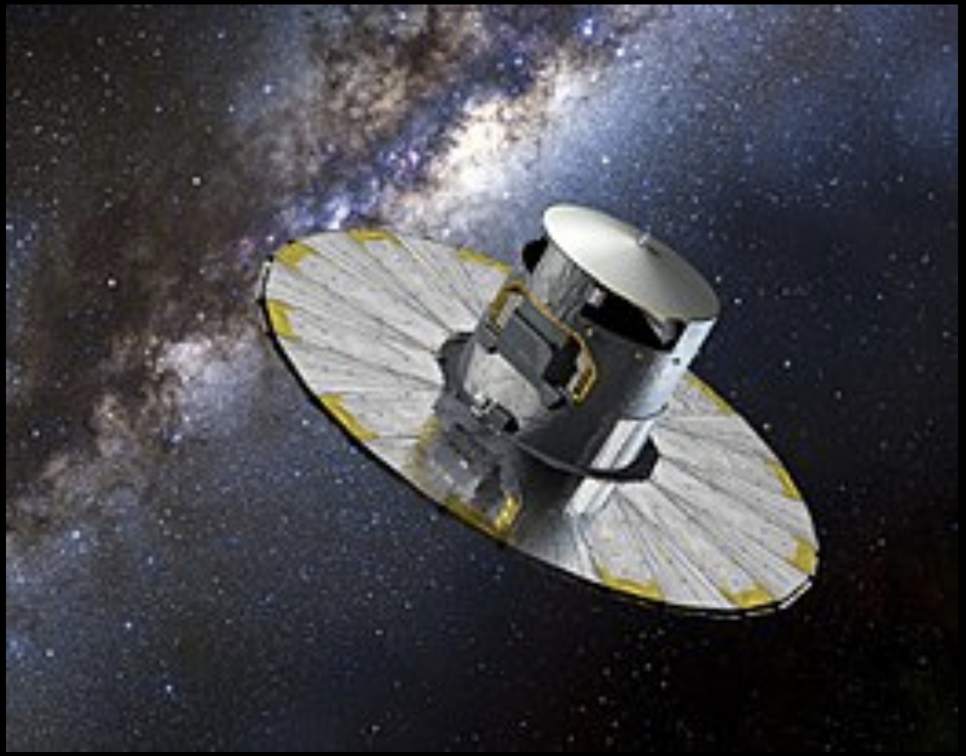
Finding streams kinematically

"**Angle-Actions**" - map orbital parameters into variables that are conserved for orbits in slowly varying potentials
→ hence streams remain clustered in "<u>action space</u>" long after they have ceased to be visible in star counts

Computing these variables for stars requires full orbital information
→ **Need complete 6D kinematic data to find streams this way…**



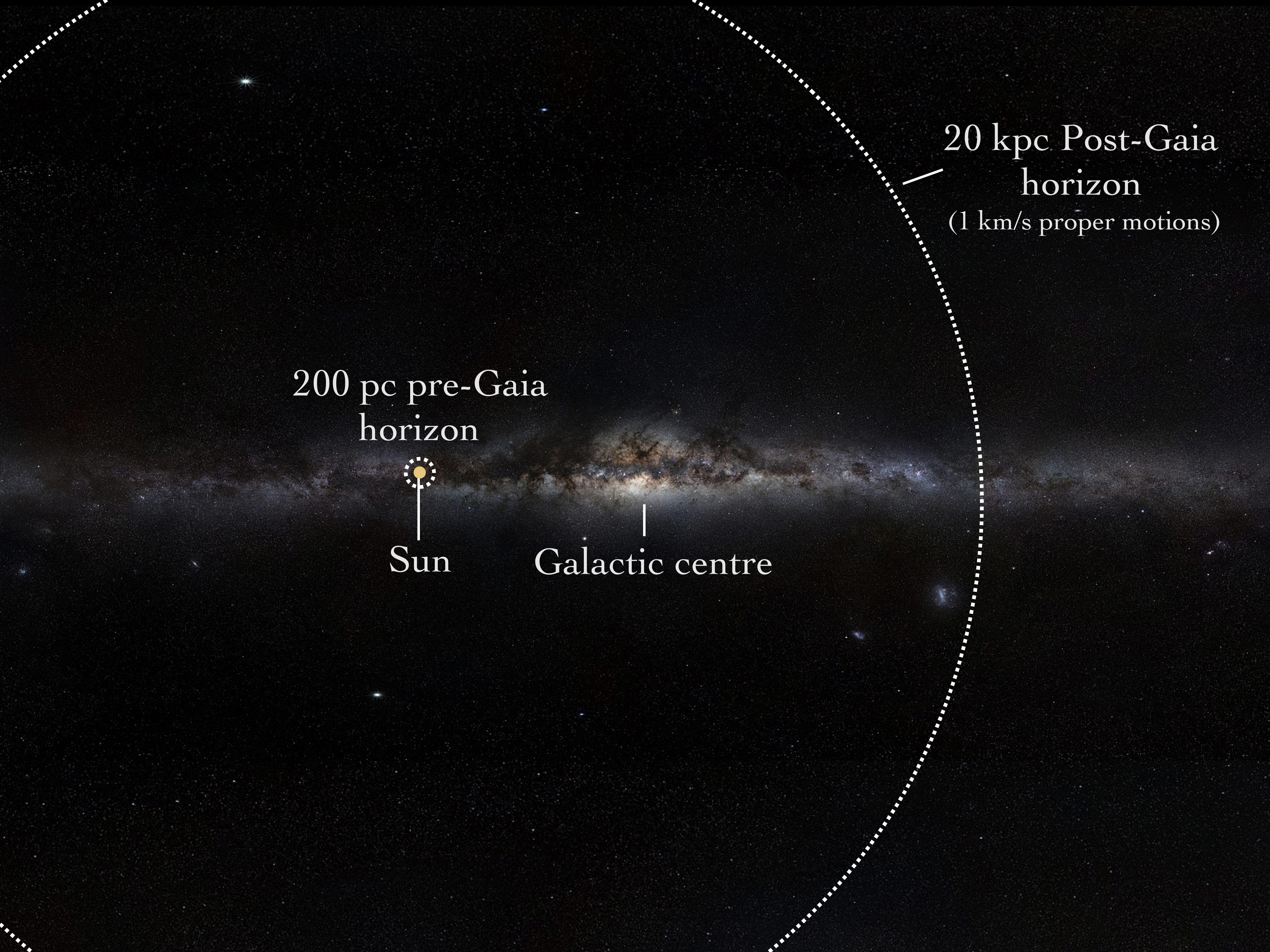
Gaia



- Launched in 2013
- Will operate until ~2022
- 1.7 billion stars (1% of MW)
- Parallax+proper motion on 1.3 billion
- 20 million stars with distance precise to 1%
- 40 million stars with tangential velocity precise to < 0.5 km/s
- 7 million stars with full 6D solution (x, y, z, v_x, v_y, v_z)

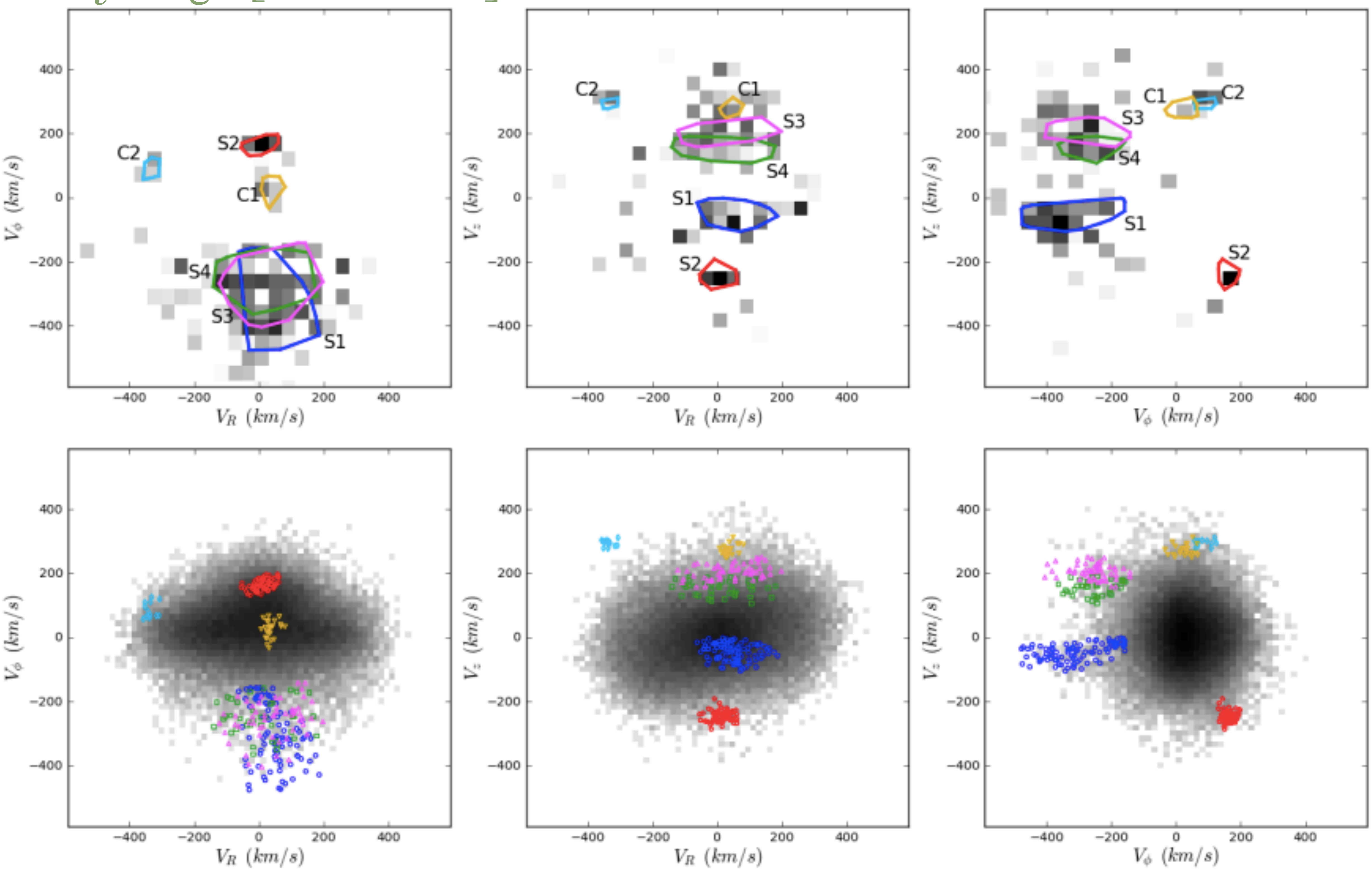
Compared to predecessor, Gaia has 10,000 times more stars, over a volume 100,000 times larger, with 1000 times better accuracy


200 pc pre-Gaia
horizon
Sun
Galactic centre


20 kpc Post-Gaia
horizon
(1 km/s proper motions)
200 pc pre-Gaia
horizon
Sun
Galactic centre

Substructure in Gaia

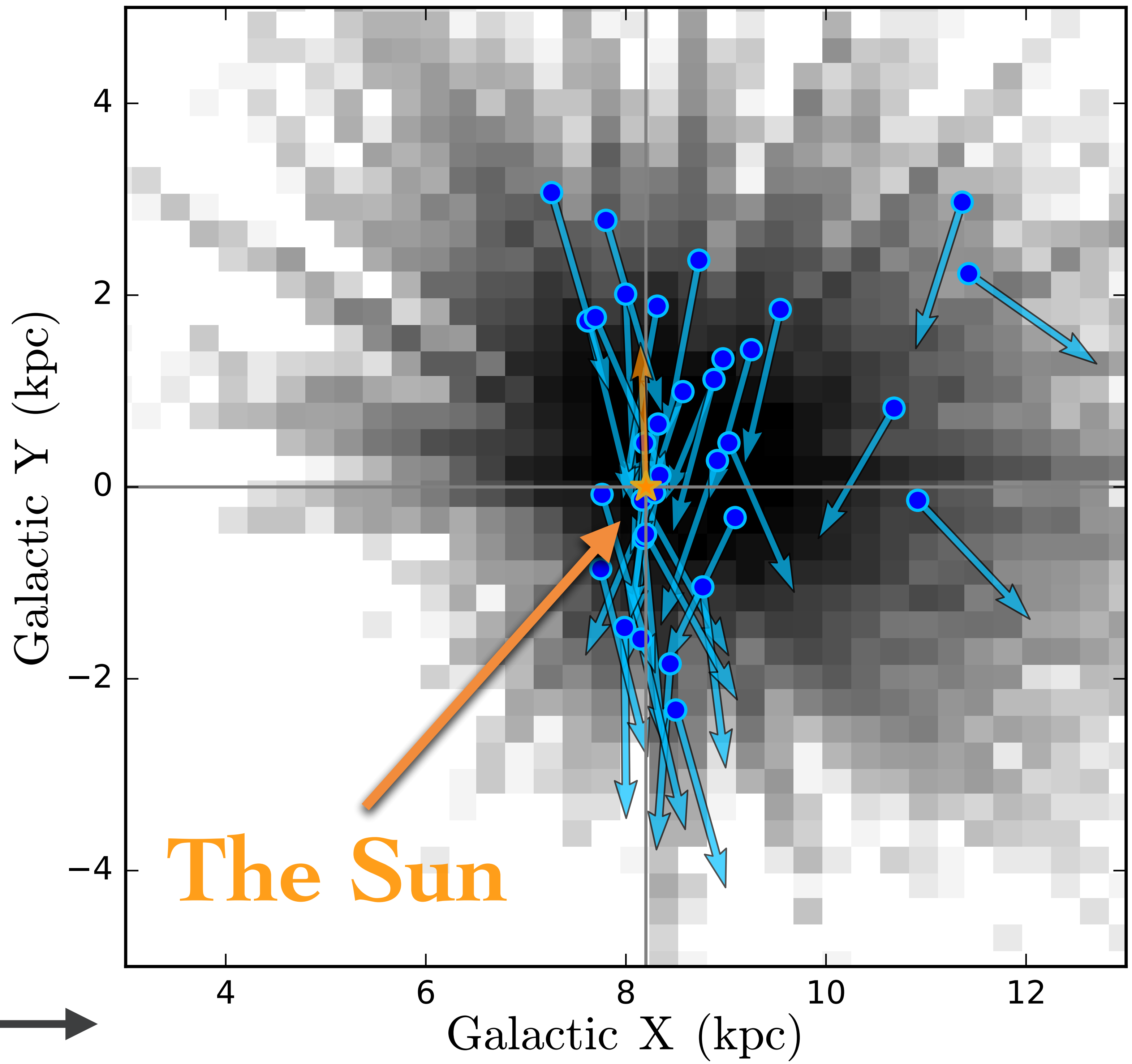
Myeong+ [1712.04071]

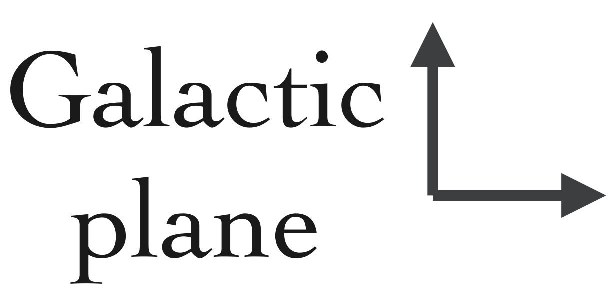


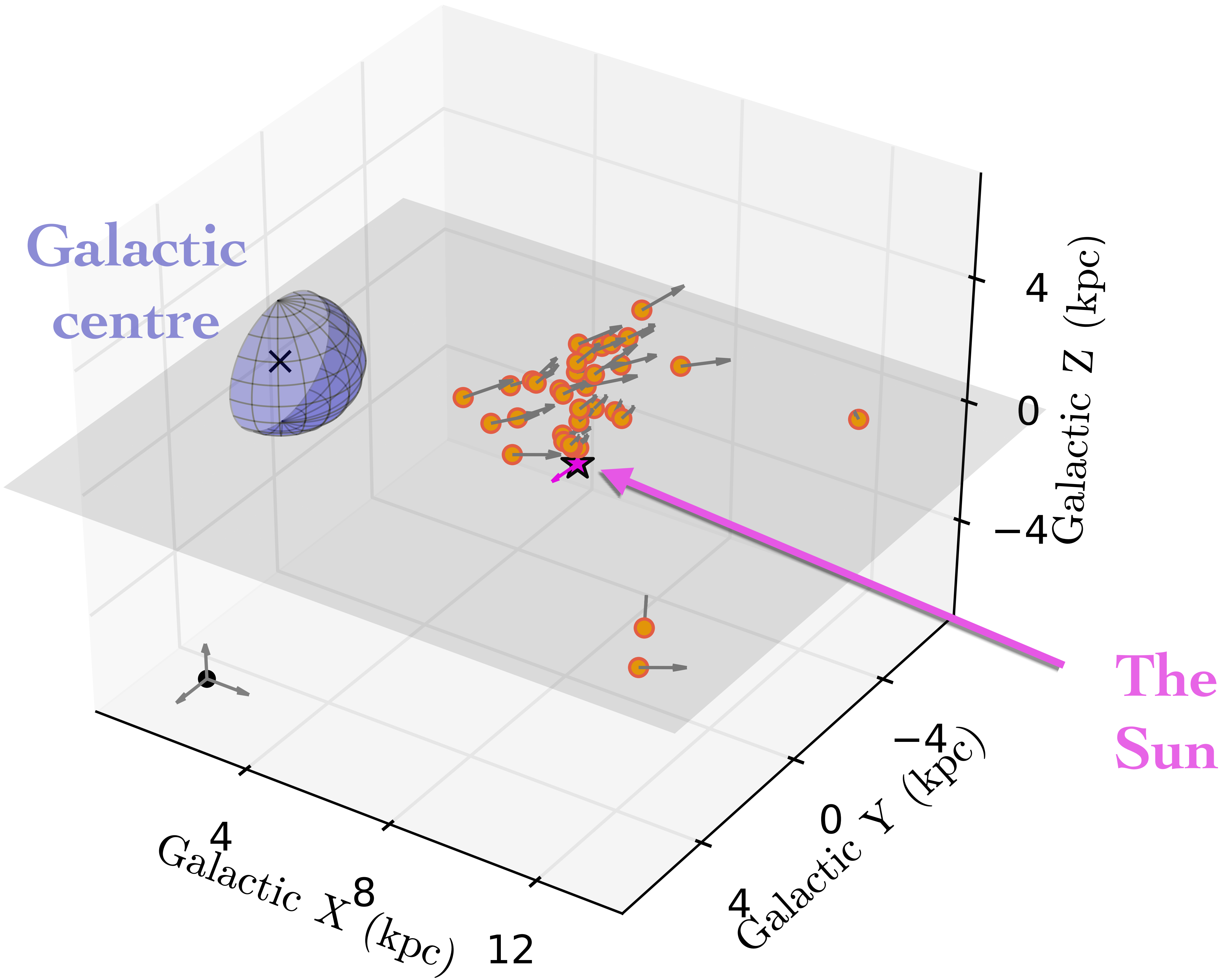
The S1 stream

S1 stream

→ Stars identified with common accretion history streaming with orbits intersecting our location





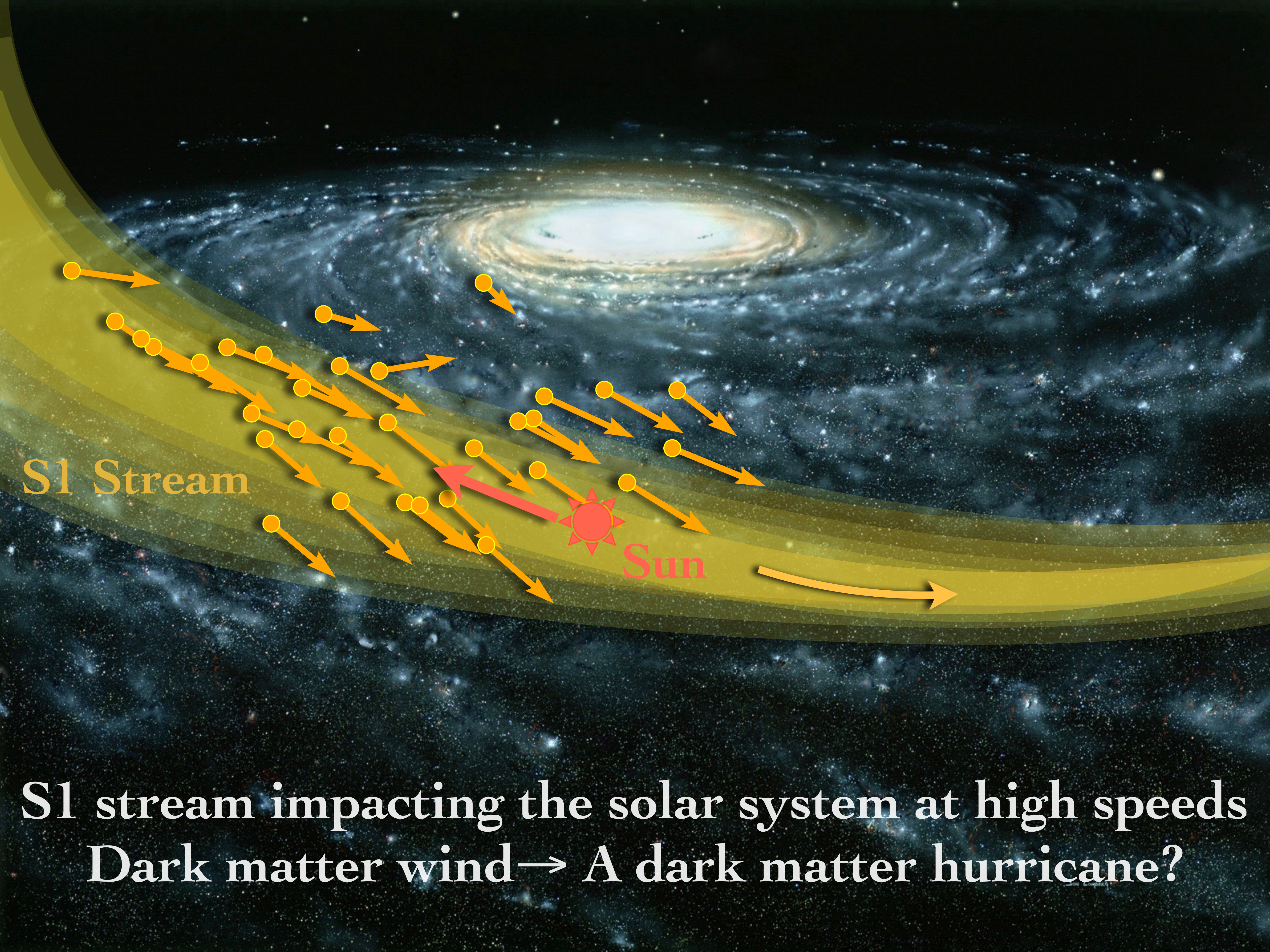

Galactic
centre
4
0
−4
Galactic Z (kpc)
−4
0
4
Galactic Y (kpc)
4
8
12
Galactic X (kpc)
The
Sun

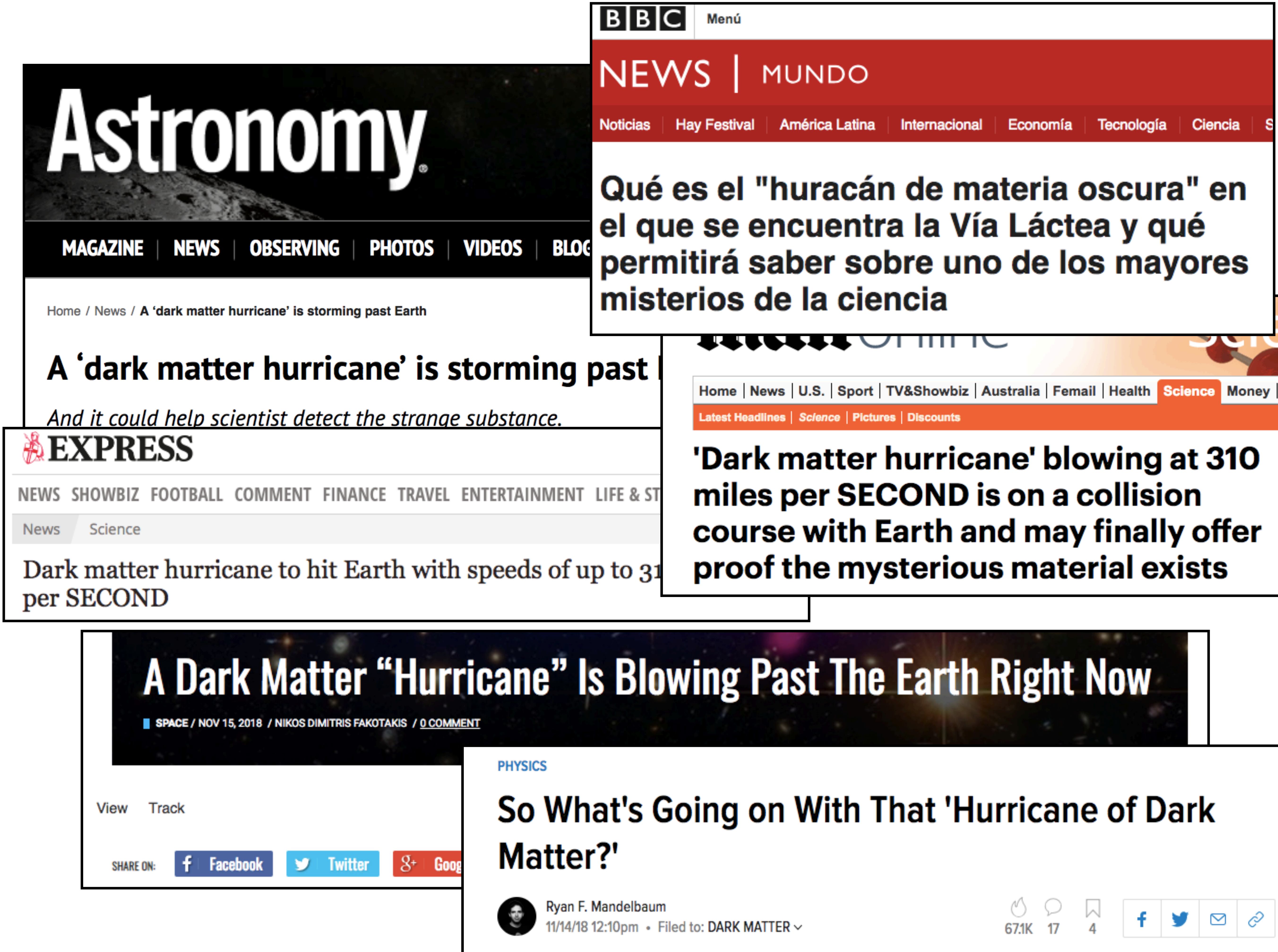
S1 stream: what we know so far

Galactic velocity: $\mathbf{v}_{\rm str} = (8.6,\ -286.7,\ -67.9)\ {\rm km\,s^{-1}}$
→ Stream on a strongly retrograde orbit, so DM impacts us at high velocity ~ 500 km/s

Velocity dispersion: $\sigma_{\rm str} = 46\,{\rm km\,s^{-1}}$
→ Suggests a dwarf spheroidal origin, around the mass of the present day Fornax satellite galaxy accreted over 8-10 billion years

Dark matter content: $0 + \epsilon < \rho_{\rm str} < 0.55\,{\rm GeV\,cm^{-3}}$
→ Upper bound: is *probably* the local DM density probed over length scales smaller than the stream
→ Lower bound: Progenitor very likely had dark matter but other than that we cannot say, must remain agnostic


S1 Stream
Sun
S1 stream impacting the solar system at high speeds
Dark matter wind→ A dark matter hurricane?



Astronomy
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A 'dark matter hurricane' is storming past
And it could help scientist detect the strange substance.
BBC Menú
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Qué es el "huracán de materia oscura" en el que se encuentra la Vía Láctea y qué permitirá saber sobre uno de los mayores misterios de la ciencia
EXPRESS
NEWS SHOWBIZ FOOTBALL COMMENT FINANCE TRAVEL ENTERTAINMENT
News Science
Dark matter hurricane to hit Earth with speeds of up to 31
per SECOND
Home | News | U.S. | Sport | TV&Showbiz | Australia | Femail | Health | Science | Money
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'Dark matter hurricane' blowing at 310 miles per SECOND is on a collision course with Earth and may finally offer proof the mysterious material exists
A Dark Matter "Hurricane" Is Blowing Past The Earth Right Now
SPACE / NOV 15, 2018 / NIKOS DIMITRIS FAKOTAKIS / 0 COMMENT
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SHARE ON: Facebook Twitter
PHYSICS
So What's Going on With That 'Hurricane of Dark Matter?'
Ryan F. Mandelbaum
11/14/18 12:10pm • Filed to: DARK MATTER
67.1K 17 4

Urgent: “Scientist “Claim Dark Matter Hurricane” Is Coming

28,497 views 701 62 SHARE SAVE

Paul Begley
Published on Nov 14, 2018

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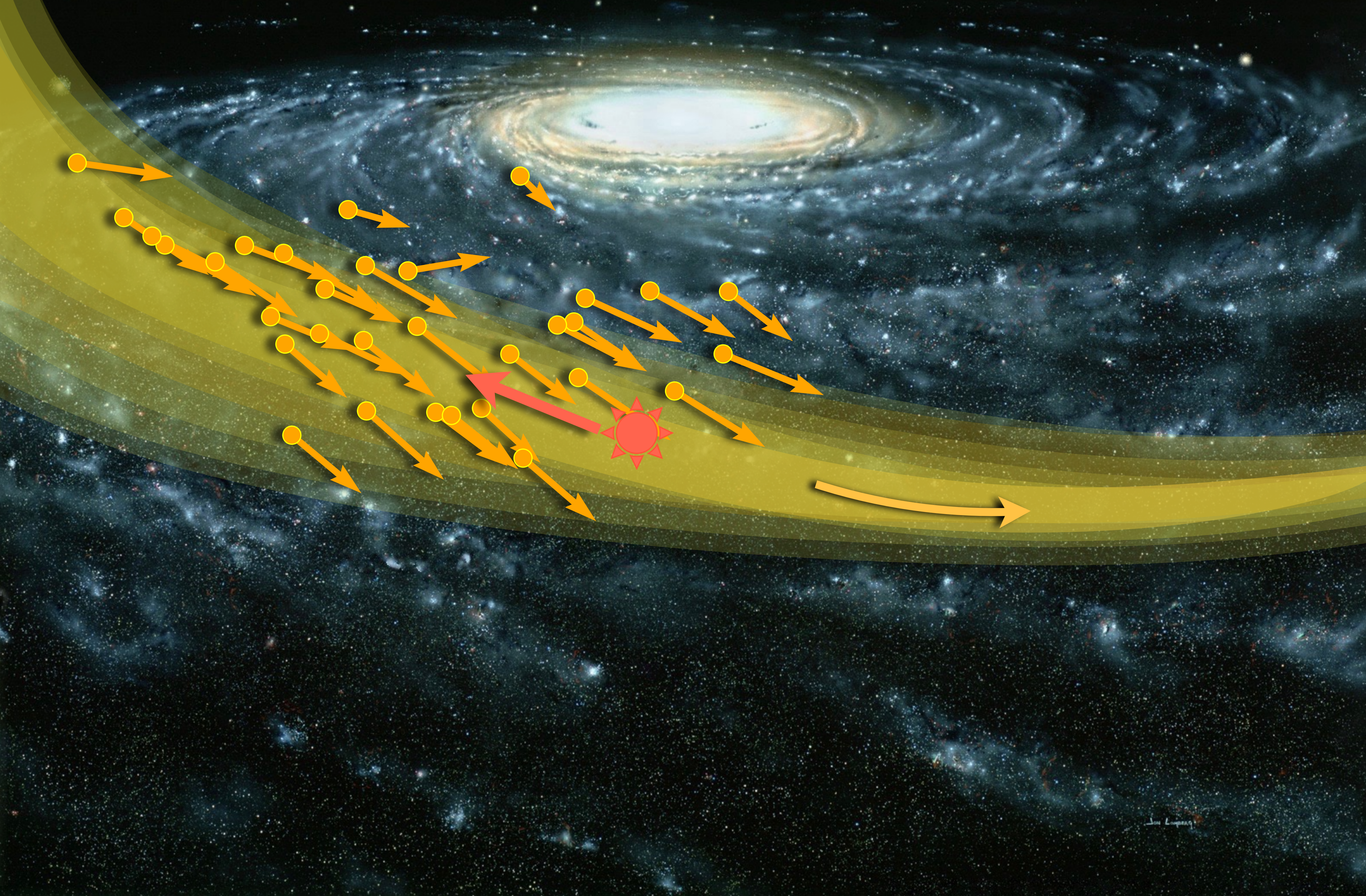
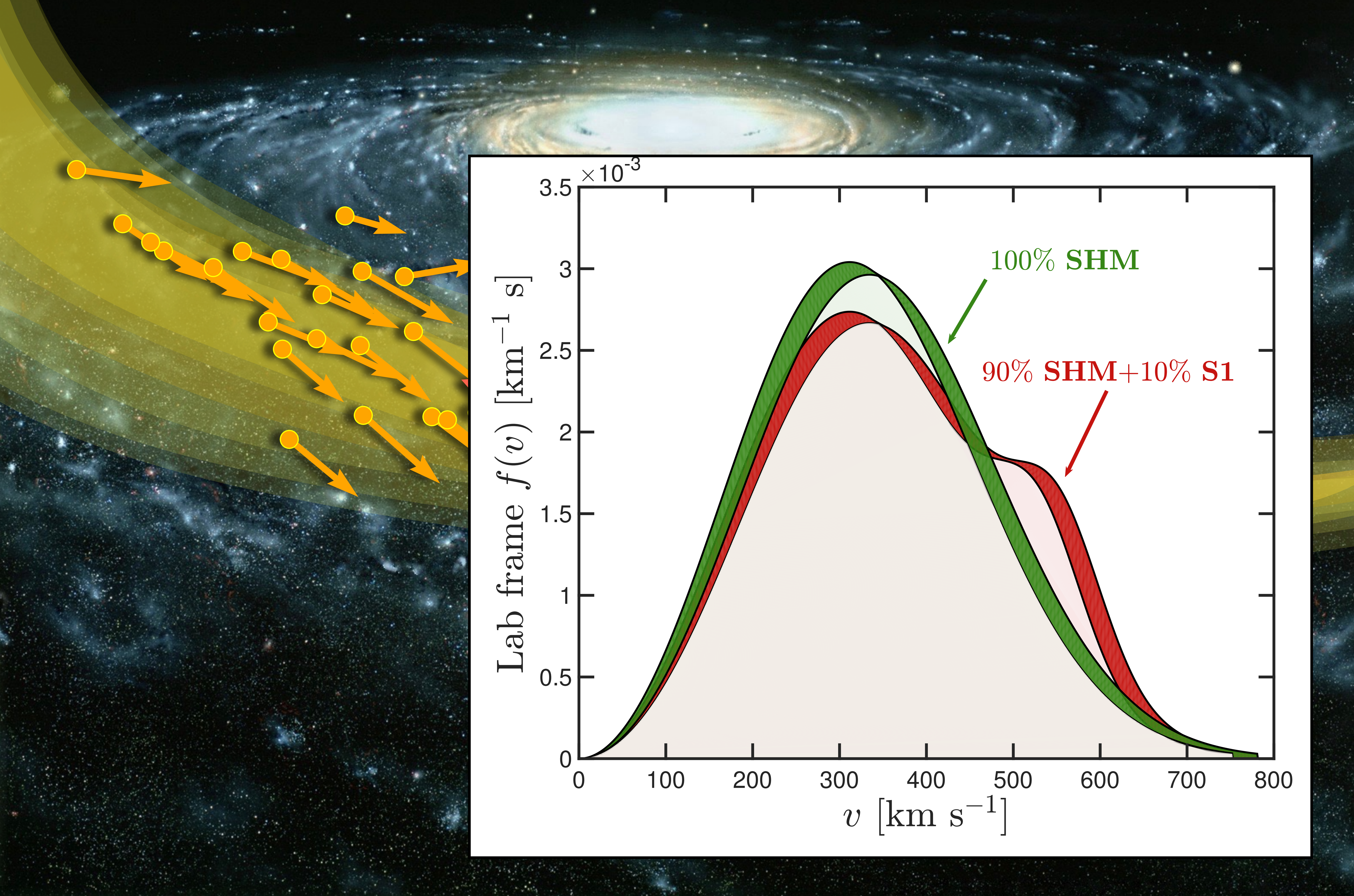
Approaching dark matter hurricane will collide with earth, predict scientists

- Conspiracy theorists believe that the dark matter hurricane will result in an imminent apocalypse on earth.

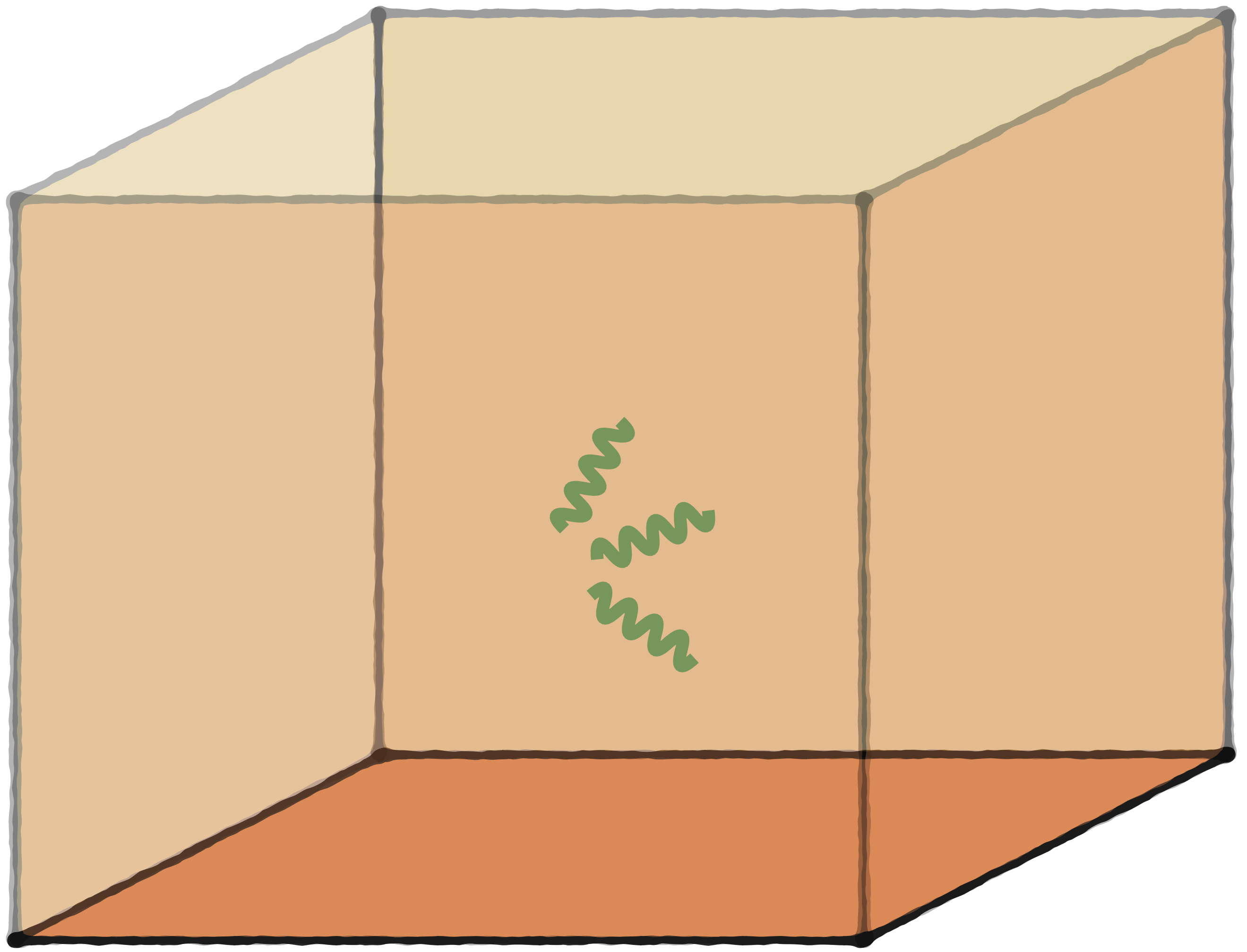
Modelling S1



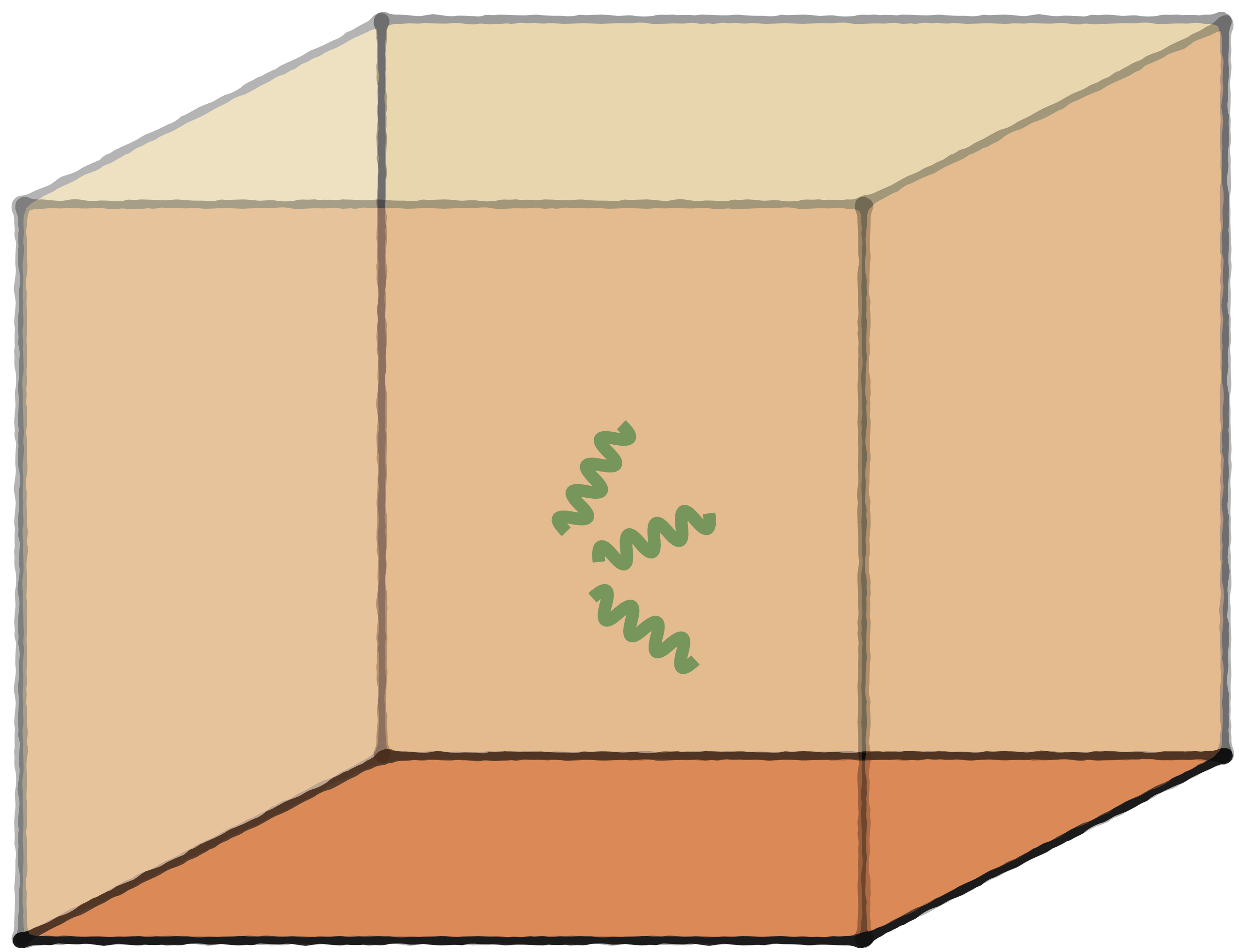
Modelling S1



How to build a WIMP detector

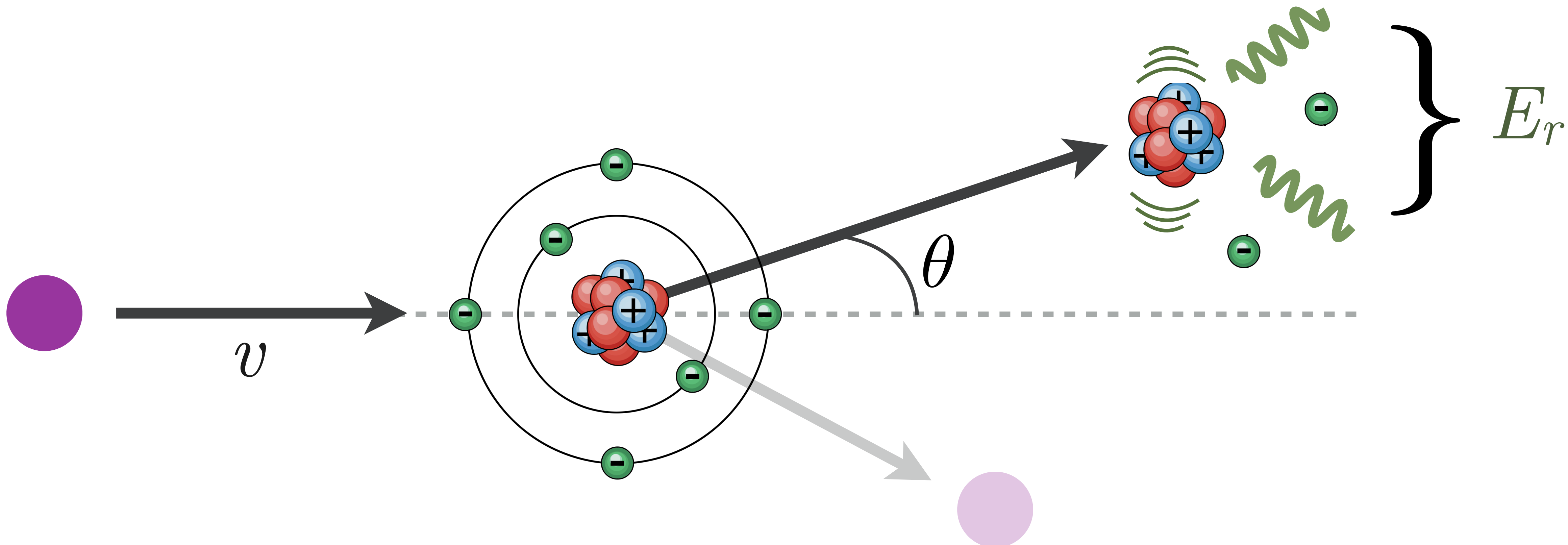


How to build a WIMP detector



Make a very quiet box

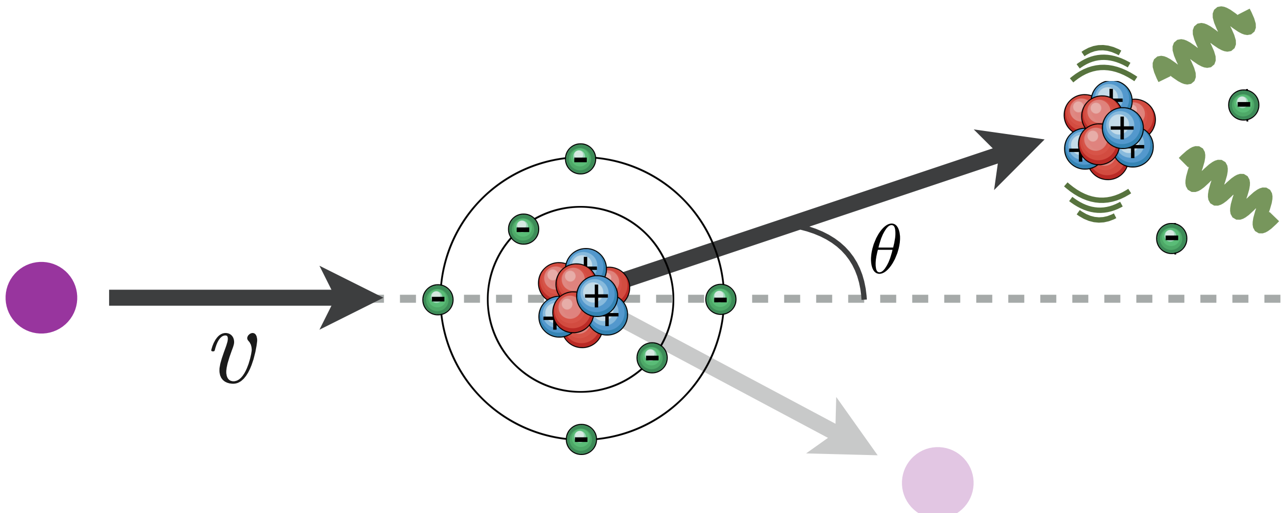
WIMP direct detection



$$\text{“Signal”} \propto E_r = \frac{2 m_N m_\chi^2}{(m_N + m_\chi)^2} v^2 \cos^2 \theta$$

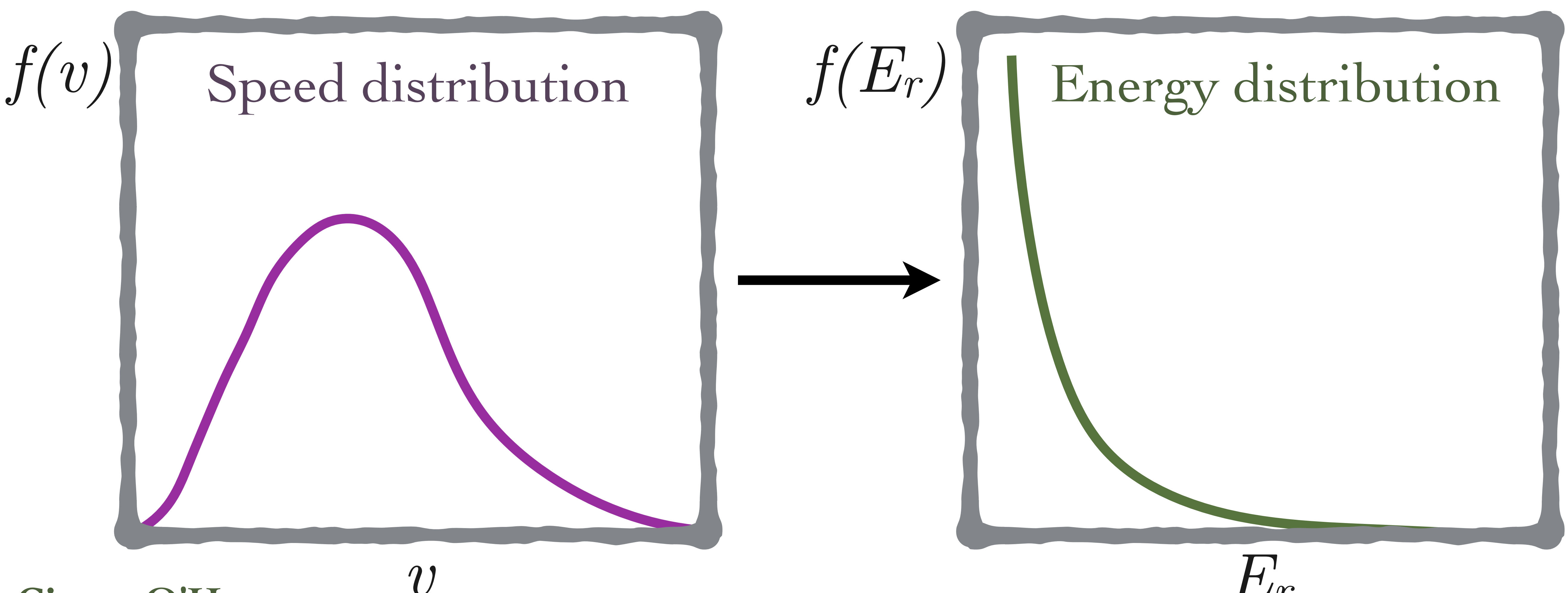
m_N = Nucleus mass
m_χ = WIMP mass

WIMP direct detection

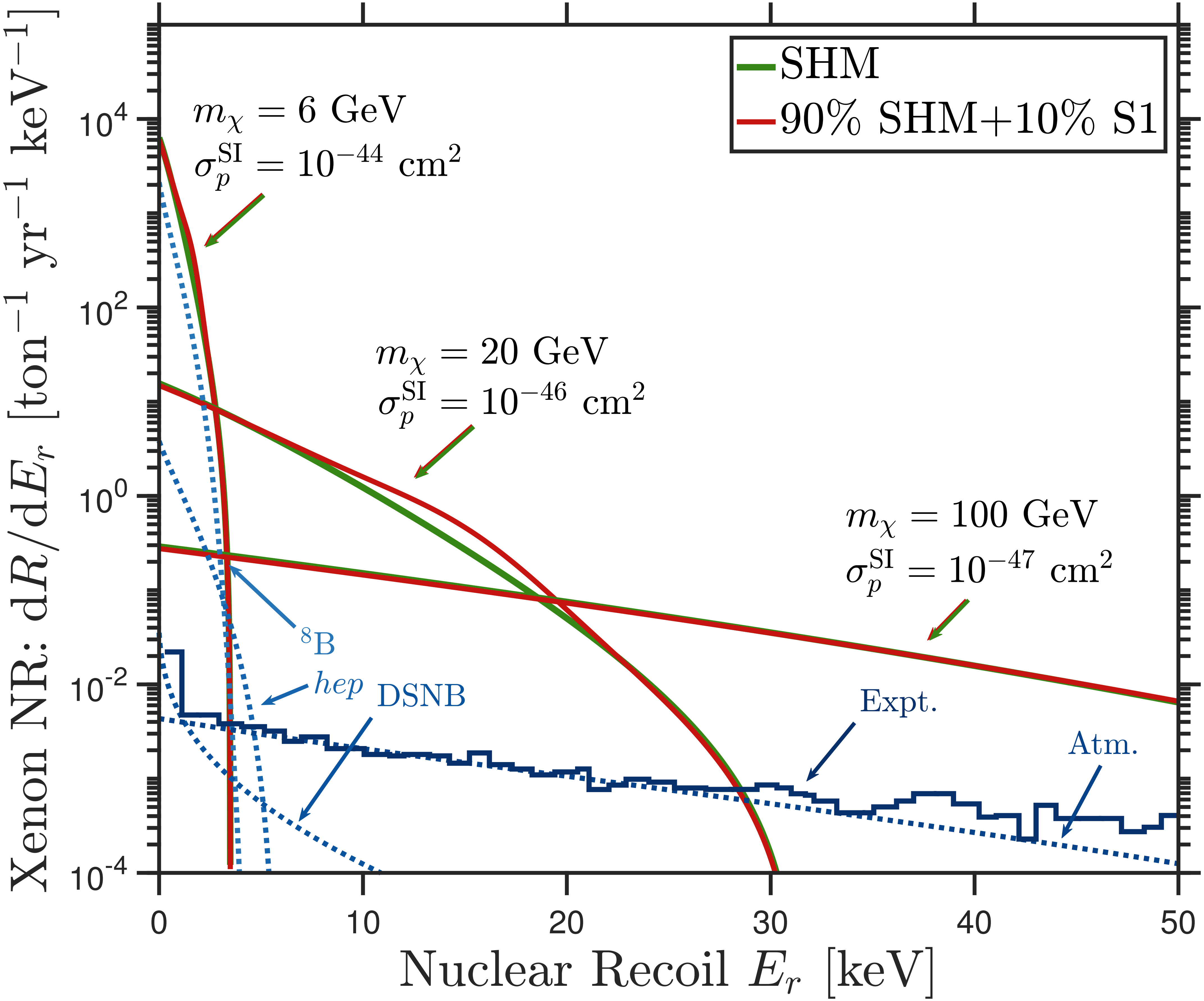


Angle not measurable so for a given speed:

$$E_r \in \left[0,\ v^2 \frac{2 m_N m_\chi^2}{(m_N + m_\chi)^2}\right]$$

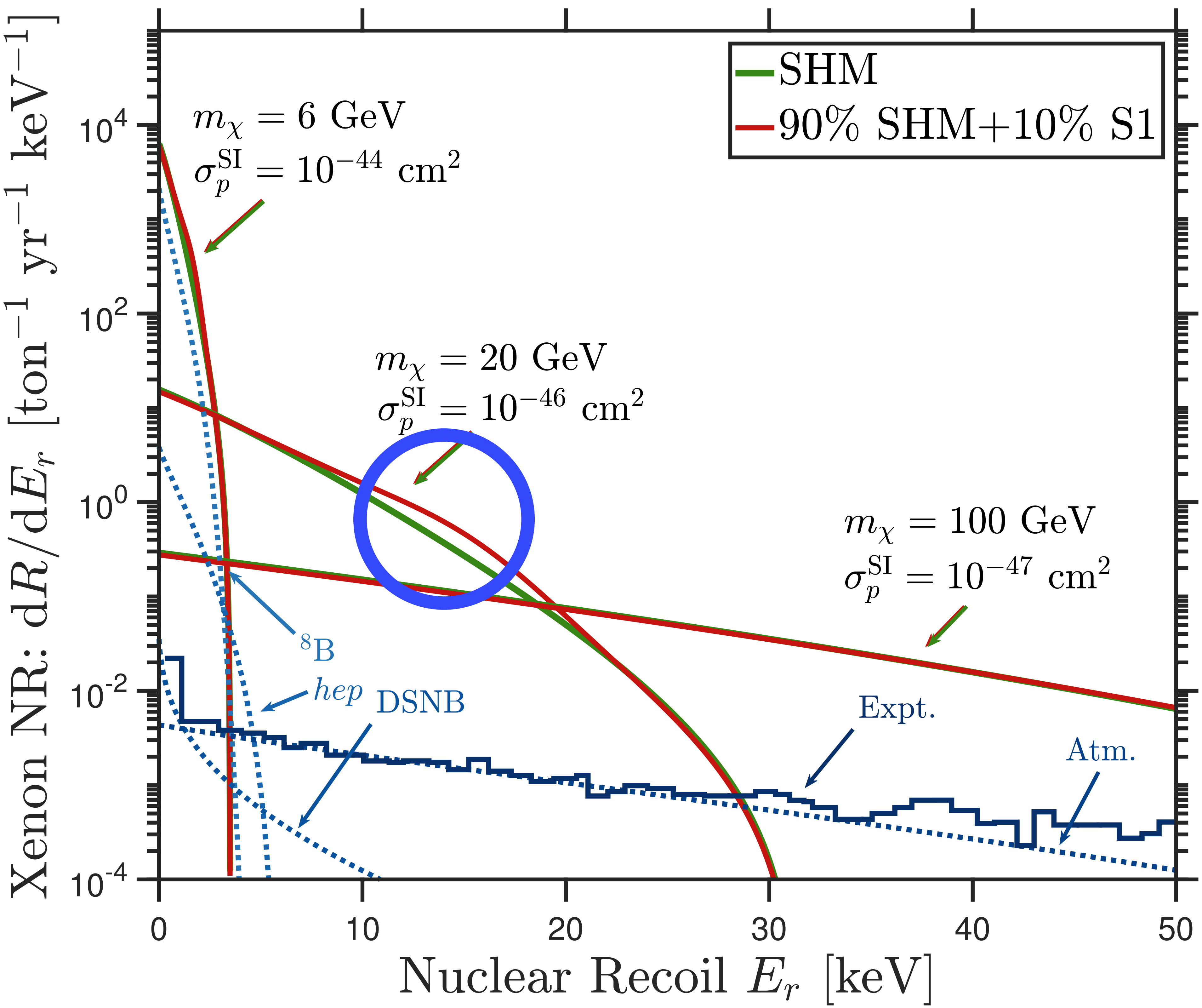


Ciaran O'Hare



SHM
90% SHM+10% S1
$m_\chi = 6$ GeV
$\sigma_p^{\rm SI} = 10^{-44}$ cm^2
$m_\chi = 20$ GeV
$\sigma_p^{\rm SI} = 10^{-46}$ cm^2
$m_\chi = 100$ GeV
$\sigma_p^{\rm SI} = 10^{-47}$ cm^2
^{8}B
hep
DSNB
Expt.
Atm.
Xenon NR: dR/dE_r [ton^{-1} yr^{-1} keV^{-1}]
Nuclear Recoil E_r [keV]
10^4
10^2
10^0
10^{-2}
10^{-4}
0
10
20
30
40
50

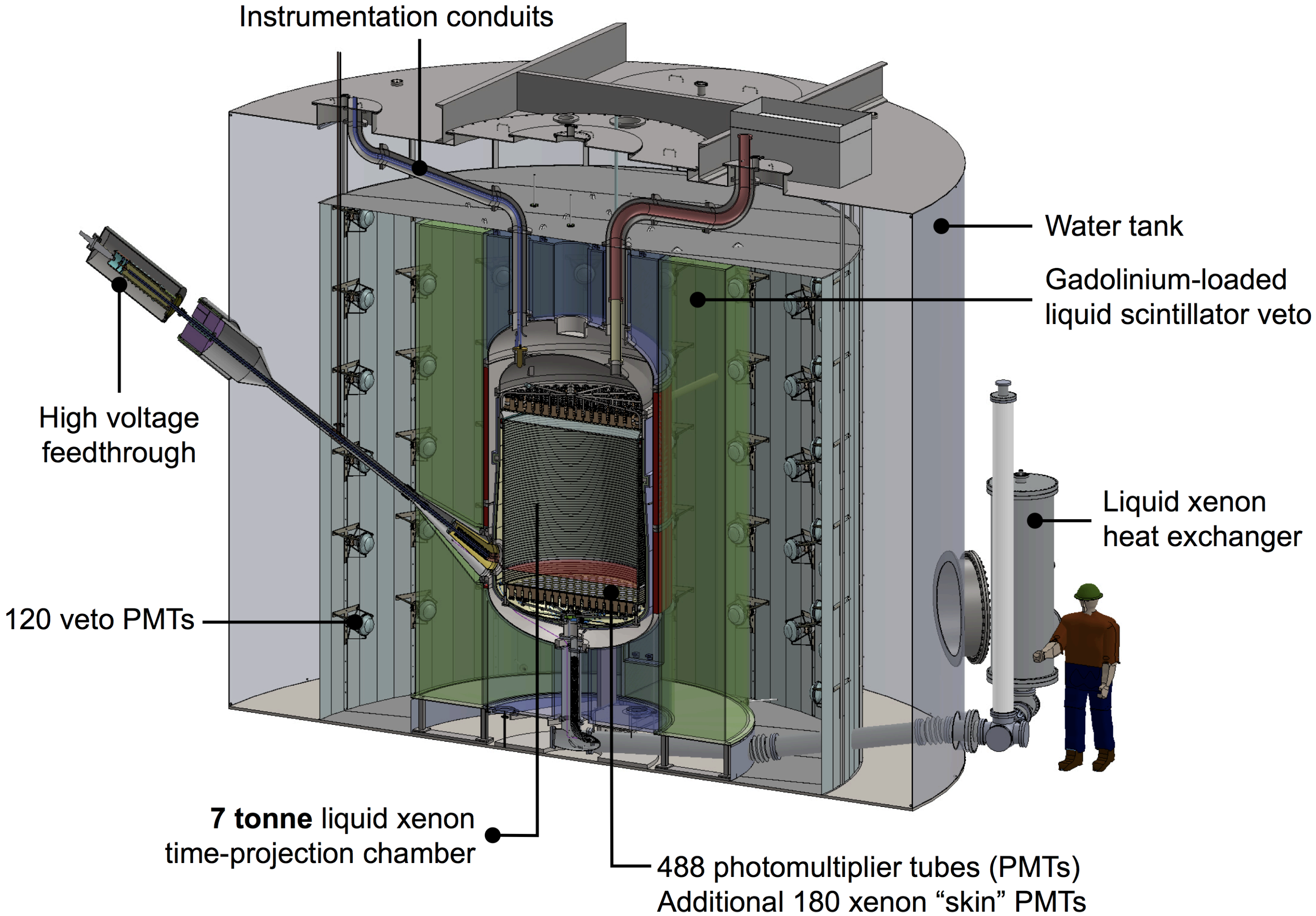
Q: How strong does the hurricane need to be to detect it in an experiment?



In other words: How big does this bump need to be for the experiment to tell the difference?

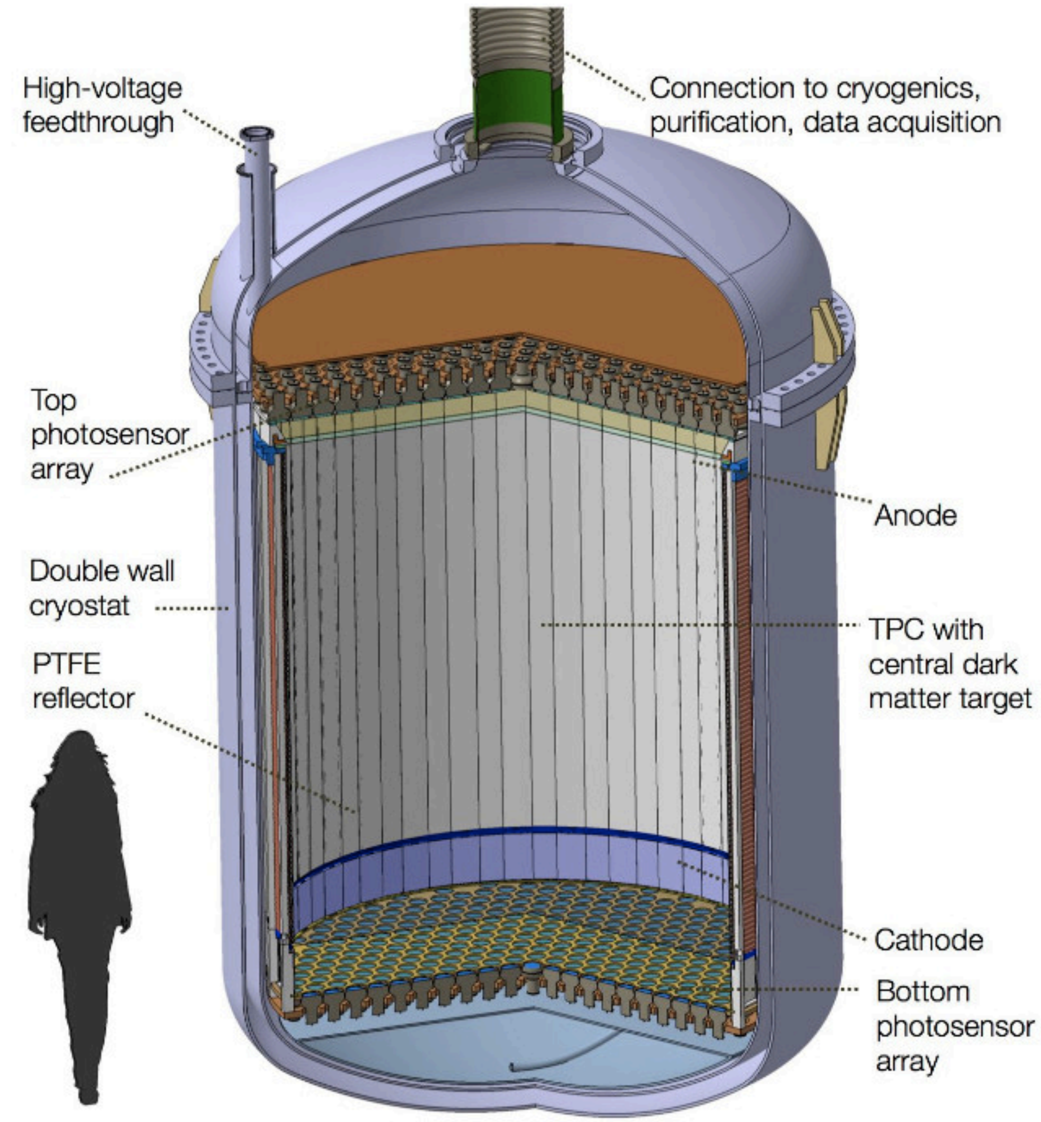
Liquid Xe time projection chambers

LZ



Target mass: 5.6 tons

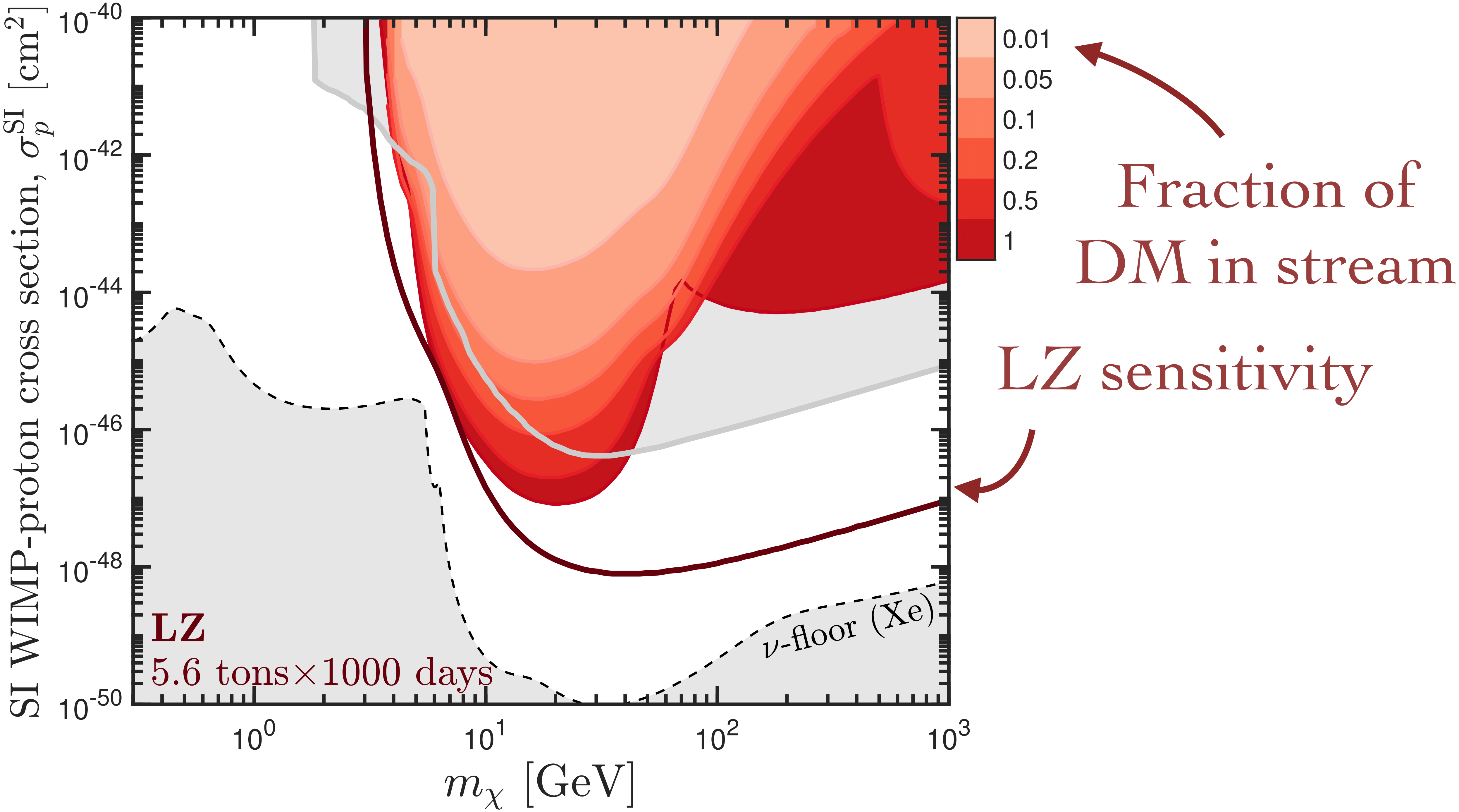
DARWIN



Target mass: ~40 tons

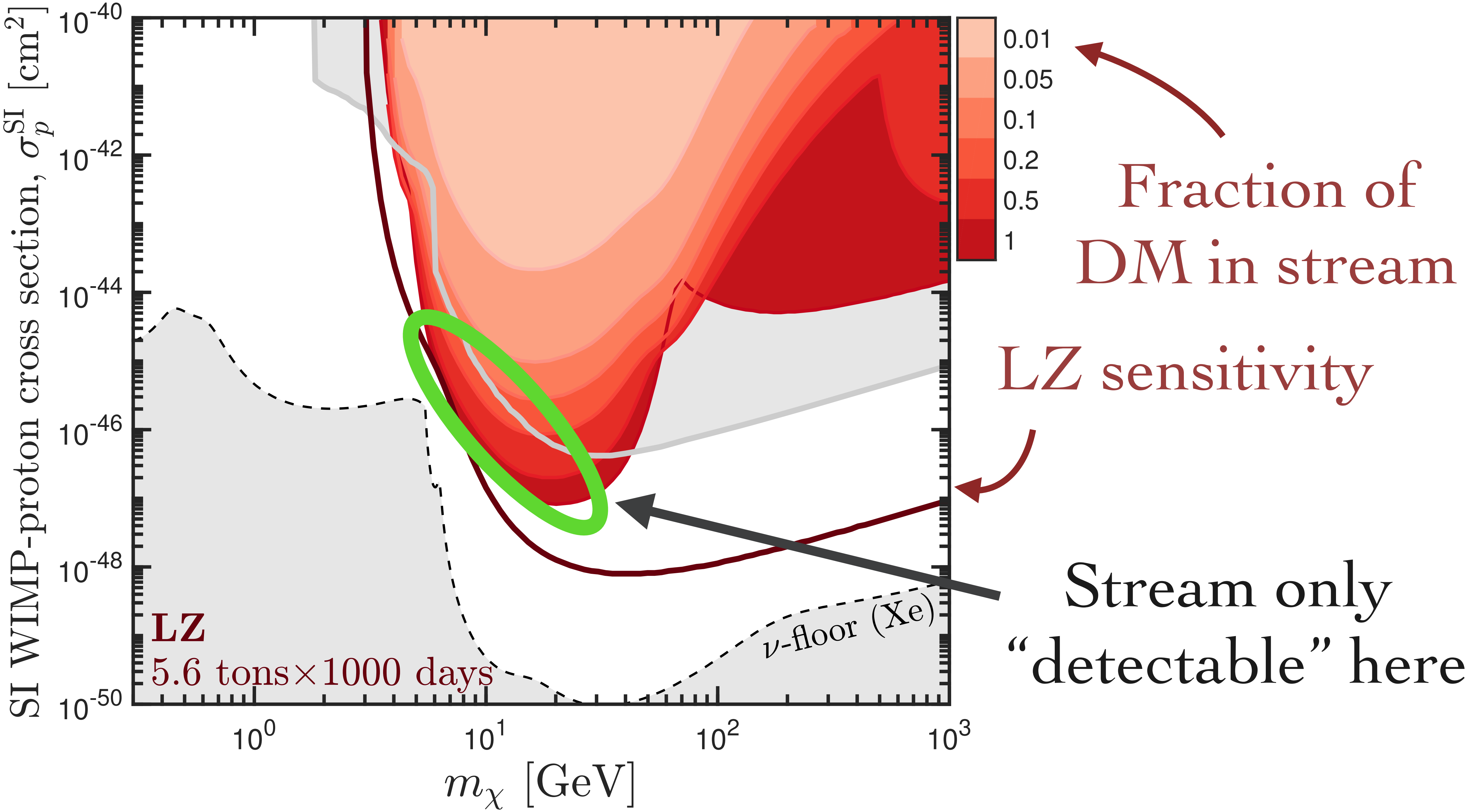
S1 in LZ

Red regions: range of WIMP masses and couplings for which the stream can be distinguished from the halo in LZ at 3 sigma



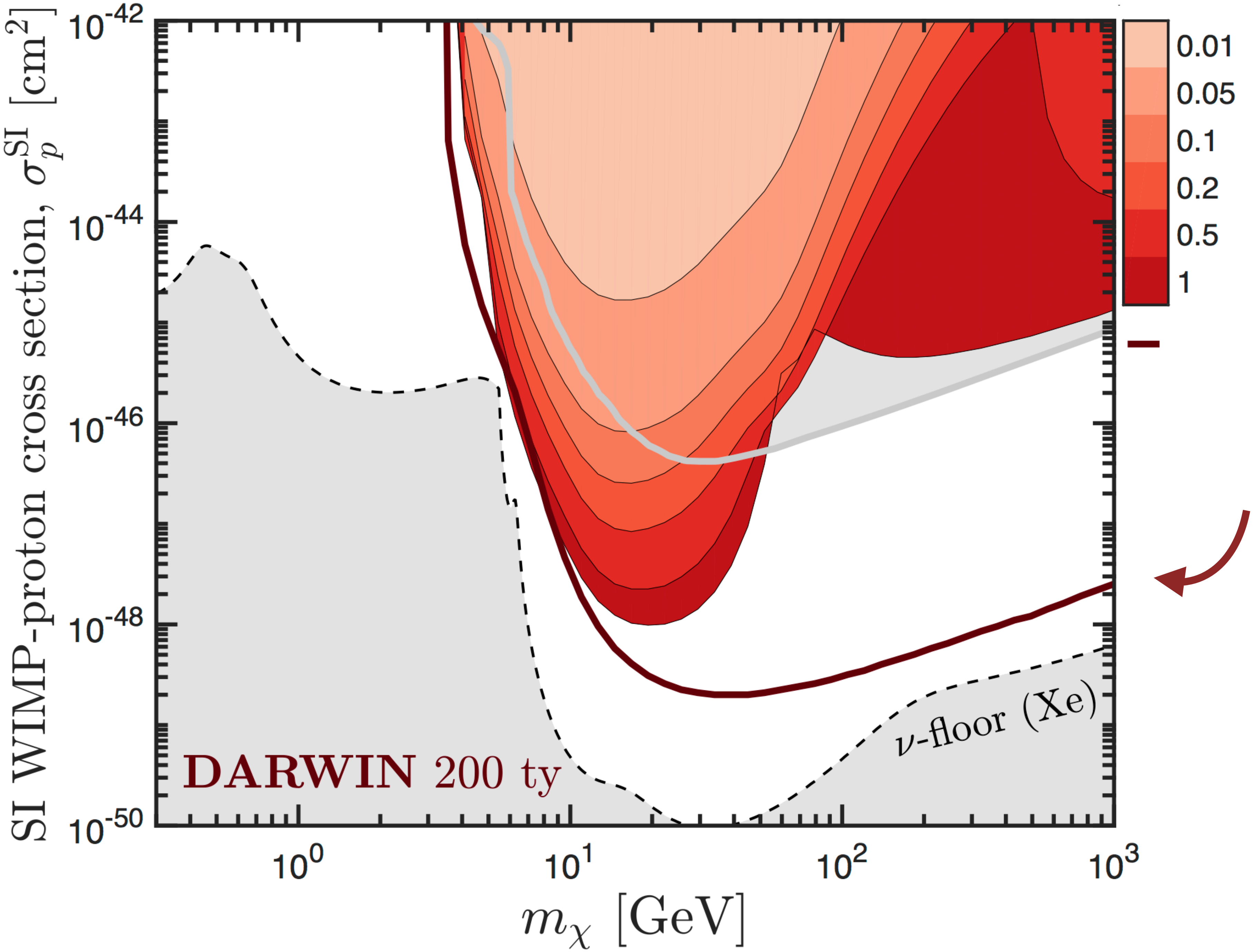
S1 in LZ

Red regions: range of WIMP masses and couplings for which the stream can be distinguished from the halo in LZ at 3 sigma



S1 in DARWIN

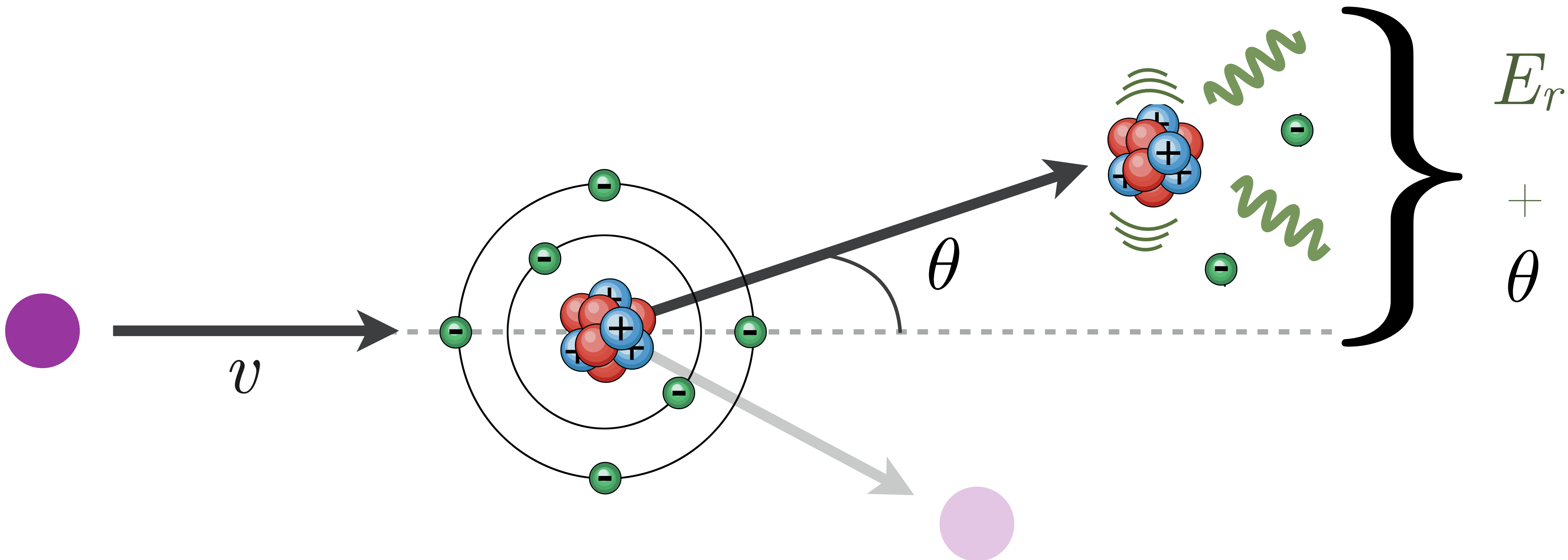
Red regions: range of WIMP masses and couplings for which the stream can be distinguished from the halo in DARWIN at 3 sigma



Fraction of DM in stream

DARWIN sensitivity

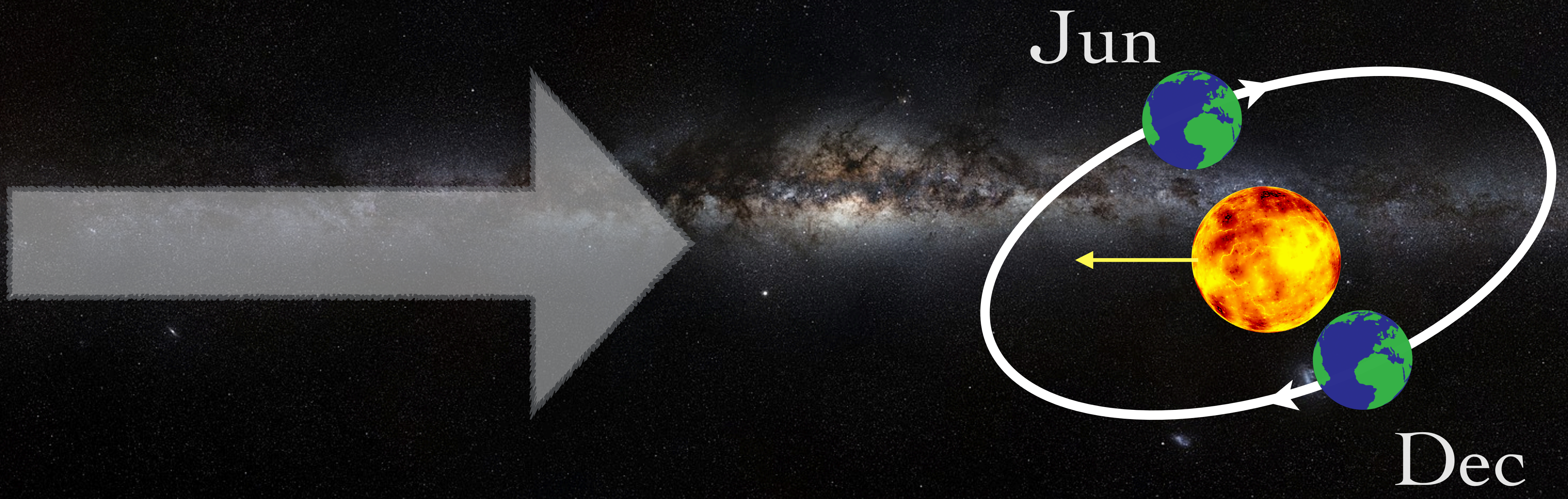
Directional detection of WIMPs



$$E_r = \frac{2 m_N m_\chi^2}{(m_N + m_\chi)^2} v^2 \cos^2\theta$$

If both energy and angle are measurable → solve for v

Stream is counter-rotating, so will enhance the anisotropy of the DM flux



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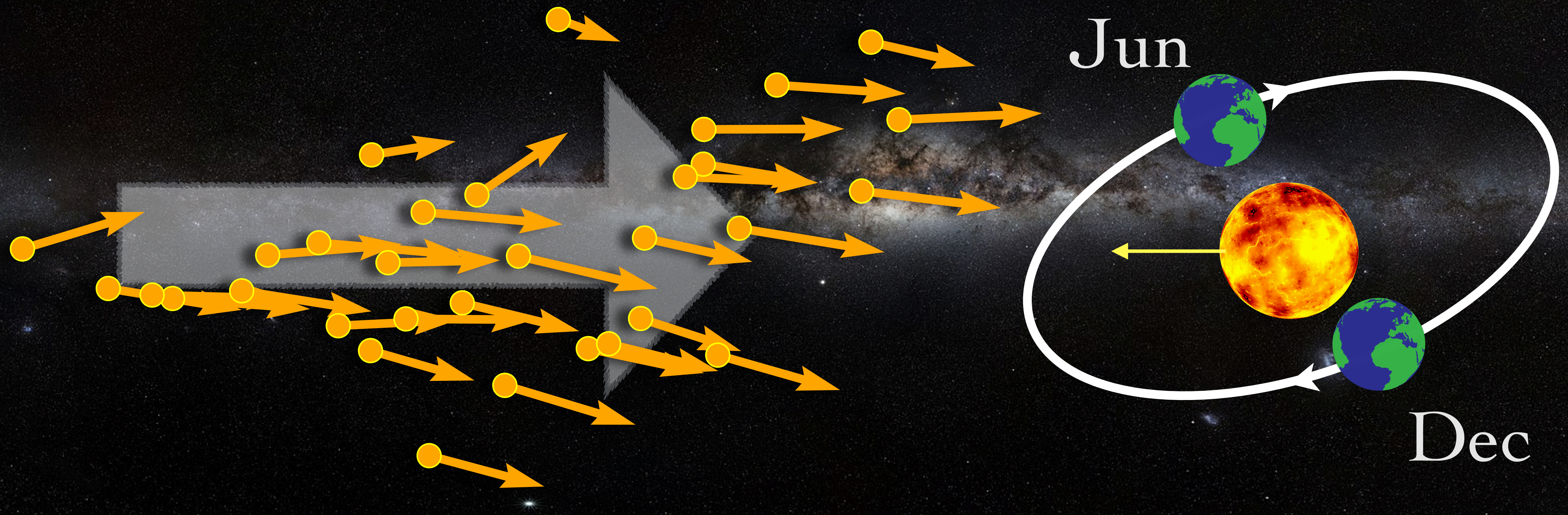
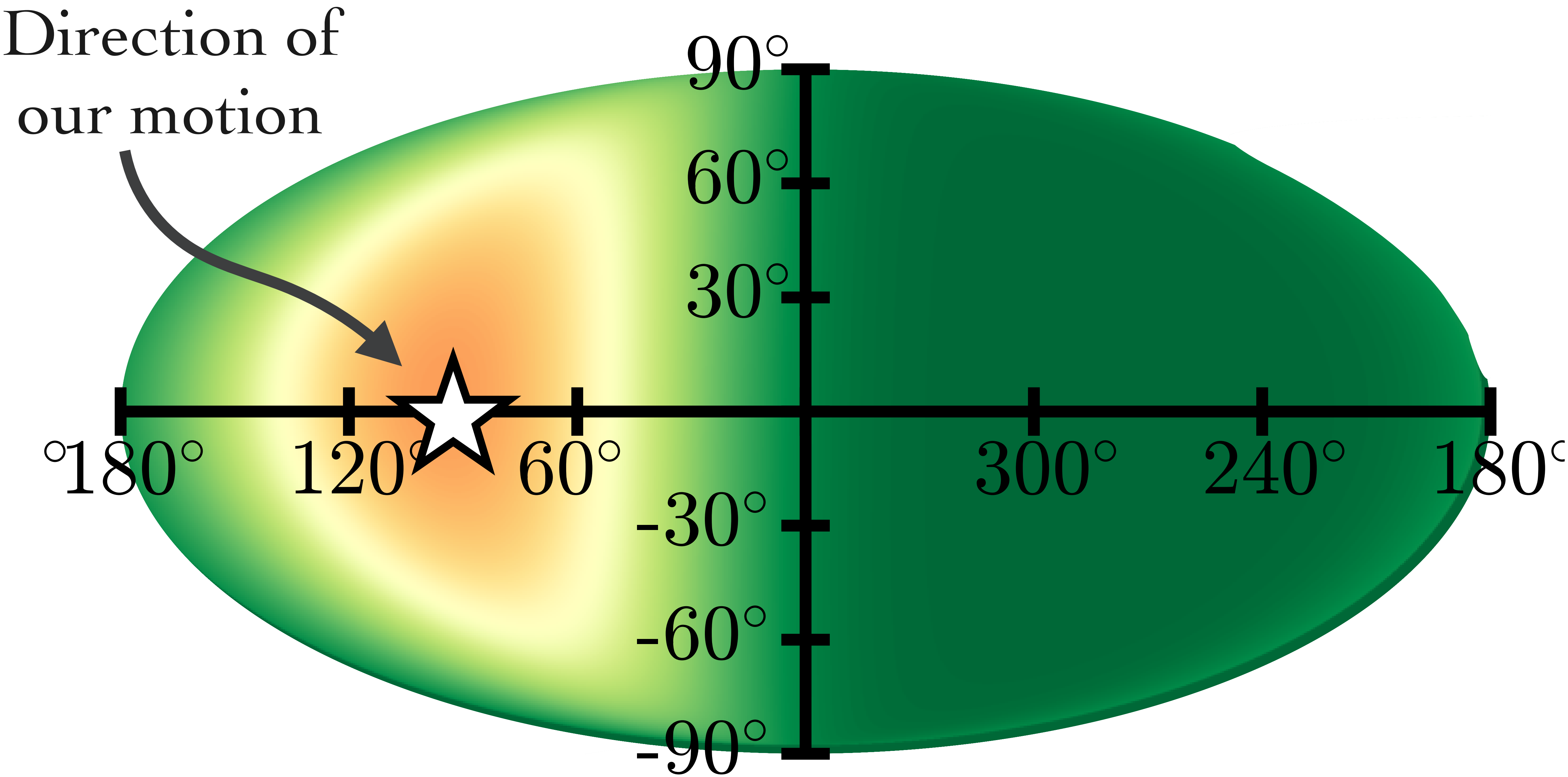
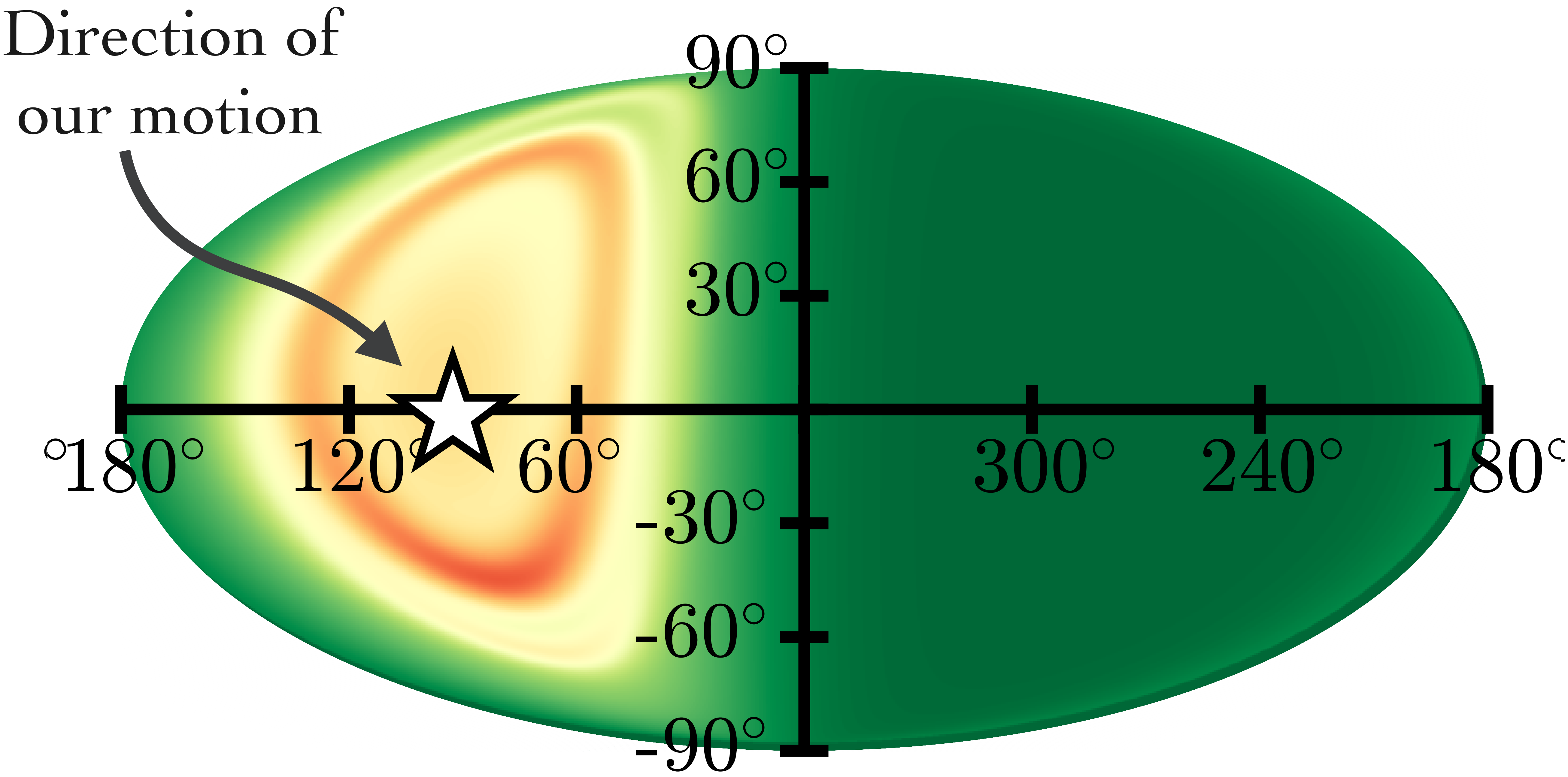


<u>Directional</u> detection of WIMPs

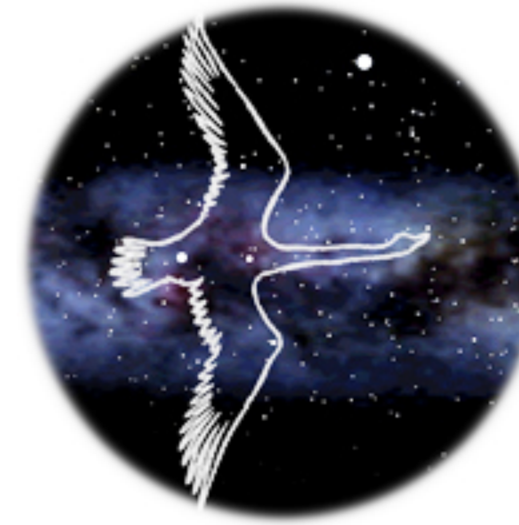


<u>Directional</u> detection of WIMPs



Halo + 10% S1

CYGNUS



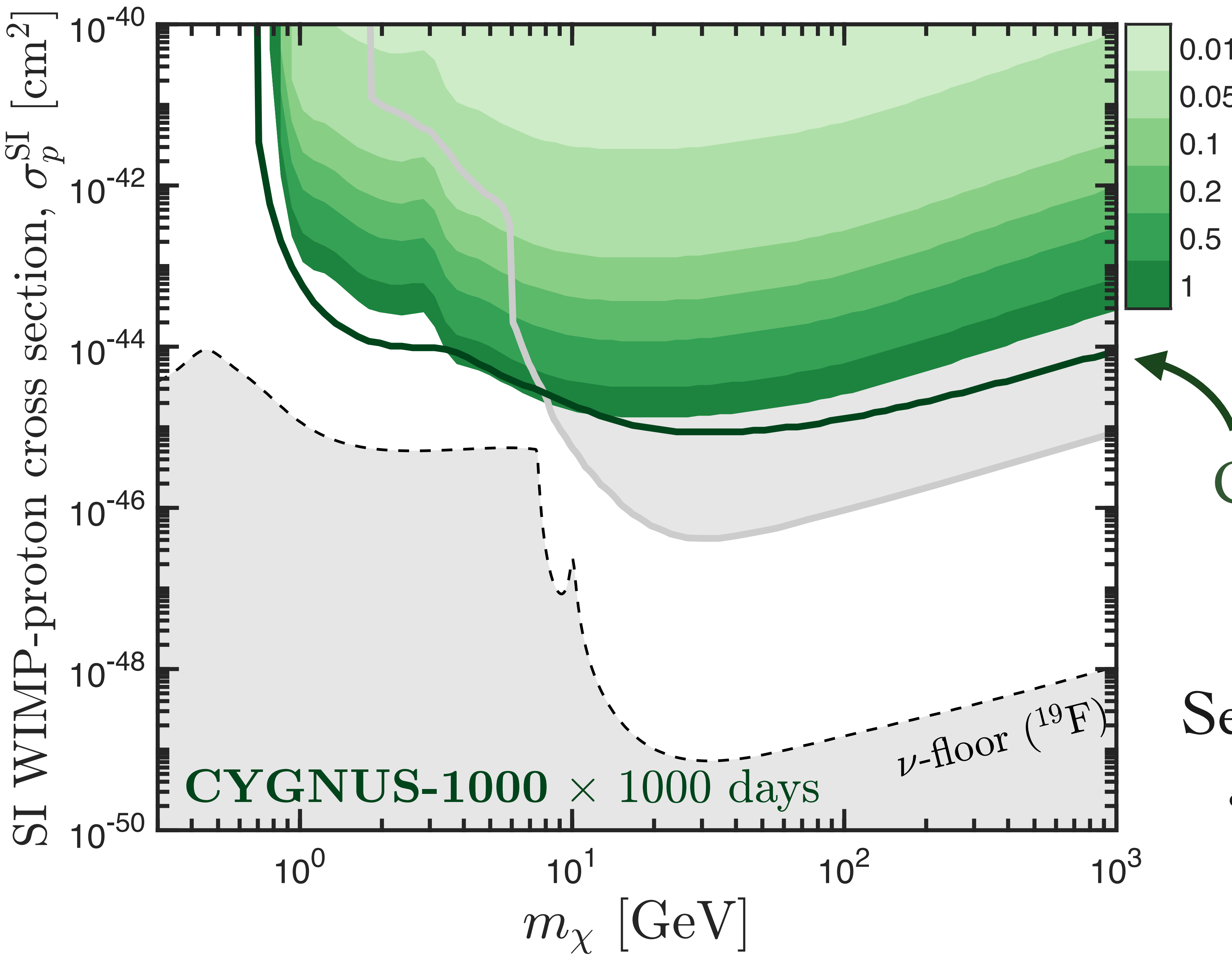
- A low pressure gas TPC
- Current plan: SF_6 at 20 torr and He at 740 torr
- Various readout technologies being compared (MWPCs, μPIC, pixel chips, optical, micromegas)
- Main goal: circumvent the neutrino floor
- Secondary goal: study DM astrophysics
- Paper coming soon…

CYGNUS: Feasibility of a Nuclear Recoil Observatory with Directional Sensitivity to Dark Matter and Neutrinos

E. Baracchini,[1,2,3] P. Barbeau,[4] J. B. R. Battat,[5] B. Crow,[6] C. Deaconu,[7] C. Eldridge,[8] A. C. Ezeribe,[8] D. Loomba,[9] W. A. Lynch,[8] K. J. Mack,[10] K. Miuchi,[11] N. S. Phan,[12] C. A. J. O'Hare,[13,14] K. Scholberg,[4] N. J. C. Spooner,[8] T. N. Thorpe,[6] and S. E. Vahsen[6]

S1 in CYGNUS

Green regions: range of WIMP models for which the stream can be distinguished from the halo in CYGNUS at 3 sigma

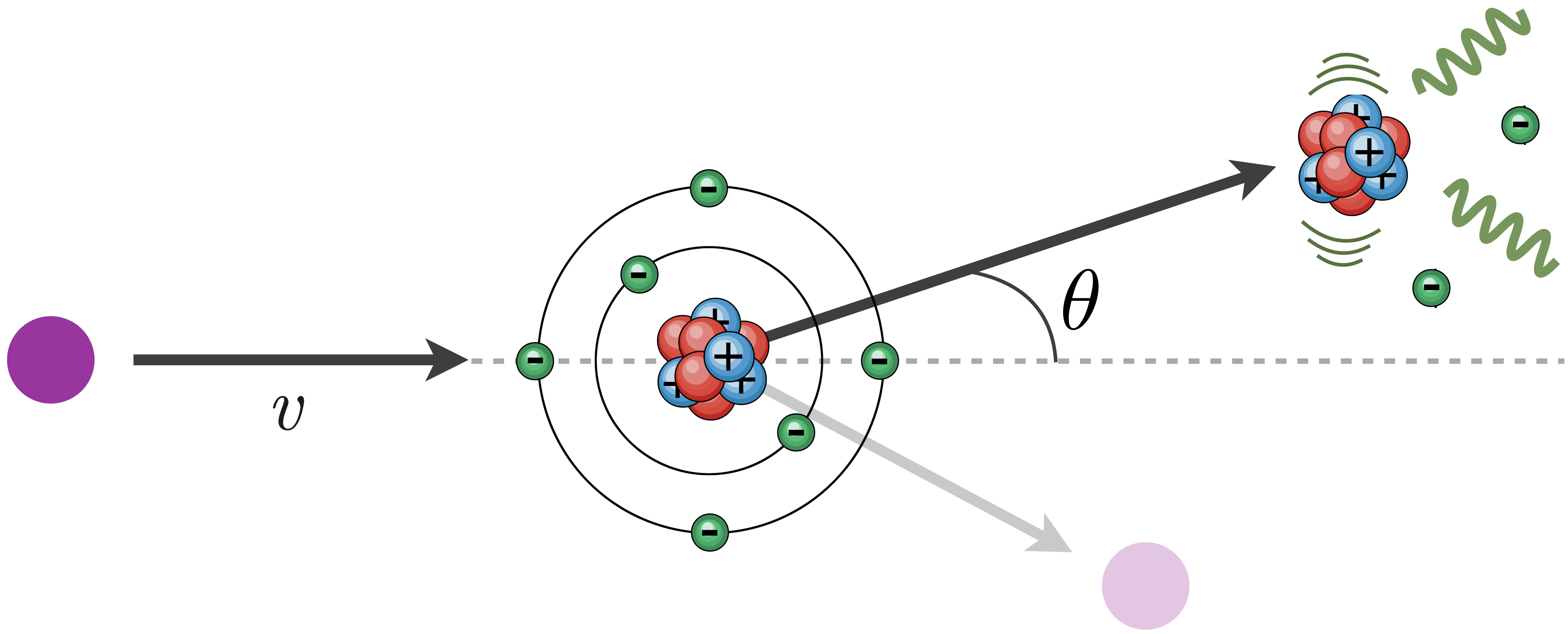


Fraction of DM in stream

CYGNUS sensitivity [He:SF_6]

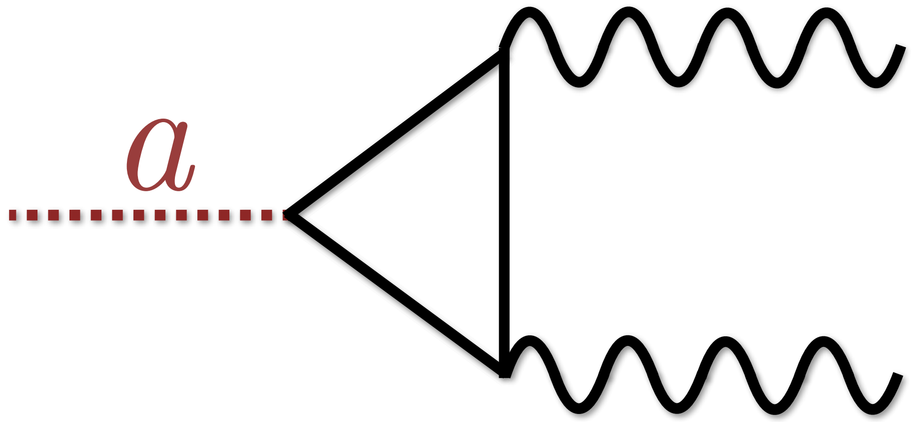
Sensitivity to stream across all masses

WIMP direct detection



Axion-photon coupling: $g_{a\gamma}$

$$\mathcal{L} = \frac{1}{4} g_{a\gamma} a(\mathbf{x},t) F_{\mu\nu}\tilde{F}^{\mu\nu}$$



For QCD axion: $g_{a\gamma} \propto m_a$

$$\nabla \cdot \mathbf{E} = \rho_q - g_{a\gamma}\mathbf{B}\cdot\nabla a$$

$$\nabla \times \mathbf{B} - \dot{\mathbf{E}} = \mathbf{J} + g_{a\gamma}(\mathbf{B}\,\dot{a} - \mathbf{E}\times\nabla a)$$

$$\nabla \cdot \mathbf{B} = 0$$

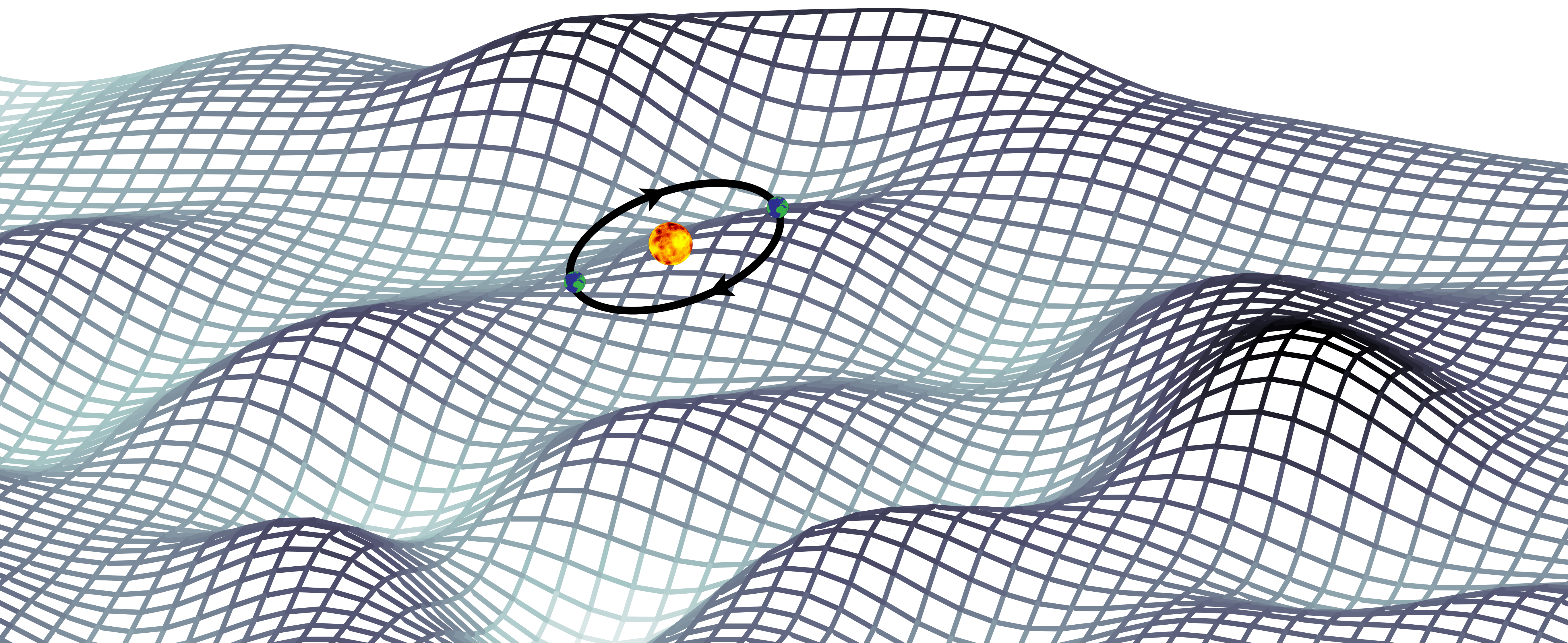
$$\nabla \times \mathbf{E} + \dot{\mathbf{B}} = 0$$

$$(\Box + m_a^2)a = g_{a\gamma}\mathbf{E}\cdot\mathbf{B}$$

The local axion field

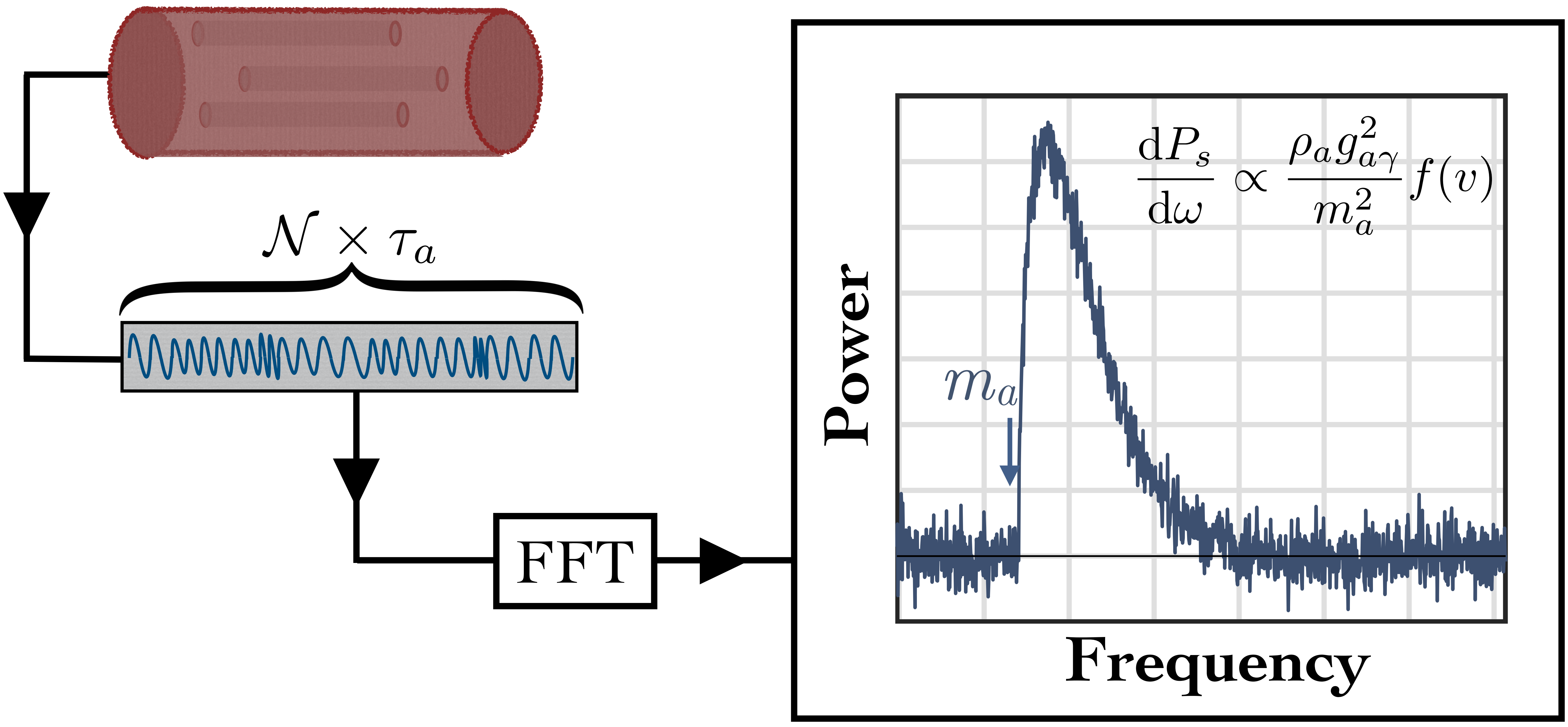
$$a(\mathbf{x}, t) \approx \frac{\sqrt{2\rho_a}}{m_a} \cos\left(\omega t - \mathbf{p}\cdot\mathbf{x} + \alpha\right)$$

Oscillating at ~the axion mass with coherence time $\tau \sim \dfrac{1}{m_a \langle v \rangle^2}$



Measuring the axion distribution

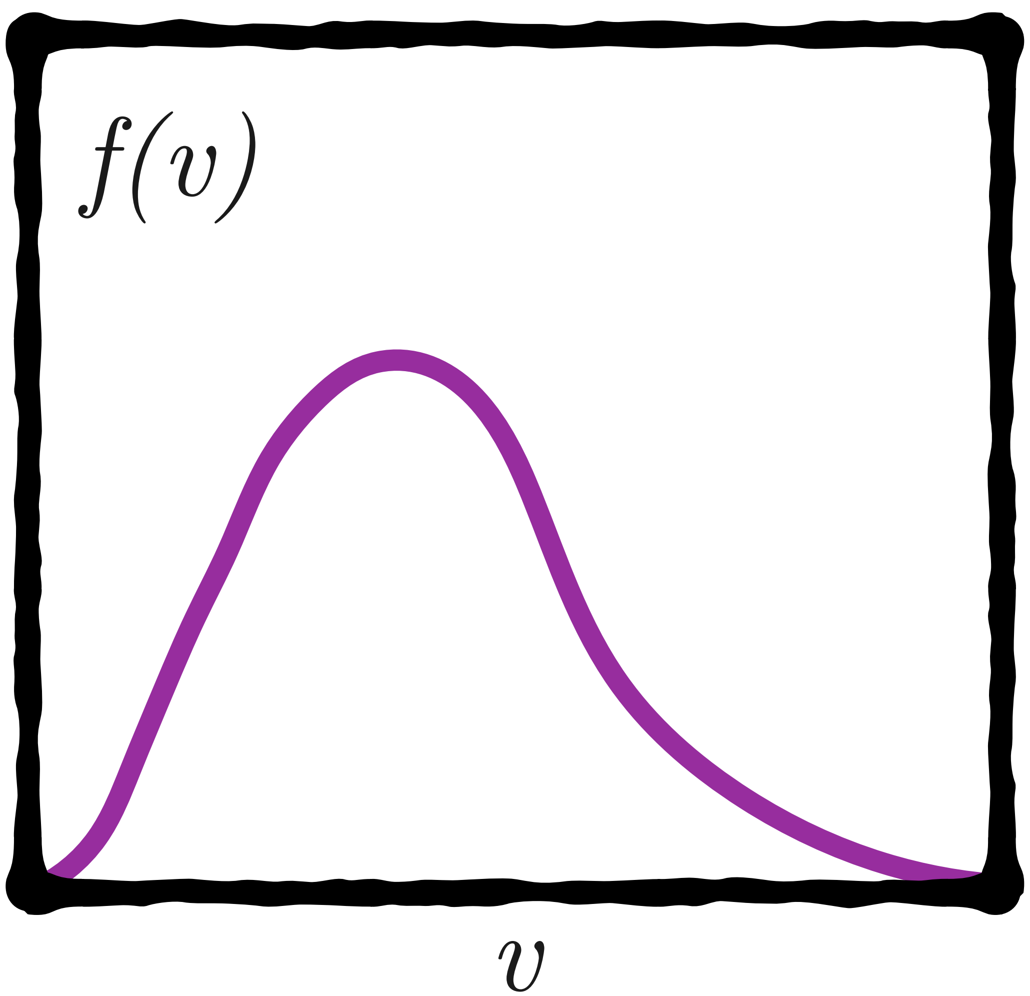
Sampling axion field over many coherence times:
→ Power spectrum ~ $f(v)$



Measuring $f(v)$ in a haloscope

$$\omega = m_a \left(1 + \frac{v^2}{2}\right)$$

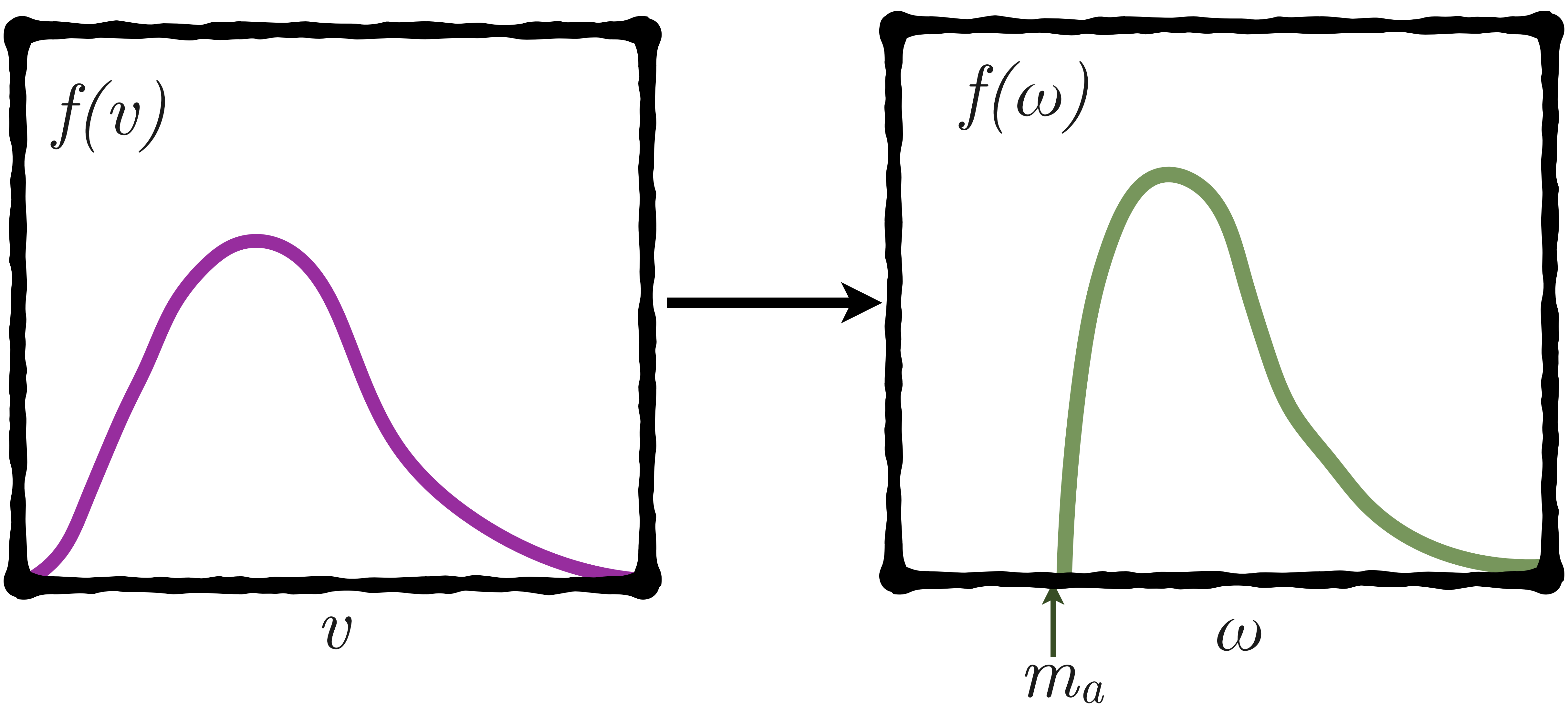
A haloscope can effectively make a direct measurement of the astrophysical speed distribution



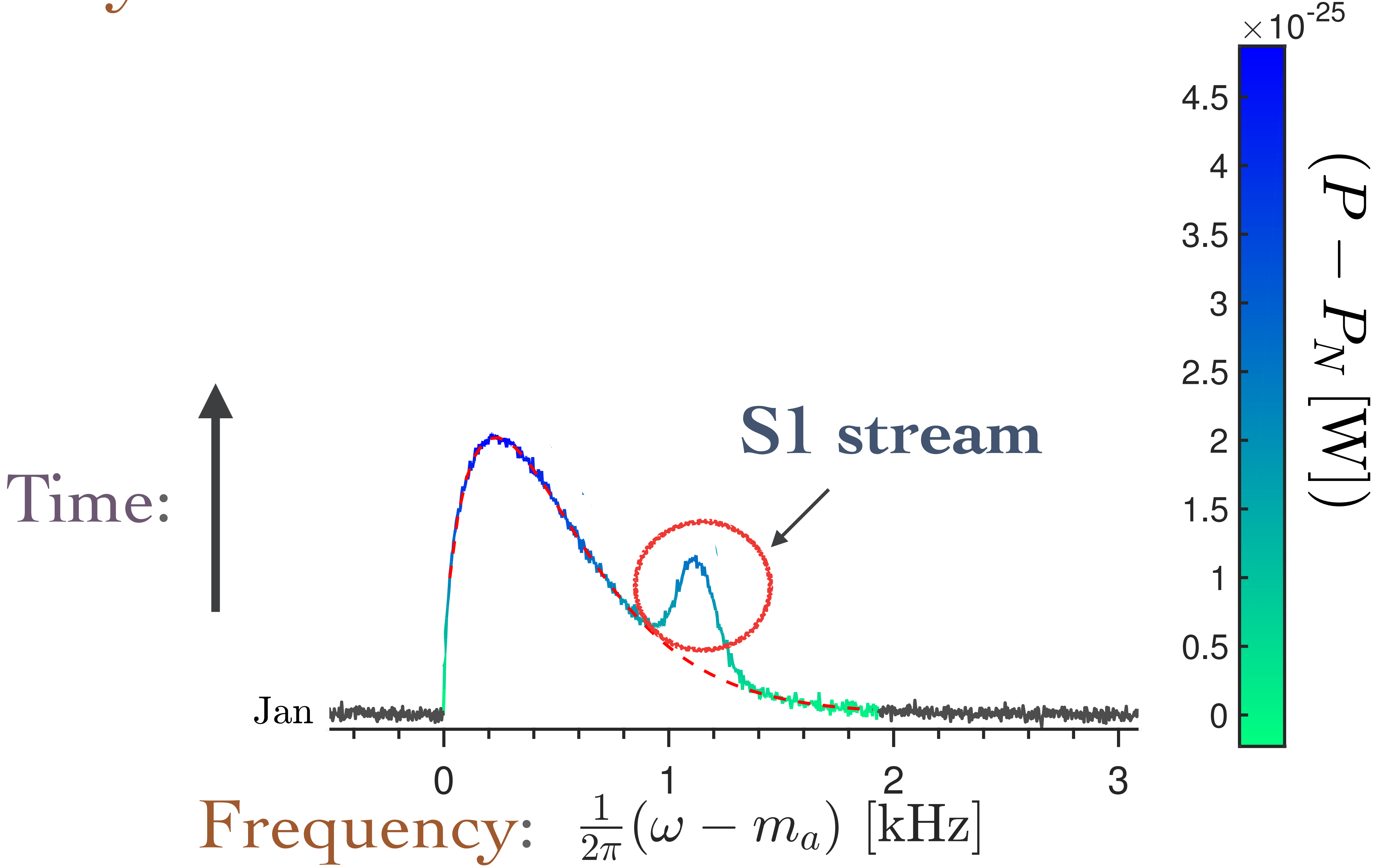
Measuring $f(v)$ in a haloscope

$$\omega = m_a \left(1 + \frac{v^2}{2}\right)$$

A haloscope can effectively make a direct measurement of the astrophysical speed distribution

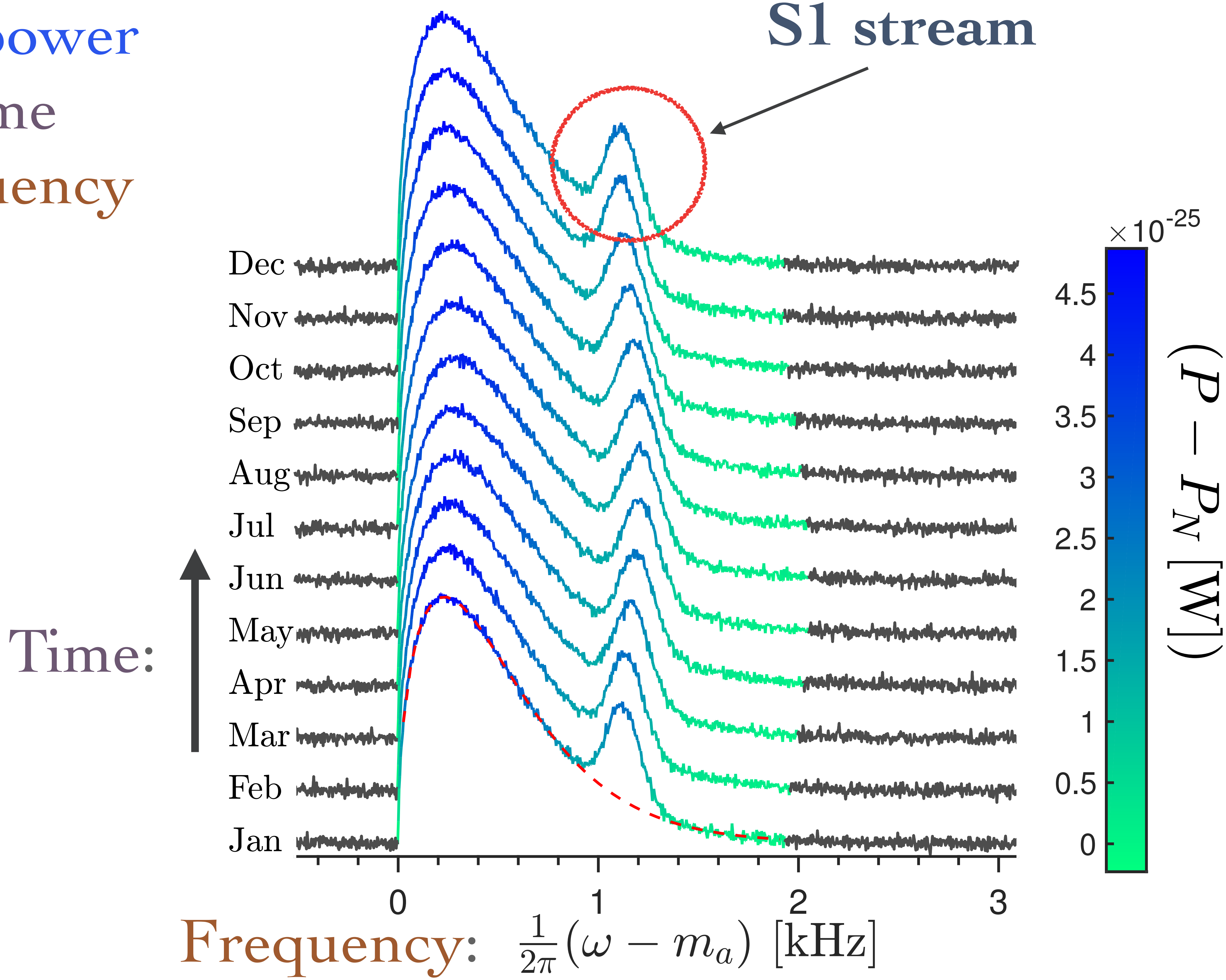


Axion haloscope:
Signal power
vs time
vs frequency

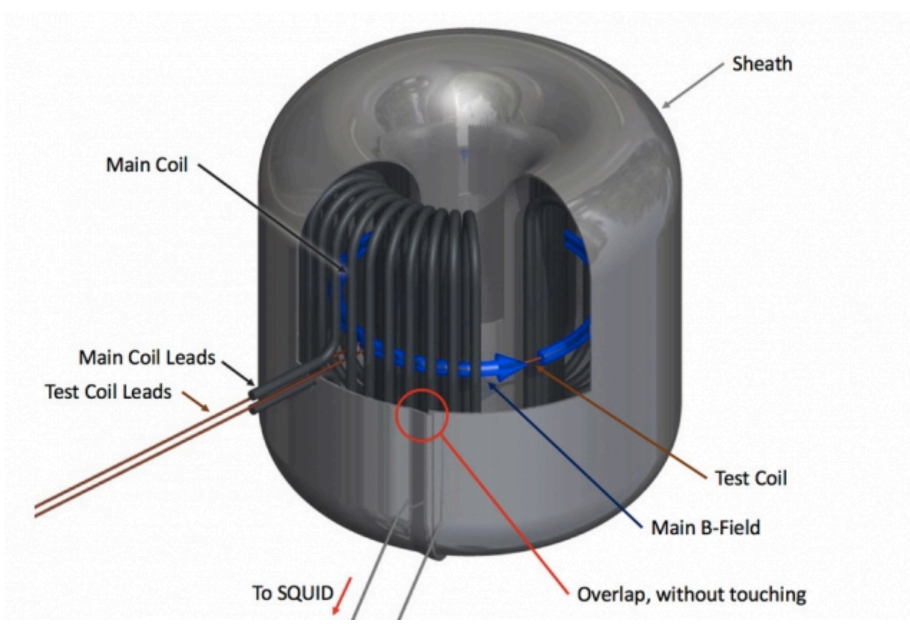


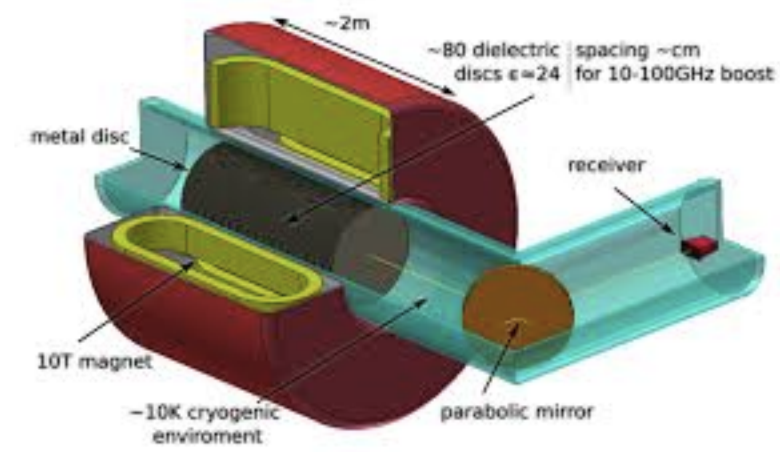
Axion haloscope:

Signal power
vs time
vs frequency



(some) Axion haloscopes



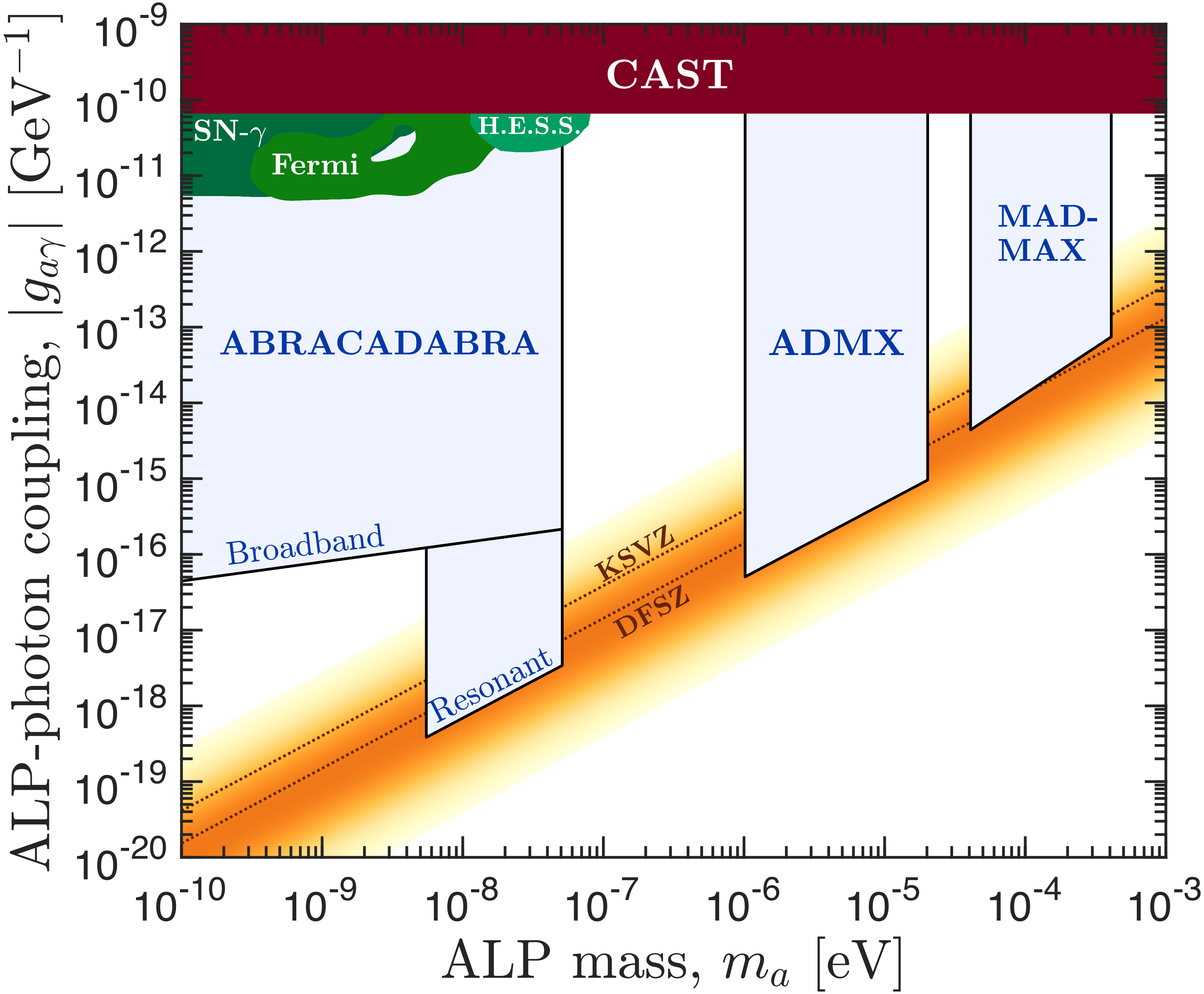


ABRACADABRA	ADMX	MADMAX
DM-Radio	CAPP	ORGAN
KLASH	HAYSTAC	BRASS

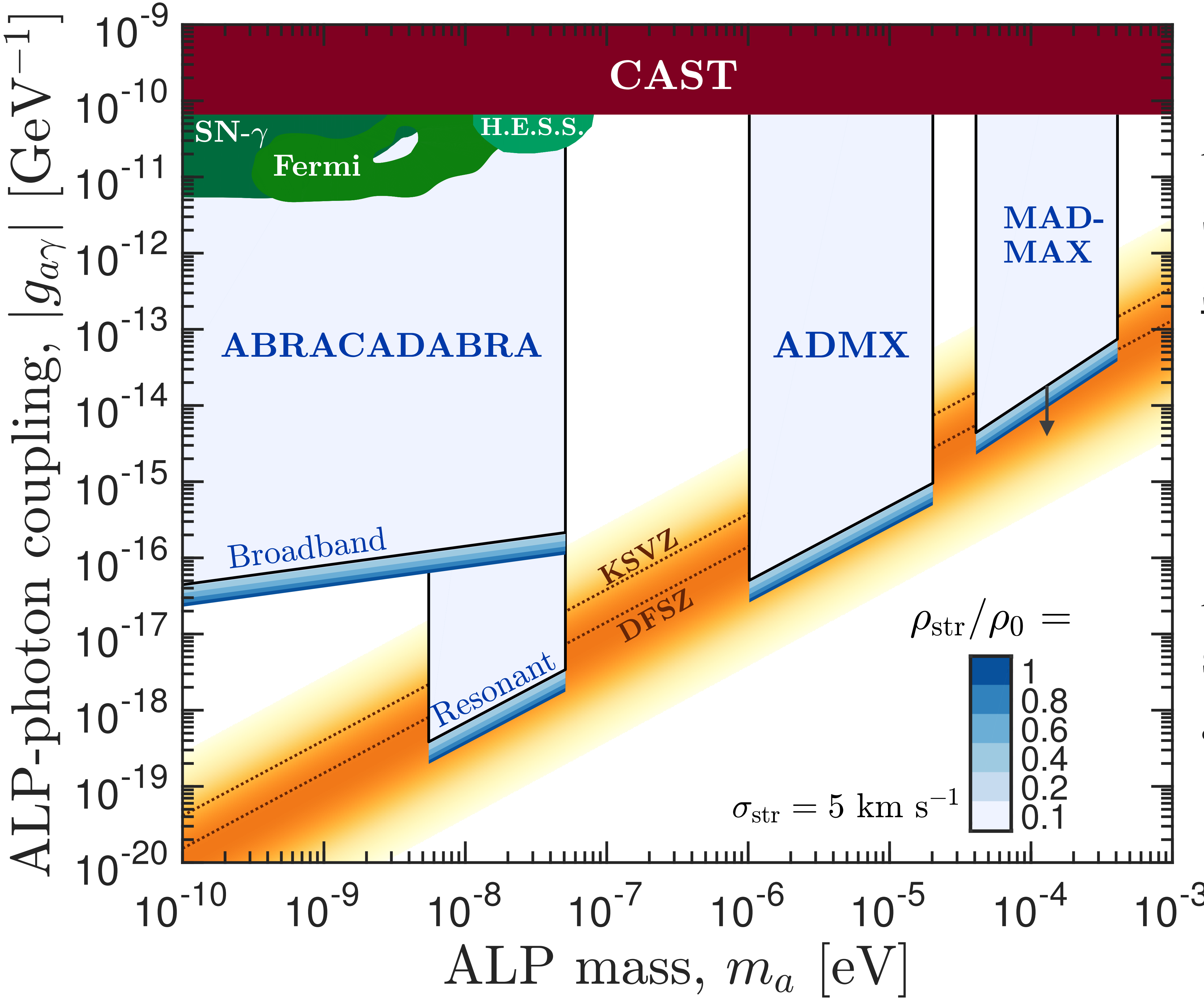
m_a [eV]

$<10^{-7}$	10^{-6} - 10^{-5}	10^{-4}

Axion experimental projections



Impact of streams on axion searches:



Axion searches like <u>sharp</u> signals

↓

A cold S1 stream <u>improves</u> axion sensitivity

Take home points

S1 stream probably bringing a hurricane of dark matter into our solar system

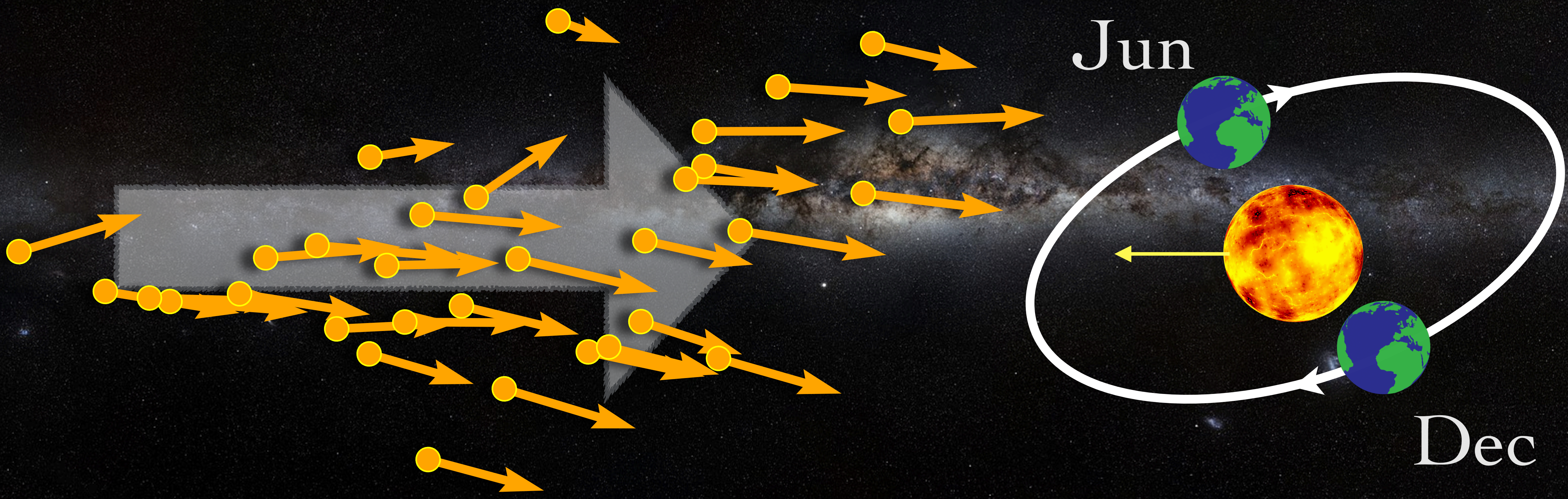
- Hard to detect in xenon detectors
- Easier to detect in directional detectors
- Easiest to detect in axion detectors

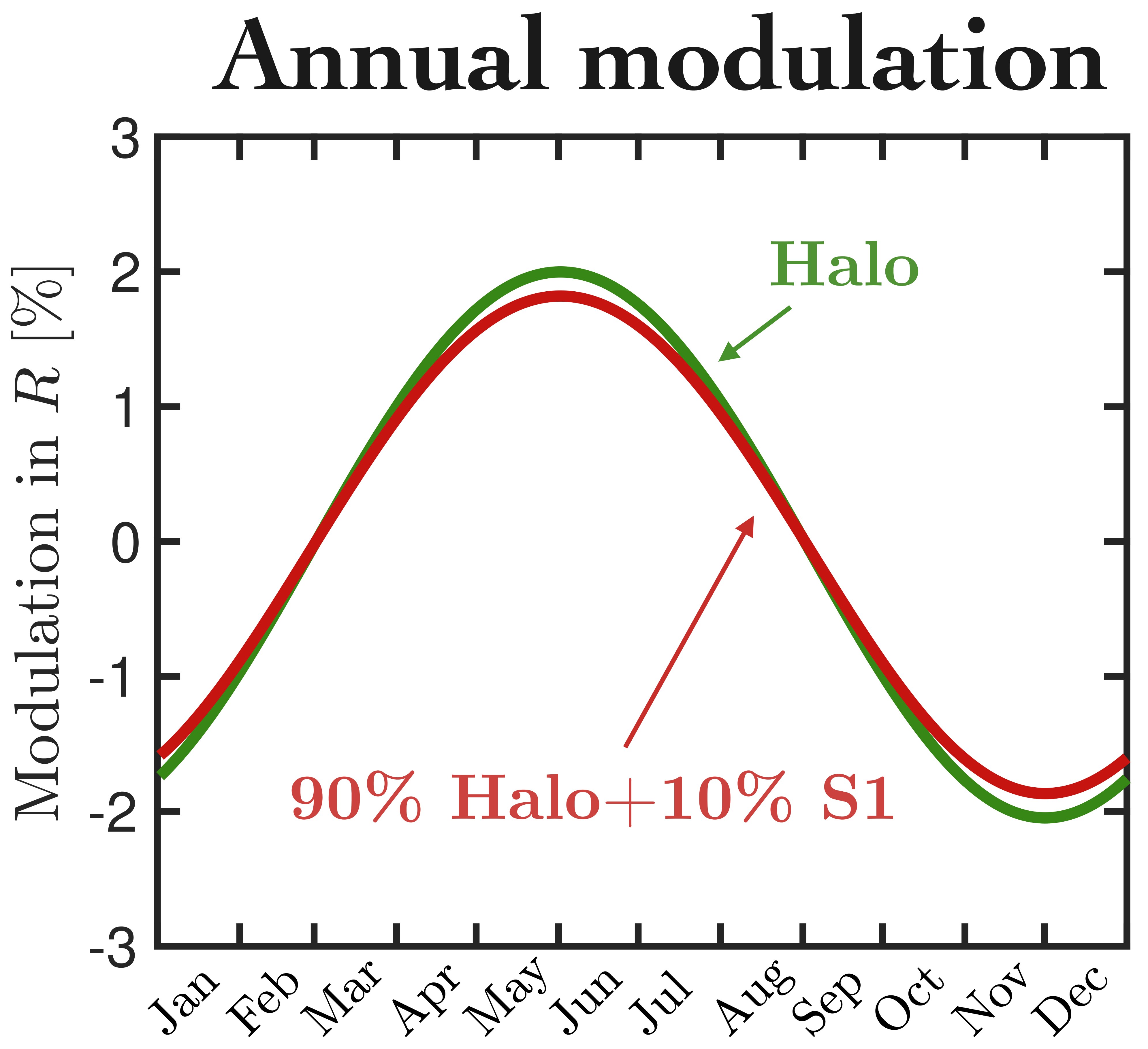
arXiv:[1807.09004]

Extras

Annual modulation?

Annual modulation?





Annual modulation
Modulation in R [%]
3
2
1
0
-1
-2
-3
Halo
90% Halo+10% S1
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

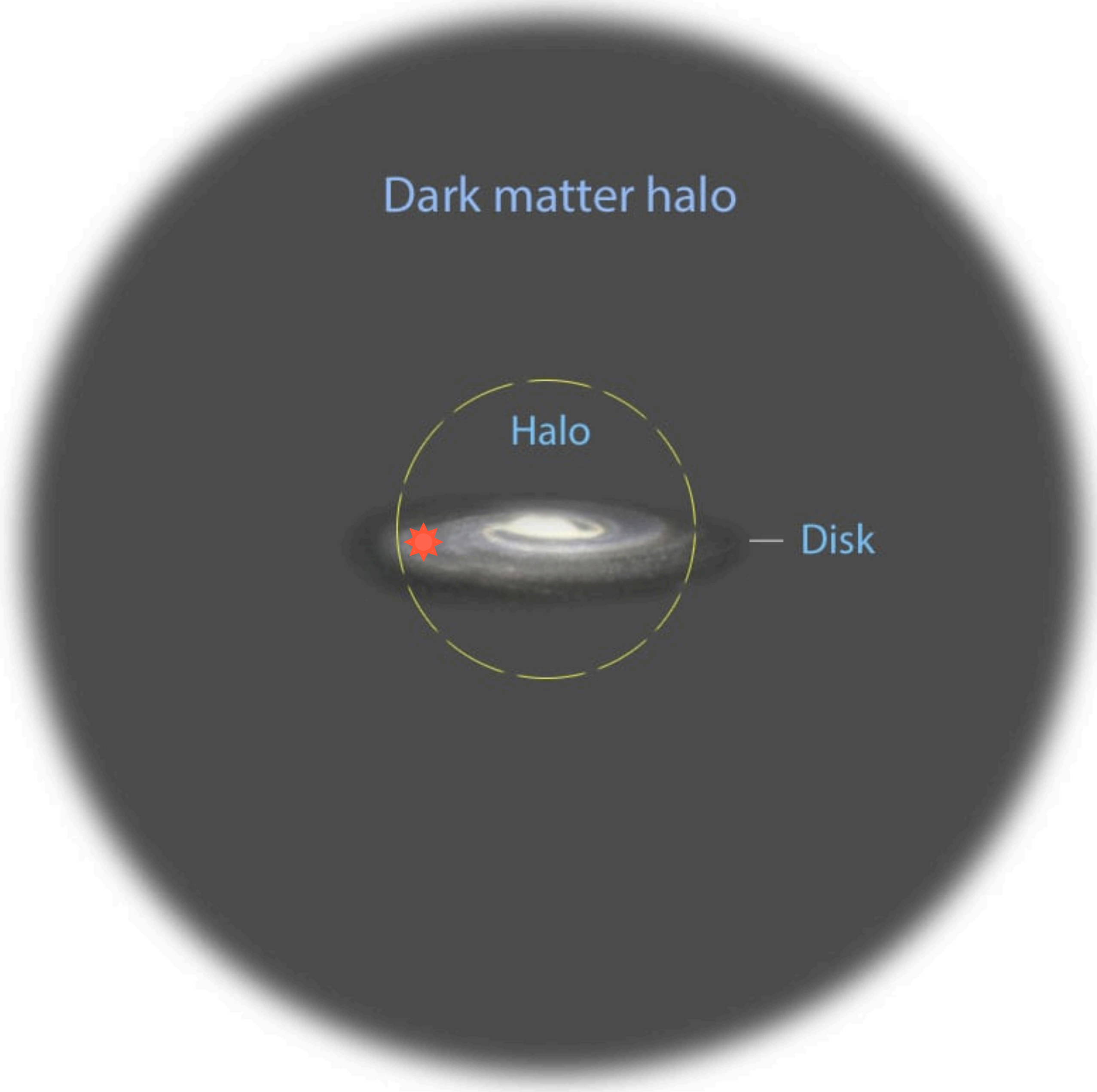
The Standard Halo Model

<u>Motivation</u>: Simplest spherical model with asymptotically flat rotation curve

- → Density ~ $1/r^2$
- → Isothermal
- → Gaussian velocities
- → Truncated at $v_{\rm esc}$

$$f(\mathbf{v}) \sim \exp\left(-\frac{|\mathbf{v}|^2}{v_{\rm rot}^2}\right)$$

$$\rho_{\rm dm} = 0.3\,\mathrm{GeV\,cm^{-3}}$$
$$v_{\rm rot} = 220\,\mathrm{km\,s^{-1}}$$
$$v_{\rm esc} = 544\,\mathrm{km\,s^{-1}}$$



SHM is a *standard*, i.e. it's okay for it to be wrong in certain aspects, but we should still want to refine the model with data

I) **Sphericity**

→ Most recent Jeans analysis with RR lyraes continue to favour a very spherical halo for the inner most 15 kpc [1806.09635]

II) **Rotation speed** $v_0 = v_{\rm rot}(r = 8\text{ kpc})$

→ Proper motion of Sgr A* → $v_0 = 233 \pm 3$ km/s (±1% sys.) [1602.07702]

→ 23,000 APOGEE/*Gaia* red giants → $v_0 = 229 \pm 0.2$ km/s (±5% sys.) [1810.09466]

III) **Local density**

→ Recent analyses give higher values (~0.5) than canonical 0.3 GeV/cm^3

→ More Gaia analyses forthcoming, no big surprises are expected

IV) **Isotropic? → Definitely not…**